Compendium In Solar-Cookers & Food-Dryers

2nd. Revised Edition

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2nd. Completely Revised Edition 1999.
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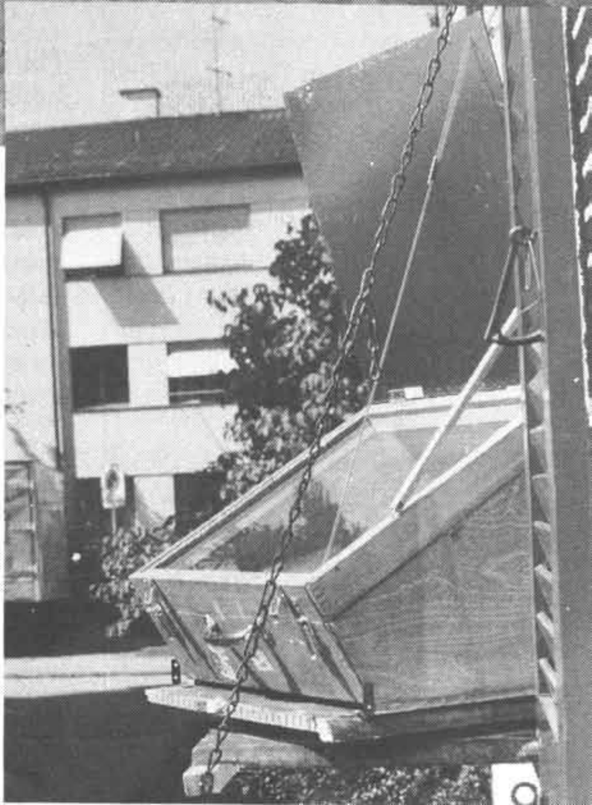

NB:

It should be noted that this now Completely Revised 2nd. Edition Compendium, has been revised as a result of great inspiration from the work of the Finnish NGO - TEP [Technology for Life]. - Kindly contact them directly for further information or assistance:
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Indeed, this Compendium is intended and presented in grateful thanks, and to perhaps bring these authors to a wider public.

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- The Danish branch organization for heat and ventilation: CD - "Multi-Sol", showing mounting/assembly work processes for solar-collectors. http://www.vvsu.dk
- During 1998, a CD on access to wind-energy info. - should be issued under a common EU project, with as the coordinating Danish partner; - Handelshøjskole in Århus DK.
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- An energy/development CD-library is available from Belgium. E-mail - humanity@innet.be http://www.oneworld.org/globalprojects/humcdrom

Plus:

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Solar drying

For centuries, a wide range of products have been dried by the sun and wind in the open air. The purpose of drying may be to preserve the products for later use, or it may be an integral part of the production process, as in timber drying. In the context of this book, solar drying refers to technologies that capture the sun's energy for drying in a more efficient way than simple open-air 'sun-drying'. On the other hand, solar driers are simpler and cheaper to run than fuelled driers. The basic principle of a solar drier is that air is heated by the sun in a collector, and then passed over the produce which is to be dried. The advantages and disadvantages of using solar driers compared with other methods of drying are shown in Table 5.

Table 5. Comparison of drying technologies

	Sun-drying	*Solar drying*	*Fuelled drying*
Initial cost	None	Medium	High
Operating cost	Low	Low	Medium
Temperature control	None	Poor	Good
Continuous operation	No	No	Yes
Speed of drying	Slow	Medium	Fast
Protection from pests	No	Yes	Yes

One well-known type of solar drier is shown in Figure 4. This was designed for rice-drying but its principles of operation apply to all solar driers. Air is drawn through the drier by natural convection. It is heated as it passes through the collector and then partially cooled as it picks up moisture from the rice. The rice is heated both by the warm air and directly by the sun. The exhaust air escapes through the chimney at the top of the drying chamber.

The amount of moisture that the air can absorb depends both on its temperature and on its moisture content. Hot air can absorb far more water than cooler air. Similarly, dry air can absorb more water than wet air. The moisture content of the air can be measured as a 'relative humidity' (RH) which is the actual amount of moisture in the air as a percentage of the total that the air can hold at that temperature.

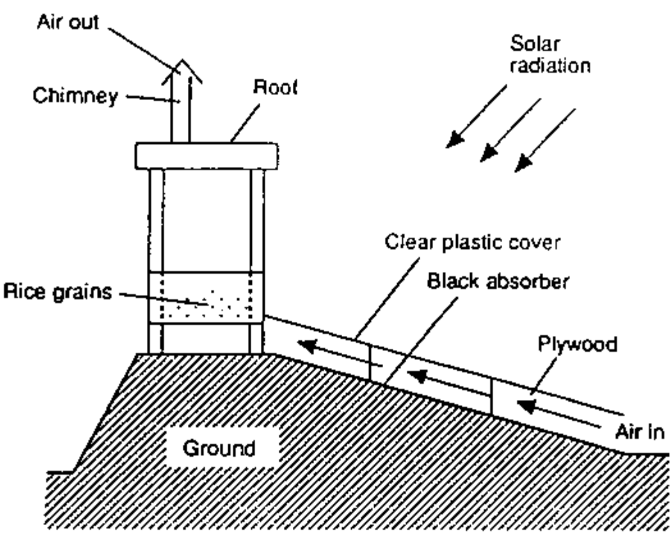


Figure 4. Natural convection solar drier

If the air entering the system is quite moist (high RH), heating is more important to achieve any drying effect. Also, the hotter the air is, the less of it will be needed, and the faster the drying will be. The temperature in the rice grains themselves may be an important factor too, especially in the later stages of drying when moisture needs to be drawn from the centres of the grains to the surface. This temperature will depend mainly on the air temperature, but also on the sunlight heating the grains directly.

Maximum heating is not always a desirable feature, as many products can be damaged by excessive temperatures. The most severe constraints are on beans (35°C), rice (45°C) and all grains that are to be used for seed (45°C). Some systems may actually shield the produce from direct sunlight.

A more advanced system is the 'forced convection' solar drier. This uses a fan to create the airflow through the system, instead of natural convection. Drying time can be reduced by a factor of three using a fan, and the collector area can be reduced by up to 50 per cent. Together, these improvements can increase product throughput by a factor of five or six. Forced convection also has the advantage that the drying chamber need not be positioned above the collector. However, electricity generated from some other energy source is necessary to drive the fan.

A more low-tech design is the 'tent' drier. This is one of a number of simple solar driers where the collector and drying chamber are combined into one. The sun-facing side is composed of clear polythene, and the back and floor of black polythene, creating a 'greenhouse' effect. This design is low in cost, but drying times may not be much shorter than for open-air sun-drying as there is little convective circulation. The main purpose of the tent is to protect the produce from the rain, wind and pests. Tents are usually used for fruit, fish, coffee or other products for which wastage is otherwise high.

There are numerous other simple driers which work on a similar principle to the tent drier, such as box, cabinet and greenhouse driers. Box driers may incorporate thermal insulation to keep the temperature high. Solar timber kilns may include hot water storage to enable the necessary control of the drying rate.

In general, solar drying is more appropriate:

- the higher the value per tonne of the products dried
- the higher the proportion of the product currently spoiled in the open air
- the more often the drier will be used.

Faster and more complete drying reduces the rate of mould growth and increases the effective storage time.

Economic comparisons between solar driers and sun-drying methods need to take into consideration savings in produce losses. Where forced drying is required, solar drying will be most economic where small quantities need to be dried, and where the need for drying and the necessary solar energy are present for most of the year. A simple natural convection solar drier may only cost around US$20/m^2 of collector area and can pay for itself in reduced product losses in a couple of years. On the other hand, a forced convection drier, with one-tonne capacity, may cost almost US$2000 inclusive of a motorized fan. In this case, the pay-back time may be more than 10 years. An important consideration is whether or not waste heat from generators or industrial processes is available in the vicinity. It may cost less to use waste heat than to build a forced convection solar drier.

The main applications of solar driers are in agriculture, for the drying and preservation of fruit and vegetables. In addition, in some communities fish driers have been successfully used. Solar pre-heating of air for commercial applications such as timber and pulped paper drying, has also achieved some commercial success.

Solar cookers

In the rural areas of most developing countries, cooking is usually done over fires fuelled by wood. In many regions, wood-based fuels are becoming increasingly scarce for a number of reasons. This results in people walking increasingly long distances to gather firewood from an ever-dwindling resource. The solar cooker can provide a solution to this problem in certain situations, although its use is by no means widespread at present. Solar cookers also avoid the indoor air pollution which is associated with indoor wood stoves.

A solar cooker simply uses the energy of the sun to cook food, and designs vary according to the type of food preparation that is required. The two principal designs are the 'oven' type and the 'stove' type. The essential difference is the same as that between conventional ovens and stoves (or open fires): stoves apply heat directly to the bottom of the cooking pot, whereas ovens provide a hot space in which the food is placed. Related to the oven is the solar 'hot box' which is less sophisticated and operates at lower temperatures. The suitabilities of the different designs to the main styles of cooking are shown in Table 6.

Table 6. Suitability of solar cookers to preparation methods

Method	*Minimum temp.*	*Time taken*	*Suitable design*
Food cooked in boiling water or steam	Meat 100°C	1–4h	Stove/ oven
	Rice 70°C		Stove/ oven/ hot box
Food is baked e.g. bread and cakes	150°C	Long period	Oven
Food is shallow-fried in oil	Very high temp.	Short period	Stove

The essential features of an oven-type solar cooker are:

- an airtight enclosure (the oven) with well-insulated walls
- a transparent window which allows sunlight to enter the oven but does not allow heat to escape.

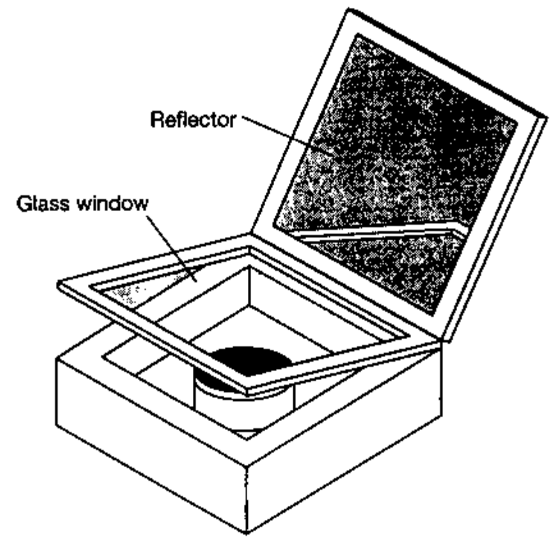
Most types have at least one reflective panel that directs sunlight into the oven from a wider area. Two common designs are shown in Figure 5. Ovens are distinguished from hot boxes by having more reflective panels, better insulation and a smaller internal volume, combining to give higher internal temperatures.

The hot box can cook rice and dhal in 2–4 hours on a hot sunny day in India. The oven would take 1–2 hours. The oven would need frequent re-orientation to face the sun, whereas the hot box is less sensitive to adjustment. The main disadvantages of hot boxes are their inability to reach the high temperatures required for boiling and the long length of time they take to cook. On the other hand, there is little risk of burning food and so little attention is required. Hot boxes are particularly suited to dishes which benefit from longer, slower cooking, such as curries and soups.

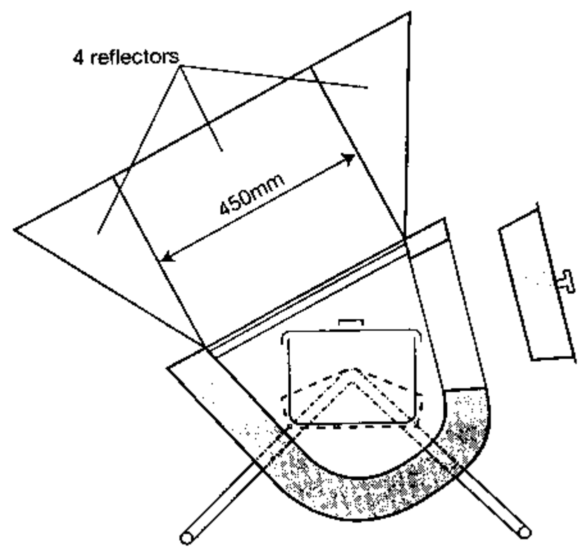
Although successful cooking depends on the weather, the combined heat capacity of food, pot and oven is enough to maintain temperatures over brief cloudy periods. Likewise, food will be kept hot for a while after the sun goes down, making evening meals possible.

Tens of thousands of single-reflector hot boxes have been sold in India, partly as a result of state and government subsidies amounting to up to 60 per cent of the price.

Stove-type solar cookers are known as concentrating cookers. Their essential feature is that they focus the sun's light from a wide area directly onto the bottom of the cooking vessel by using a reflector of a suitable shape. The ideal shape is a parabolic dish. However, this is difficult to produce, so most designs approximate to it using simple construction techniques.



(a) Solar 'hot box'



(b) Solar oven

Figure 5. Two types of solar cooker using reflector panels ▶

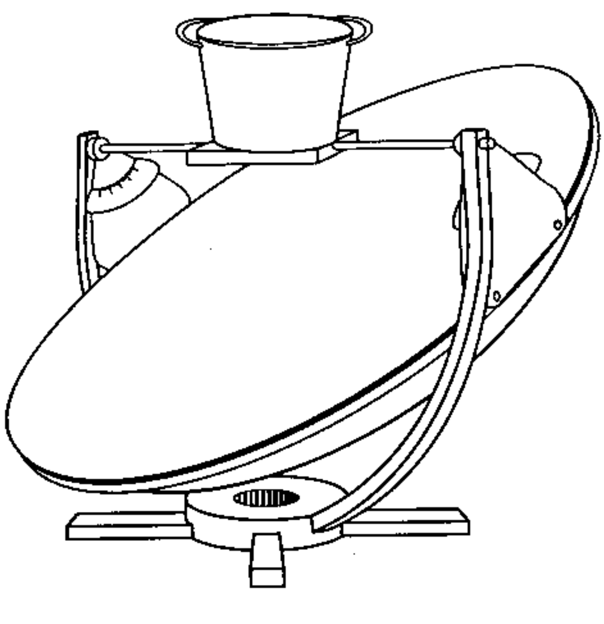


Figure 6. Concentrating solar cooker

Figure 6 shows a concentrating solar cooker. Most designs are just over 1m in diameter, and can deliver about 700W to the cooking pot. This would bring about 3 litres of rice and water to the boil in 1 hour, and would also allow high temperature shallow frying. These cookers are, however, vulnerable to cloudy periods, especially when used for frying. They also require intervention to keep them facing the sun which may interfere with other activities the cook might wish to carry out. Cooking outdoors in the heat under the sun can also be uncomfortable.

The cook needs to attend to the cooker fairly frequently, stirring the food, and swivelling the whole assembly to keep it pointed at the sun. These devices are very sensitive to orientation. Some care needs to be exercised when adjusting the cooker, as temperatures as high as 850°C are possible at the focus.

Concentrating solar cookers have only found widespread user acceptance in China, where there are tens of thousands in use in the provinces of Gansu, Tibet and Inner Mongolia. The Chinese cookers are composed of a mosaic of tiny mirrors on a moulded concrete dish, all mounted on a swivel. A lighter design uses a smaller number of larger mirrors mounted in a metal framework.

So far, dissemination of the technology in other countries has been unsuccessful for non-technical reasons such as cooking and eating traditions. Solar cookers will be better accepted if current cooking and eating habits are well matched to the cooker's characteristics (for example, if the main meal is eaten at midday). Some change in habits will always be needed, and readiness to change will depend largely on necessity.

When selecting a solar cooker the following factors should be taken into account:

- Can meals be produced reliably at the desired time of day?
- Does the design of cooker match the type of cooking required?
- How long does cooking take?
- Where does cooking normally take place?
- Does the cook sit, stand or squat?
- Does the cooker fulfil any other functions beside cooking? For example, open fires may be used to provide warmth and light, drive away insects, or have cultural significance.
- Does the use of the cooker interfere with other activities the cook would normally undertake?

The cost of a solar cooker is likely to depend on its design, locally available skills and materials, numbers being produced, and whether there is any state subsidy. Concentrating cookers may cost as little as US$30 but robust designs are unlikely to cost less than US$50. Analysis of the economics of using solar cookers is not straightforward. Most benefits result from reduced deforestation (from fuelwood saved) and time saved collecting fuelwood which are not easily quantified and are very site-specific. While an economic case can be made for the use of solar cookers they are rarely chosen for economic reasons.

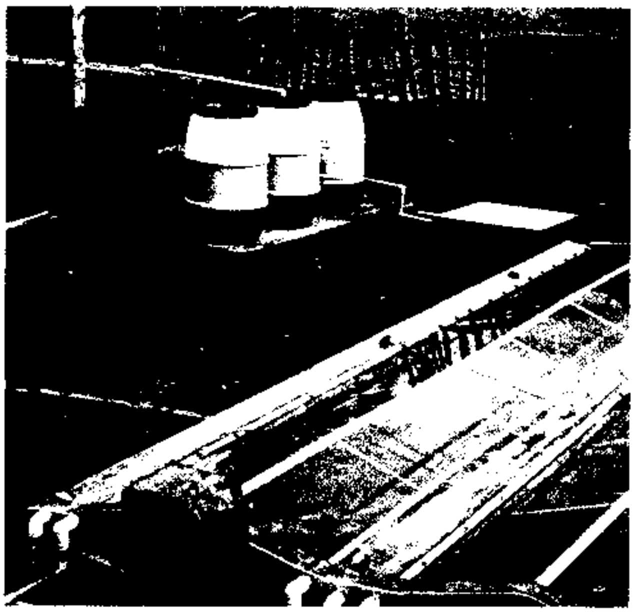
Solar distillation

In many areas, pure drinking water is in short supply. Often water sources are brackish (i.e. contain dissolved salts) and are unfit for consumption. Distillation is a simple process which can produce potable water from any source, however saline. Water is evaporated by a heat source, leaving behind the salts and impurities, and then the vapour is condensed and collected as pure water. With solar stills, the heat source is the sun's energy.

The water to be distilled sits in a basin in an enclosure with an inclined glass cover. The sunlight enters through the glass cover and heats the floor of the basin. This passes its heat to the water and causes it to evaporate into water vapour. The glass cover is in contact with the air, and so is cooler than the vapour in the still. This causes the vapour to condense and the water runs down the cover into a gutter.

Good solar stills need the following features:

- Low absorption glass cover. This maximizes the radiation reaching the water, increasing evaporation. It also keeps the temperature of the glass itself low, so maximizing condensation. Plastic can be used but is less effective.
- A good absorber surface for the basin floor. This is to capture as much of the incident radiation as possible and maximize evaporation.
- Good wall and floor insulation to keep heat in the still.
- A shallow basin, so that there is not so much water to heat.
- The condensing surface should dissipate heat quickly. This can be enhanced by cooling it with a second flow of water or air.



Solar still in Las Salinas village, Dominican Republic (IT Power)

The most common design is the single-basin still. Efficiency is about 25 per cent and greatest output is in the early evening when the feed water is still hot but outside temperatures are falling. Basins can be made from sand concrete or waterproofed concrete or, if factory manufactured, ferroconcrete.

Multiple-effect basin stills have two or more compartments, where the condensing surface of one level is the floor of the upper compartment. Thus the heat is transferred to the upper compartment and efficiencies are higher (typically 35 per cent). However, cost and complexity also increase.

A third option is a 'wick' still. Feedwater flows slowly through a porous, radiation-absorbing pad (the wick). This has two advantages, first that the pad can be tilted to give a better sun angle, and second that there is less water in the still at any time and water is heated to a higher temperature more quickly.

Despite the proliferation of novel types, the single-basin still is the only design proven both technically and economically in the field. The cost of a simple solar still is about US$100/m² and in a tropical location the output is approximately 2–3 litres/day/m².

Table 7. Distillation methods and their applications

Daily output	*Appropriate method*	*Comments*
Few litres to 1m³	*Solar (if appropriate insolation)*	*Cost proportional to capacity*
1m³ or more	*Reverse osmosis/ electrodialysis*	*Requires electrical power source*
More than 200m³	*Vapour compression/ flash evaporation*	*Flash evaporators can be part heated by solar water heaters.*

Although the normal requirement for a person in a developing country might be 20 litres of water per day, only about 5 litres of this need be potable (drinking and cooking). Hence a still of about 2m² area could supply one person. Table 7 shows the suitability of different distillation methods in various water supply situations. In general, solar stills are more economically attractive the smaller the required output. This is because costs scale upwards with capacity, whereas other technologies have significant economies of scale.

Anthony Derrick and Roy Barlow,
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A practical reference book for PV systems design and installation. Features a comprehensive section on building electronic control units, including charge regulators and voltage adapters.

Sandia National Laboratories, *Stand-alone Photovoltaic Systems: A handbook of recommended design practices*, 1988.
A basic manual for system sizing, procurement and installation of PV systems for various applications. Includes detailed pro-forma worksheets on all aspects of system design.

University of Massachusetts Lowell photovoltaic programme, International solar irradiation database V1.0, 1991.
A computer database of radiation data from around the world in spreadsheet format, suitable for use on IBM compatible PCs. Available from Univ. of Mass., 1 University Avenue, Lowell, MA 01854, USA.

Solar thermal references and further reading

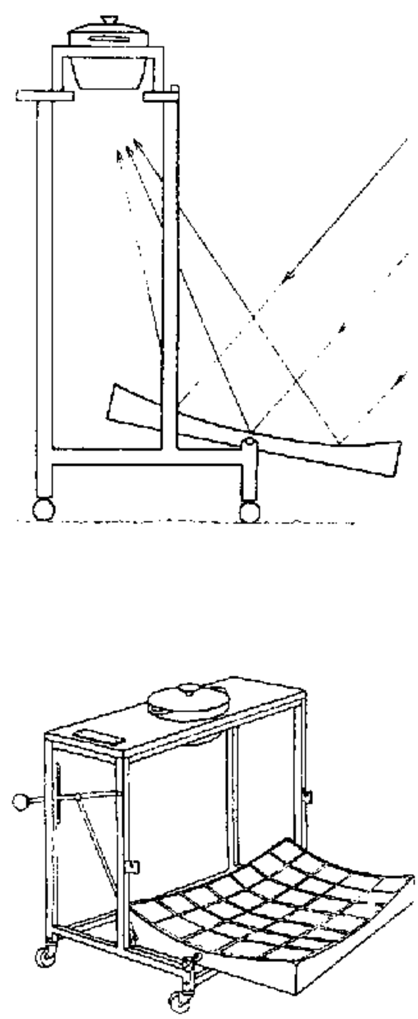
Alward, R., *Solar Cooker Manual*, BBrace Research Institute, 1982.
Results of a comprehensive worldwide survey of solar cookers and food warmers. Aims to enable field workers to make an appropriate and informed choice.

Bokalders, V. and Kristofersen, L., *Renewable Energy Technologies: Their applications in developing countries*, IT Publications, London, 1991 (first published Pergamon, Oxford, 1987).
A basic but wide-ranging overview of the energy technology options for various applications in developing countries. Aimed at development workers, administrators and planners.

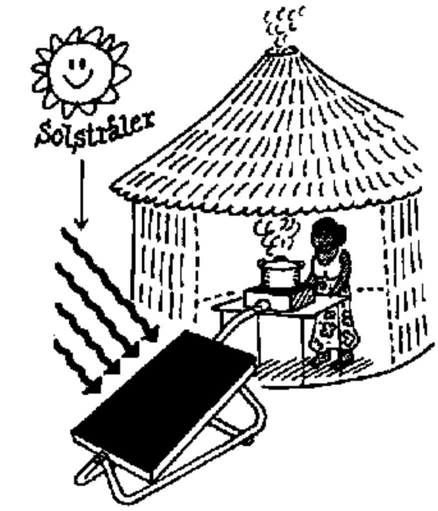
Duffie, J. A. and Beckman, W. A., *Solar Engineering of Thermal Processes*, John Wiley & Sons, 1980.
For the more advanced student, the definitive engineering text in solar thermal processes.

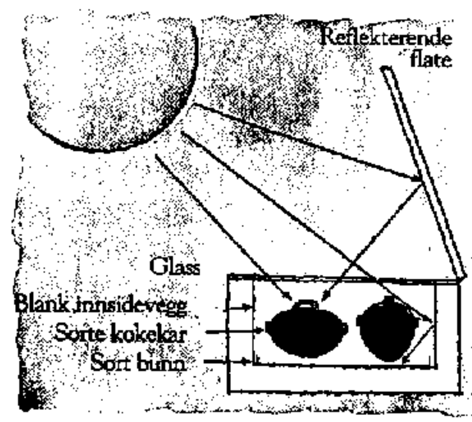
Dunn, P. D., *Renewable Energies: Sources, conversions and applications*, Peregrinus Ltd, London, 1986.
Gives a sound background to the physical principles behind renewable energy technologies at small scales, and how these can be applied in the design of equipment.

Hislop, D., ed. *Energy Options: An introduction to small-scale renewable energy technologies*, IT Publications, London, 1992.
A brief look at the basics of the various renewable energy technologies.



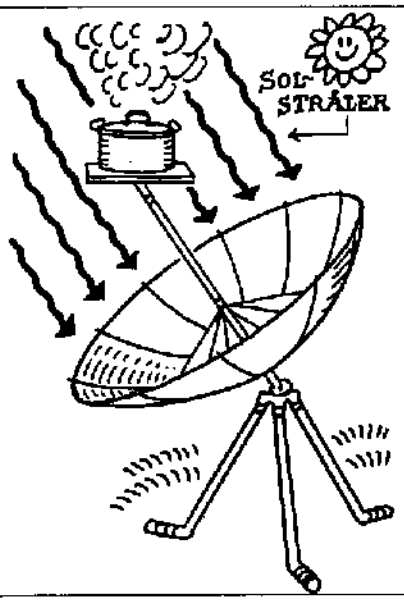
Koker som i praksis kan muliggjøre at det kokes innendørs. Solreflektoren må da plasseres på utsiden av veggen.



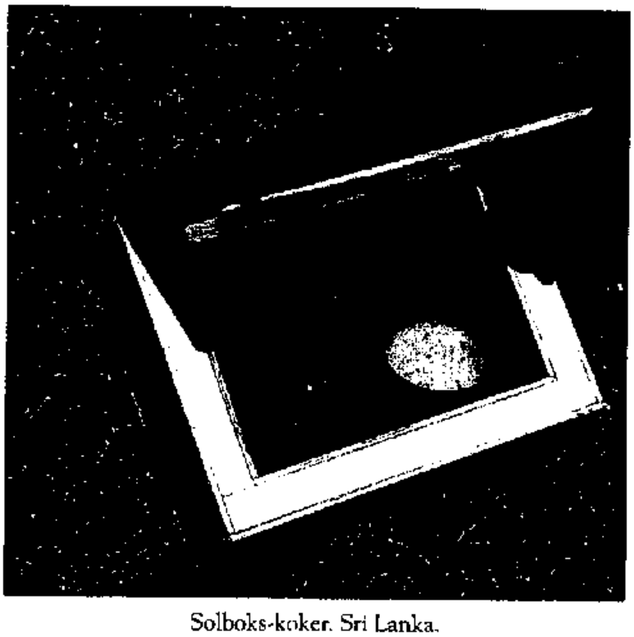


"We had a kilo of goat meat in the small solar box and many of our Kamba people returned at intervals to look unbelievingly at the sizzling meat. The thermometer showed 115°C and the meat was perfectly cooked in two hours."

Sister Mary of Lourdes, Kitui, Kenya.



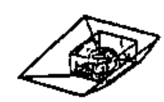
Solkoking ved refleksjon og konsentrering.



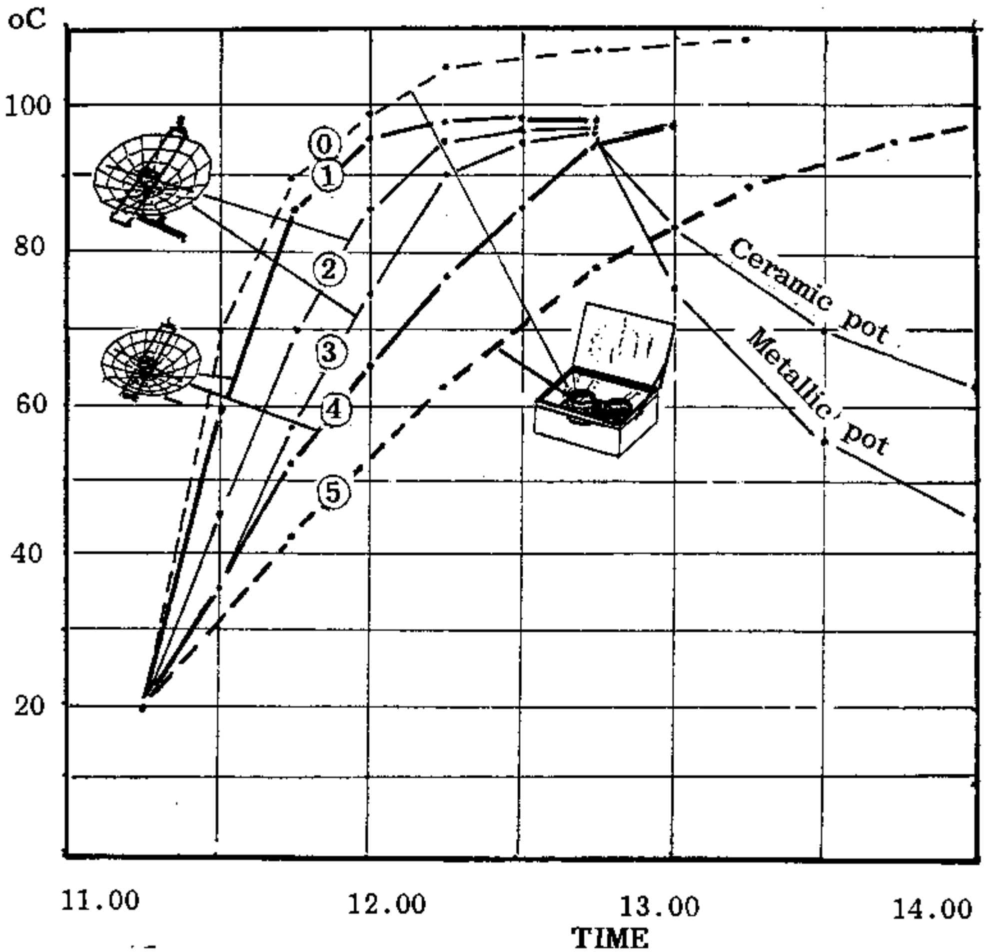
Solboks-koker. Sri Lanka.

Different models of solar cookers

A number of different designs exists. Here we will confine ourselves to a discussion of the three main types: the box, the parabolic (reflective) and the panel designs. Box cookers are the most common type, and there are over 500,000 box cookers in India alone. Parabolic cookers are especially popular in China, where at least 200,000 are in use. Panel cookers have recently been introduced and mostly used in refugee camps in Africa. (There are very effective and more expensive industrially-made Chinese, German [SK-14] and Swiss [ULOG] models.)

<table>
<tr><th></th><th>Box cooker</th><th colspan="2">Parabolic cooker</th><th>Panel cooker</th></tr>
<tr><td>Characteristics</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td></td><td></td><td>V-3</td><td>V-4</td><td></td></tr>
<tr><td>Pot number x volume l</td><td>3 x 2-4</td><td colspan="2">1 x 2-3</td><td>1 x 2</td></tr>
<tr><td>Max temperature C</td><td>150</td><td colspan="2">200</td><td>125</td></tr>
<tr><td>Boiling time for 1 litre, if radiation 800w/m2, hours</td><td>1 3/4</td><td colspan="2">3/4</td><td>2 1/4</td></tr>
<tr><td>Possibility for stirring</td><td>poor</td><td colspan="2">good</td><td>poor</td></tr>
<tr><td>Aiming time necessary at every hours</td><td>1-2</td><td colspan="2">1/3</td><td>1-2</td></tr>
<tr><td>Reflector area m2</td><td>0.4</td><td colspan="2">0.4</td><td>0.3</td></tr>
<tr><td>Manufacture
-requires craft skills</td><td>some</td><td colspan="2">some</td><td>no</td></tr>
<tr><td>-suitable for "do-it-yourself"</td><td>good</td><td colspan="2">good</td><td>excellent</td></tr>
<tr><td>-suitable for industrial and small-scale production</td><td>good</td><td colspan="2">excellent</td><td>excellent</td></tr>
<tr><td>Lifetime, years</td><td>5</td><td>10</td><td>20</td><td>1</td></tr>
<tr><td>Cost of materials in USD</td><td>35</td><td>10</td><td>14</td><td>5-10</td></tr>
<tr><td>Weight, kg</td><td>11</td><td>4</td><td>2.5</td><td>1.2</td></tr>
<tr><td>Measures, meter</td><td>0.5x0.6x0.4</td><td colspan="2">0.7x 0.2 x1.0</td><td>0.5x0.5x0.2</td></tr>
<tr><td>Common features</td><td>slow, easy to use, possibility for several pots, moderate price</td><td colspan="2">fast, need time for watching, very durable, cheap</td><td>slowest, easy to use, modest capacity, cheapest</td></tr>
</table>

COMPARISONS BETWEEN DIFFERENT SOLAR COOKERS



0 = **Air temperature in box cooker**
1-5 = **Water temperature in the pot**

Type of cooker	Refl.area m2	Amount of water l.	Pot
1. Parabolic	0.4	1	Metallic 2 l.
2. Parabolic	0.8	2	Metallic 3.5 l.
3. Parabolic	0.8	2	Ceramic 3.5 l.
4. Parabolic	0.4	2	Metallic 3.5 l.
5. Box	0.4	1	Metallic 2 l.

Weather: Bright sunshine
Ambient temperature: 21 oC
Helsinki 27.6 98

Using the Sun

We can use the sun's heat, called solar energy, for cooking, heating water, and drying crops. Cooking and heating with the sun takes longer than a fire, and it can only work when the sun is shining. But the sun's energy is free.

Solar cookers

The most common kind of solar cooker looks like a big dish which is shiny like a mirror inside. The cooking pot hangs in the middle of the dish. When the sun shines, the shape of the dish makes all the heat shine onto the pot, and it becomes hot enough for the food inside to get cooked.

In summer, the cooker takes 45 minutes to boil 3 litres of water, and in winter 1½ hours. It has to be moved every 20 minutes to face the sun otherwise it does not cook properly.

This cooker costs about R40 to make. Half of the cost is for the shiny plastic. You can make a cheaper solar cooker using aluminium foil, but it does not work so well.

Solar ovens

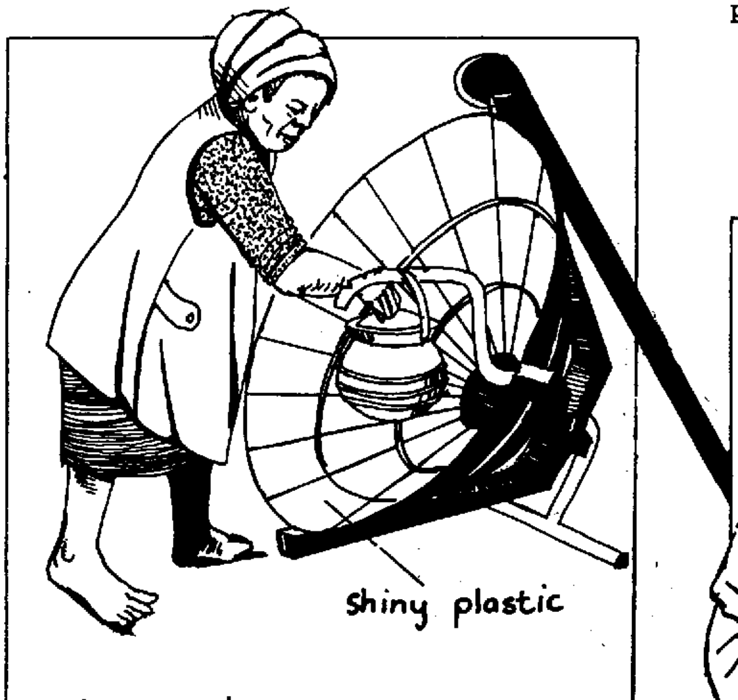
The solar oven is a different kind of solar cooker. It is a box with thick walls so that heat can not get out easily. The box is painted black inside and the sloping side is glass, which faces the sun. It works because glass lets heat in one way, but does not let it out the other way. This is why a car becomes hot inside if it is parked in the sun with the windows closed.

Heat from the sun is trapped inside the oven, so that it becomes hot enough inside to cook. You can make the oven hotter by adding mirrors or shiny metal sheets on the front to catch more of the sun's heat.

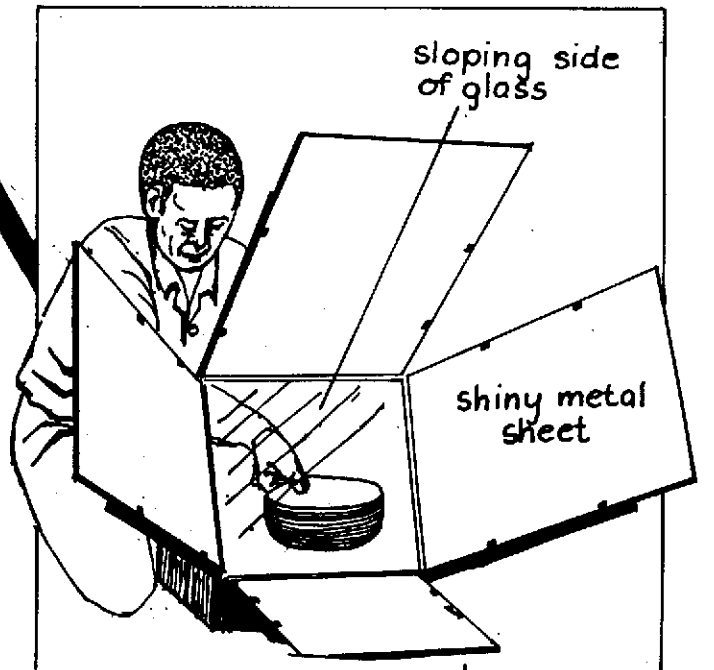
This solar oven costs about R20 to make. It does not get as hot as the other solar cooker, but it gets hot enough inside to cook food slowly. If you make it well, it is hot enough to bake bread. It only has to be moved once every hour, not every 20 minutes like the other cooker.

Write to EDA for plans for solar cookers, solar ovens, and solar water heaters (see Making a solar crop drier p 454).

Environmental and Development Agency
Box 62054 Marshalltown
2107 Johannesburg, South Africa



solar cooker



solar oven

SOLAR COOKING

Cooking by the use of solar heat is a very old art. The first solar cooker was probably that built in Bombay in 1880, and several other ingenious ovens, including that shown in Fig. 19, have originated in India.

Solar Ovens

One of the best solar ovens, little known in this country, was developed by Dr. M. K. Ghosh of Jamshedpur. Shown in Fig. 19, the Ghosh heater consists of a simple wooden box, about 24 inches square and 12 inches deep. It is lined with 2 inches of insulation (glass wool would be very satisfactory here) and it contains a blackened metal liner in which the cooking is done. The interior insulation and the hinged top are lined with shiny aluminum foil, the former to reduce radiation from the oven to the sides and bottom of the box, and the latter to reflect the sun's rays into the oven through the double cover glasses. Since much of India lies near the equator and the sun is nearly overhead at midday, the Ghosh oven does an excellent job of cooking the noon meal.

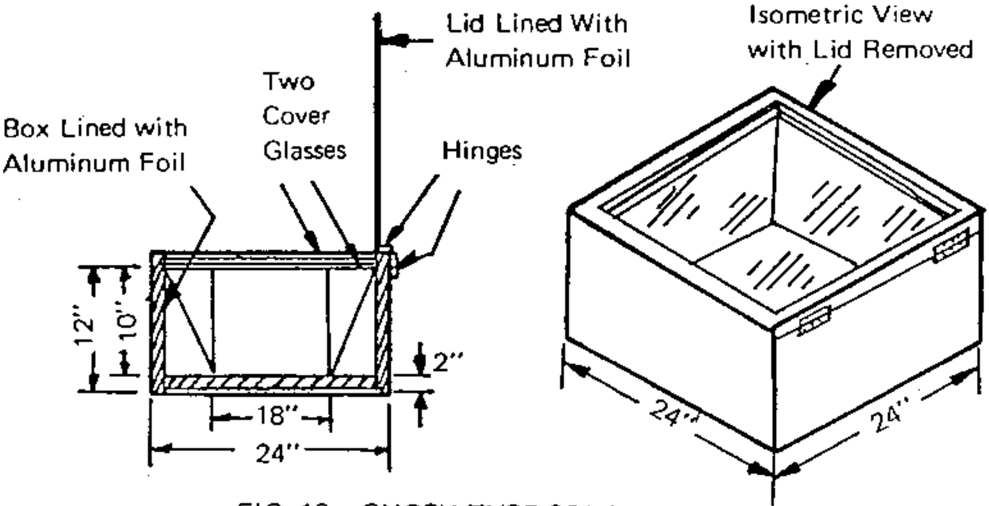


FIG. 19 GHOSH-TYPE SOLAR OVEN (Top is hinged with two glass panes spaced 3/4" apart, sides and bottom of 3/8" plywood).

Another type of oven, originated by Dr. Telkes, uses a metal box with double glazing over its open end and a hinged, insulated door at the other end. It is contained in a casing which may be made of metal or plywood, and the whole affair is arranged so that it can turn and tilt to follow the sun. Reflecting wings made of shiny aluminum (Alzak® is the best brand) are attached at an angle of 60 degrees to the plane of the cover glasses. These nearly double the amount of solar radiation which can enter the oven. On a bright sunny day, the Telkes ovens can get to 400°F from about 9:00 a.m. to 3:00 p.m.

A simplified version of the Telkes oven is described by Dan Halacy on pp. 51-62 of his excellent do-it-yourself handbook, *Solar Science Projects* (App. IV, No. 6). His oven uses the Telkes principle, but it sets the cover glasses at an angle of 45 degrees to the oven so that it does not need to be tilted.

The basic principle of operation of a reflector-type solar cooker is shown in Fig. 20, where a simple parabolic reflector, arranged on a sun-following mount, concentrates the sun's rays on a grill which can support a pot or a frying pan. This type of cooker will become hot just as soon as it is adjusted to face the sun and, according to Dr. Farrington Daniels, a 4 foot diameter reflector-type cooker will deliver the equivalent of a 400 watt electric hot plate under bright sunshine. He gives detailed instructions for the construction of a plastic shell of the proper shape which can be lined with aluminized Mylar. App. IV, No. 5, Chapter 5, pp. 89-103 covers the topic of solar cooking; pp. 102-103 gives an excellent bibliography on the subject.

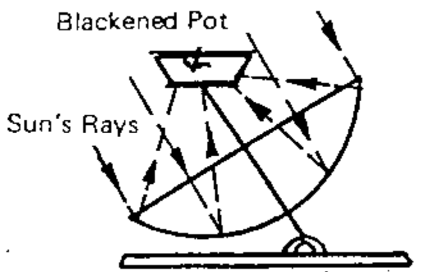


FIG. 20 REFLECTOR COOKER (Must be adjustable to follow the sun).

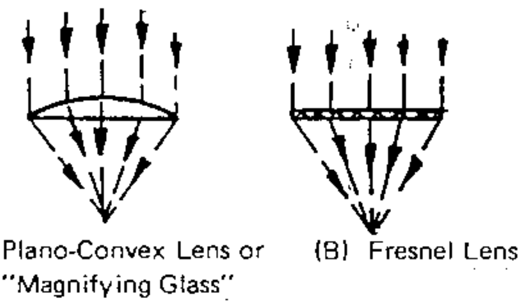


FIG. 21 SOLAR CONCENTRATORS

Dan Halacy shows how to make an even simpler reflective cooker out of corrugated cardboard and kitchen-type aluminum foil on pp. 14-27 of *Solar Science Projects* (App. IV, No. 6). He advises the use of sun glasses when you are cooking with his aluminized broiler because the reflectance can be dazzling. The reflecting surface does not get hot, but the grill area does, so be careful when you put on the pots and pans. Also, Brace Research Institute, in *How to Make a Solar Steam Cooker*, Do-It-Yourself Leaflet L-2 ($1.00), describes a steam cooker which uses the simplest of materials for making a broiler. See App. IV, No. 2 for ordering information.

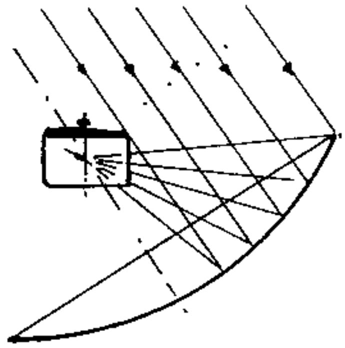
How does a parabolic (reflective, mirror) cooker work?

A well-designed and well-made parabolic cooker used in good solar conditions will have a high level of performance, better than that of an open fire. The most advanced models can be used for every kind of cooking, including baking and frying.

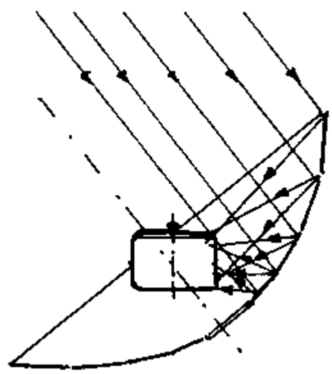
The main feature of a parabolic cooker is a parabolic mirror that concentrates the solar radiation which falls on it into a small area called the focus, where the cooking pot is situated. The focus area should be about the same size as the pot to make most efficient use of the mirror and so the reflective radiation will be absorbed by the pot.

Mirrors with a sharp focus (like satellite dishes) focus the radiation that falls on them into a very small area. **Such mirrors can be dangerous, especially for the eyes, which may be damaged if the user's head enters the area of the focus.**

**FAR FOCUS MIRROR
POTENTIALLY DANGEROUS**



**DEEP FOCUS MIRROR
IS SAFER**



Cookers with a deep focus, i.e. a focal point inside the area 'enclosed' by the rim curve of the mirror - as in, for example, the German-made Eg-Solar cooker - are safer than those with a distant focal point (as many Chinese cookers have) because a close focus makes it much less likely that the user will accidentally put his or her head into the focal area.

If you make the mirror from several sections with bended straight surfaces instead of with a parabolic curvature, the radiation has no sharp focal point at all and the radiation beam goes into the whole pot area.

In this way you may get the same performance as with curved mirrors without the danger of a sharp focal point!

The parabolic (reflective) cooker doesn't work if a cloudy period continues more than several minutes. It is more sensitive to cloudy weather than the box cooker.

It is very helpful to continue cooking in a box cooker or in a "haybox-cooker", which is a well-insulated box or basket.

The umbrella forms a focal point that can boil stew,fry and bake food almost as quick as a normal gas cooker.

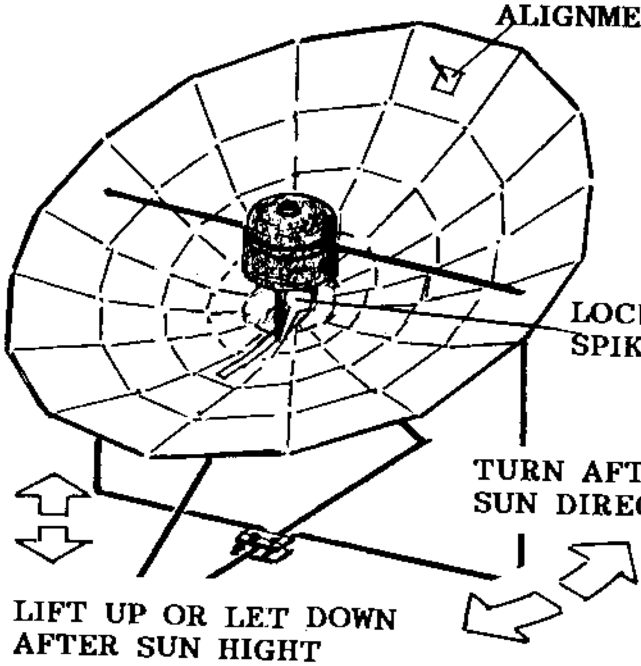
check out solar barbeque for more details

How to use the solar parabolic cooker

With a parabolic cooker as with an open fire or electric oven, you can overcook or burn food. But, in order to prevent burning, you may stir the food while it is cooking.

In general you can follow the same instructions as with box cookers (pp. 9-10). The biggest difference is that you are now operating with a higher temperature and need shorter aiming periods.

Don't put your head or facewhere the pot goes andavoid stirring and mixing your food longer than necessary! For additional safety wear sun glasses!



Find a sunny place for your solar cooker. Place the cooker on even ground. If possible, place some plywood or a metal plate under the cooker.

Aiming the cooker is very easy. You adjust it so that the shadow of the pin in the bottom disappears. You will soon learn to pre-set it a little, and after that you will only need to aim the cooker every half an hour.

If you have the V-1 cooker (whose receiver is made of cardboard), it is sensitive to rain and you must carry the cooker to a dry place after use. It is important to keep the reflecting surfaces clean.

Always use potholders!

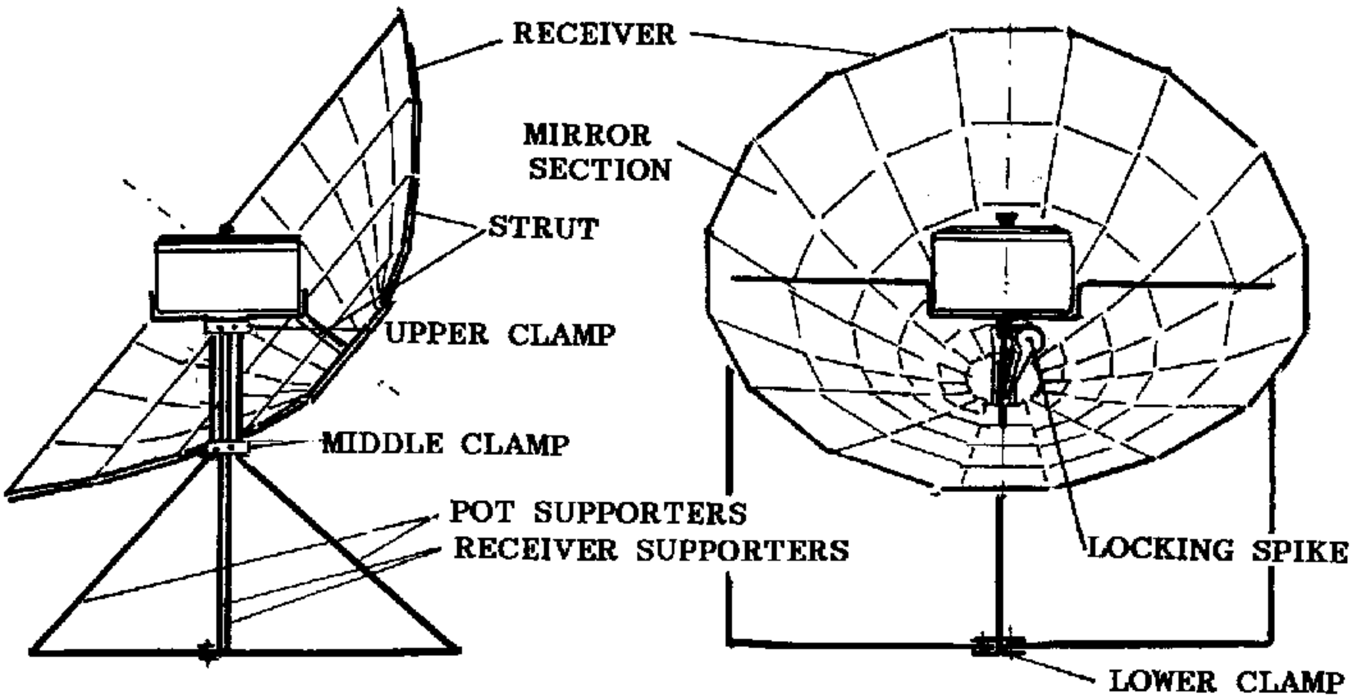
The cooking times are about half those given for the box cooker (p.11). If you have one cooker, you can only cook one dish at a time. But, if you are satisfied with your cooker and want to prepare two dishes at once, why not make another one! Or make a simple "haybox-cooker" for meals that require long simmering. In this way meals will also be kept hot so you can consume them after the sun has set.

With a parabolic cooker, you can use water as you would in ordinary (open fire) cooking. It can sterilize water even faster.

Black pots are necessary here, too. But the bottom of the pot must not be completely flat.

How to build a parabolic cooker

Structure of a parabolic (reflective) cooker



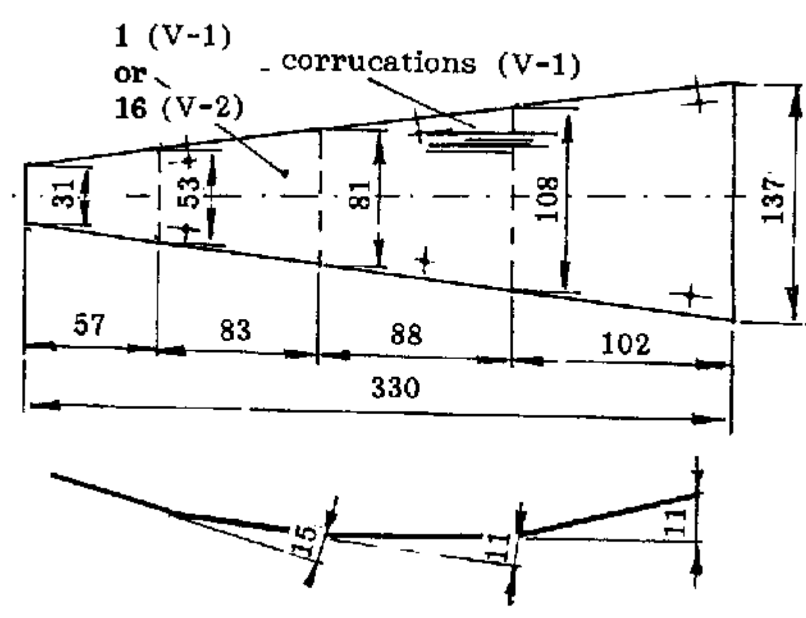
The 2 versions presented here are:
V-1: The cooker with cardboard reflector sections.
V-2: The cooker with metallic reflector sections.

Receiver

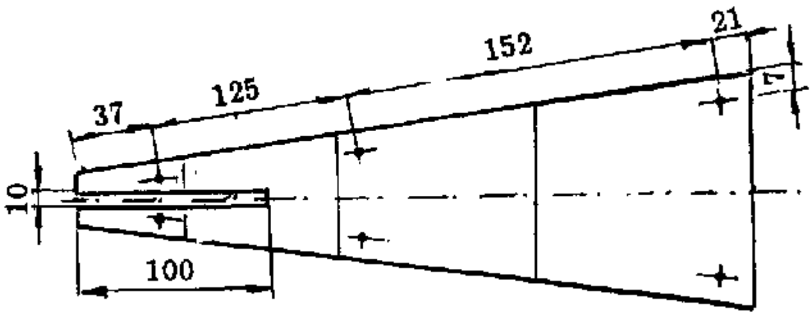
Following the drawing, cut 16 pieces for the mirror sections.

V-1: Use strong 7-8 mm thick cardboard (1), mark the folds exactly on the smooth side of the cardboard, score them lightly and bend up a little bit as shown in the diagram.

V-2: Use an aluminium sheet (16) of about 1 mm thickness, cut and bend it as in the drawing. For bending (if you have no filing vice), use some suitable slit.



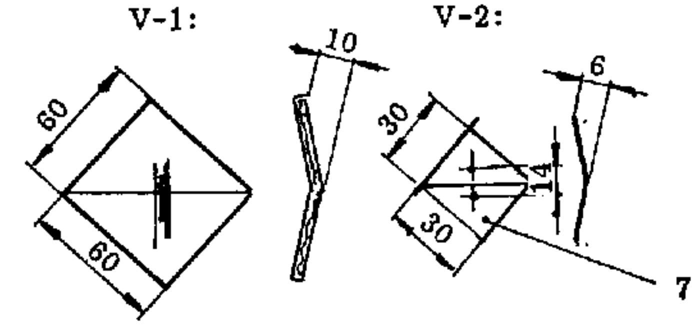
V-2: Drill six 5 mm holes along the sides of each mirror section.Cut the space for supporters in the lowest section.



Make 48 connecting pieces:

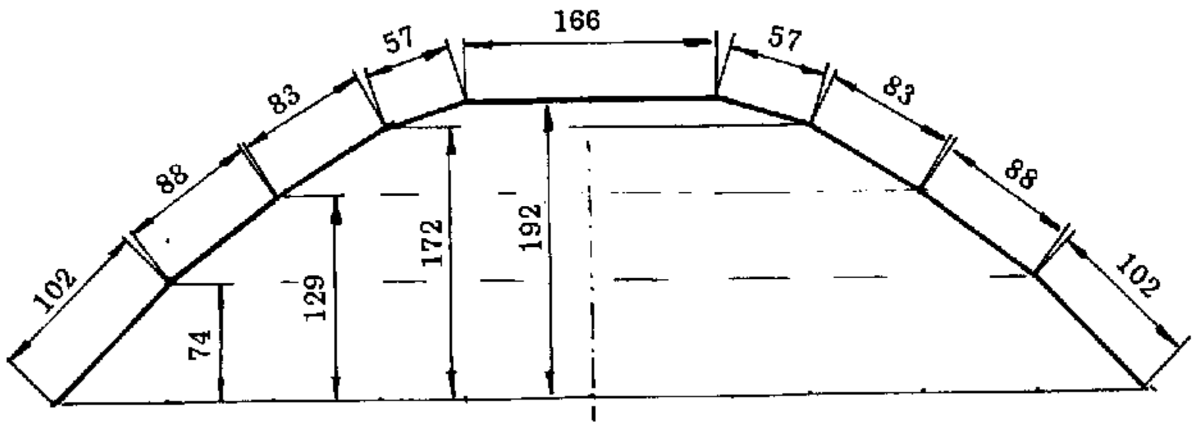
V-1: Cut from cardboard 60x60 mm and bend slightly.

V-2: Cut of 1.0 mm aluminium (7) 40x40 mm. Drill two 5 mm holes to match the holes on the reflector sections and bend according to the drawing.

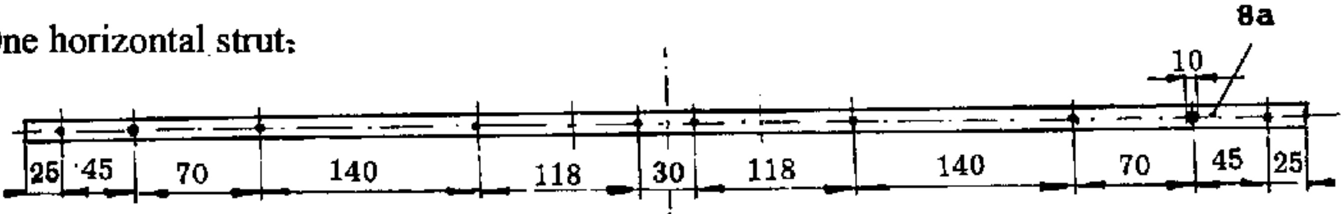


For the three struts, take a 3 x 20 mm steel bar, and cut (or saw) it to 826 mm lengths. Drill the 5 mm and 10 mm holes in the horizontal strut (8a) as shown in the diagram (the two 10 holes are the second ones from the ends); in the two vertical struts (8b) drill 5 mm holes as shown in the diagram.

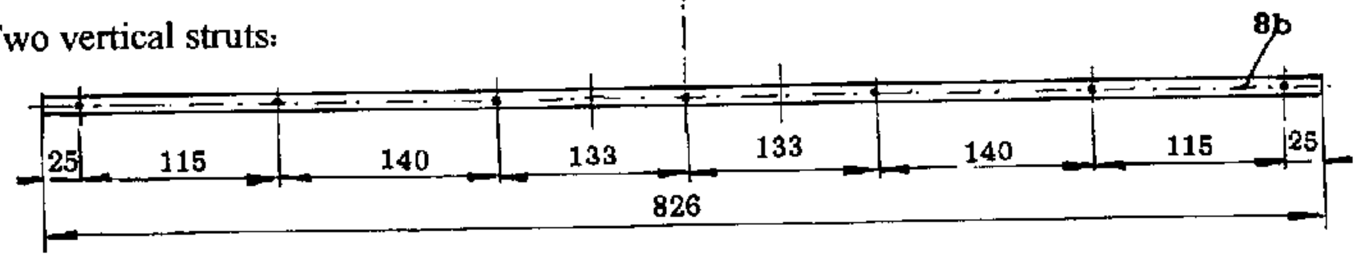
Bend exactly as in the drawing.



One horizontal strut:



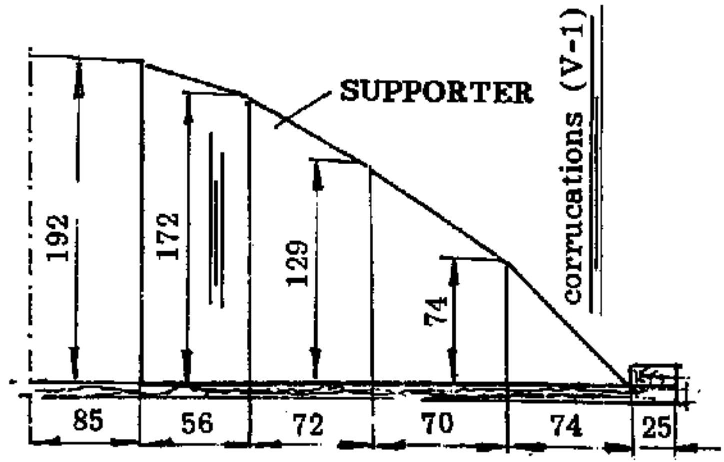
Two vertical struts:



Next construct a jig, for use in assembly work. For the base plate and 16 supporters use:

V-1: the same cardboard (1).

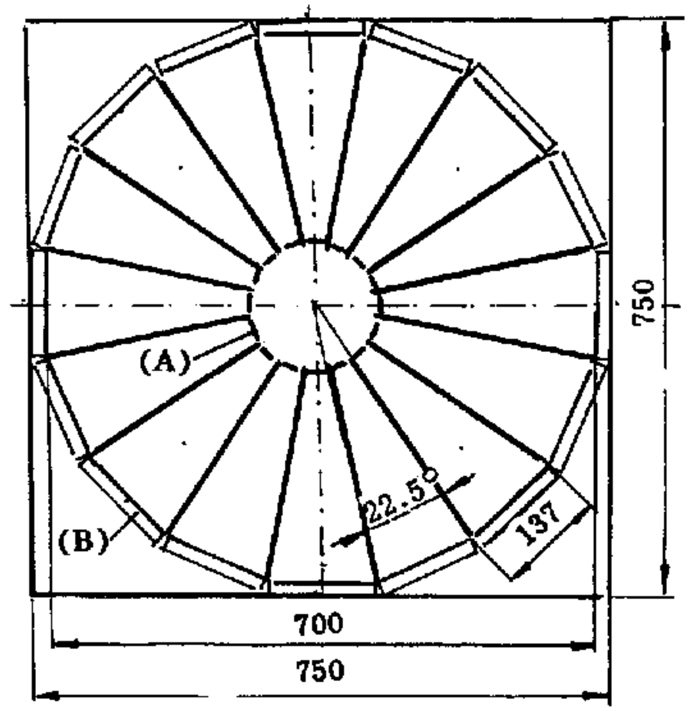
V-2: 5-10 mm plywood (4) (or a 2-5 mm steel plate if you have the possibility of welding).



Mark the location of the supporters on the base plate, and glue them to the plate. Next cut 16 inner end support strips (A):

V-1: 25x190 mm cardboard strips

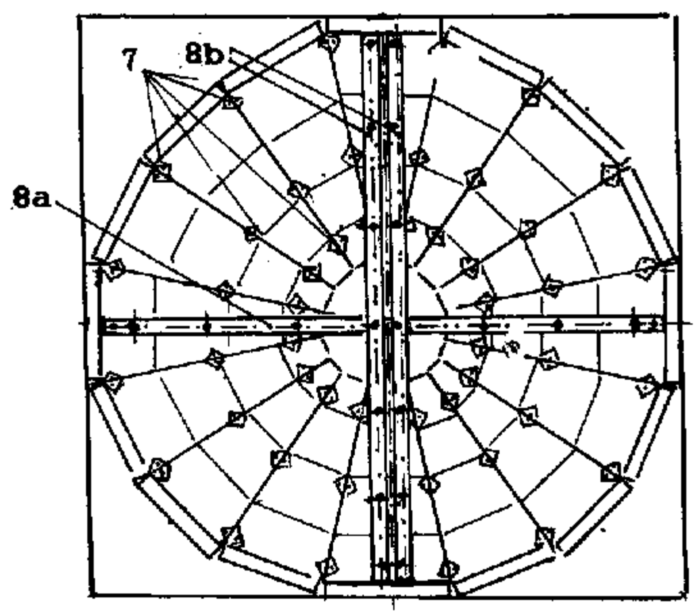
V-2: 25x190 mm plywood strips and glue them vertically between the supporters in the jig's inner circle. Cut 16 outer support strips (B), 25 x 135mm, and glue these on the outer sides.



Once the jig is complete, install the mirror sections against it:

V-1: Taping them lightly together or clamping them. Glue the joints and the connecting pieces, using tape to hold the pieces together.

V-2: Screw the mirror sections together using the connecting pieces and 4 mm screws, first lightly and then tightening them on the jig.



Fasten the vertical strut to the two horizontal struts in the middle using 4 mm screws. Then put this assembly over the receiver on the jig, drill 5 mm holes (through the holes in the struts) into the receiver sections and screw the struts to the receiver.For the reflecting surface you need aluminium foil (2). Cut these pieces to the dimensions given for the mirror sections and glue on with whiteglue.

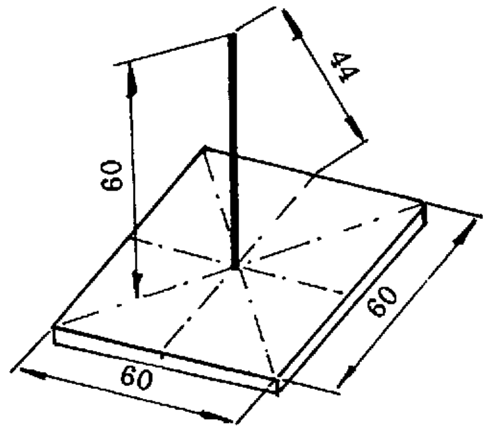
Use a spatula for spreading the glue.

For aiming the cooker, an adjusting pin is necessary. Its base plate can be made of:

V-1: plywood, glued or screwed in place

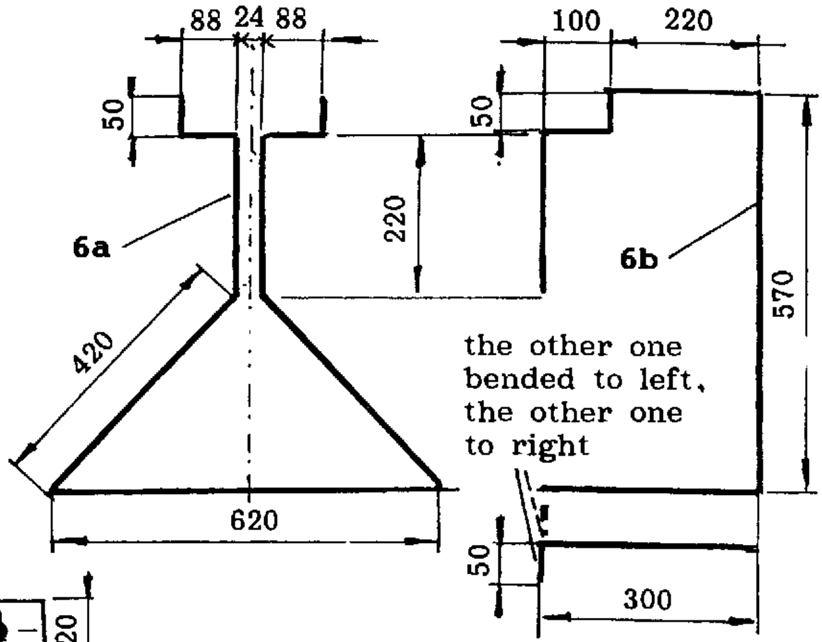
V-2: sheet metal, fastened with screws.

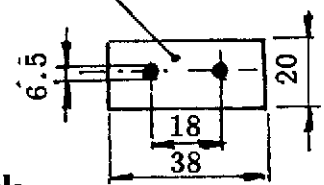
The pin can be of 6 mm thick bar (6). The base plate should be painted white. Fasten it to the top of the receiver.



Stand

The stand for the receiver and for the pot is made of 1+2 supporters (6a + 6b) made of 6 mm thick round steel bars.If you have no filing vice, use a suitable hole or slit for bending. For assembly, make 6 fastening clamps (9) of a 3 x 20 mm steel bar.





Assembly work

It is easiest to assemble the parts with the receiver facing upwards. First put the middle supporter (6a) in place and then the side supporters (6b). Then fasten the first clamps with 6 mm bolts, turn the cooker over and then fasten the other clamps.

Necessary tools

You will need more or less the same tools as for building the box cooker. Some special tools are necessary for cutting sheet metal and fastenings, and it would be good if you can find some small metal workshop near your home where you can get help. If you are working at home, a filing vice helps a lot.

For serial production you can naturally build more tools and jigs, which save a lot of working time.

In using the cooker, one important tool is a normal spike (17). When you put it between the strut and stay-supporter the receiver stays in the desired position.

Materials for the cooker

Material	V-1		V-2	
	Amount	Price*)	Amount	Price*)
1. Carboard	0.8 m2	1.50	-	-
for the jig	2.0 m2	(3.00)		
2. Aluminium foil	0.7 m2	1.50	0.7 m2	1.50
3. Glue, whiteglue	0.3 l	1.50	0.3 l	1.50
4. Plywood, for the jig			2.0 m2	(10.00)
5. Wooden batten, 25x25 jig			2.5 m	(2.00)
6. Steel bar, 6 mm round	5.5 m	2.00	5.5 m	2.00
7. Connecting pieces 1x30x30			48	0.50
8. Steel bar 3x20x826	3	2.00	3	2.00
9. Steel pieces 3x20x38	6	0.20	6	0.20
10.Screws 4 x 8 mm			100	2.00
11.Screws 4 x 12 mm	22	0.50	22	0.50
12.Bolt 6 mm x 20 mm	6	0.50	6	0.50
13.Washers 4 mm	22	0.10		
14.Tape	some	-	some	-
15.Paint for the outside	0.1 l	1.00	-	-
16.Aluminium sheet 1 mm	0.6 m2	7.00		
17.Spike	1.0	1.00		
Total		**11.80**		**18.70**)

*) Prices are estimates given in US dollars.

**) If 1 mm bright aluminium sheet (like ANOFOL) is used instead, 0.6 m2 costs 14 dollars. In this case items 2, 3 and 16 are not needed, and the total material cost is $ 22.

The cost of the one-time jig is not included in the total price.

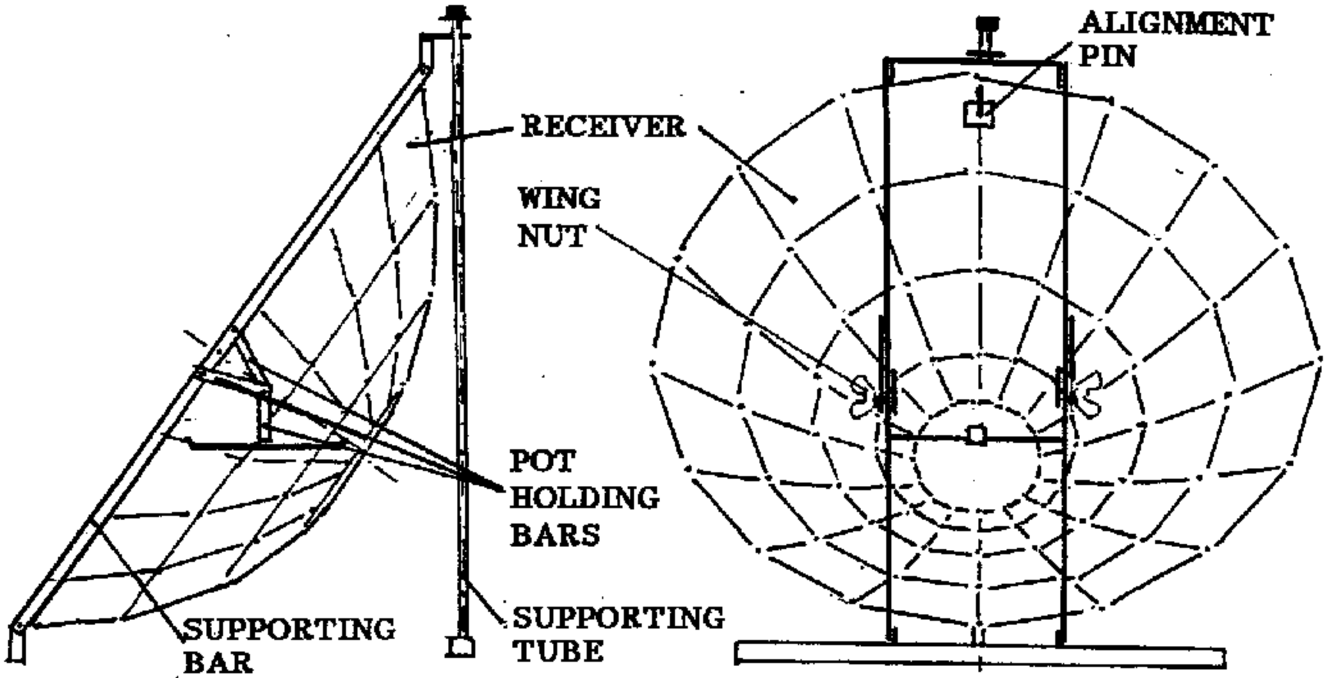
THERE ARE HUNDREDS OF WAYS OF BUILDING SOLAR COOKERS; FEEL FREE TO IMPROVE UPON OUR DESIGNS!

And you can build the cooker for a bigger pot and higher capacity. You can easily multiply all dimensions by 20%, resulting in a 40% higher capacity!

APPENDIX TO MANUAL TFL-2

HOW TO BUILD A STILL BETTER PARABOLIC SOLAR COOKER

The idea for a new parabolic cooker based on the possibility to use a thinner reflector material and bend the reflector sections. The expected life time with bright aluminium reflector is very long, (V-4), the weight only 2.5 kg and the assembly work will be very easy.



The 2 versions presented here are:

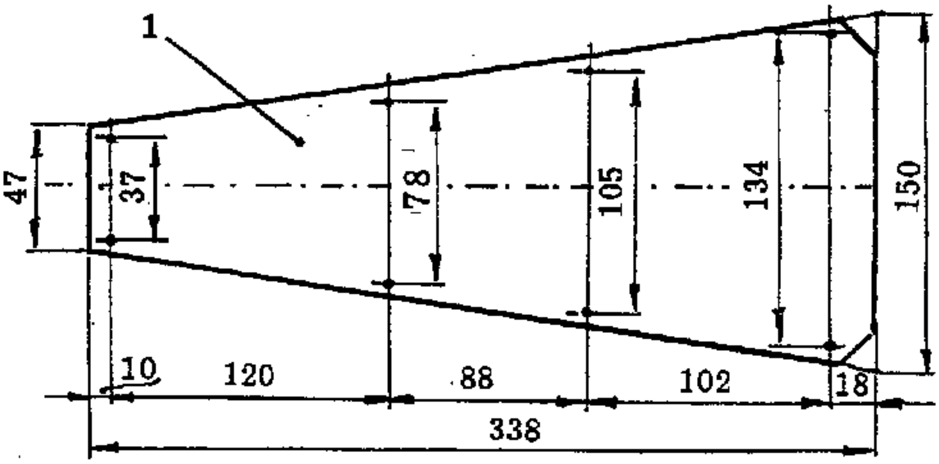
V-3: The cooker with glued foil reflector sections

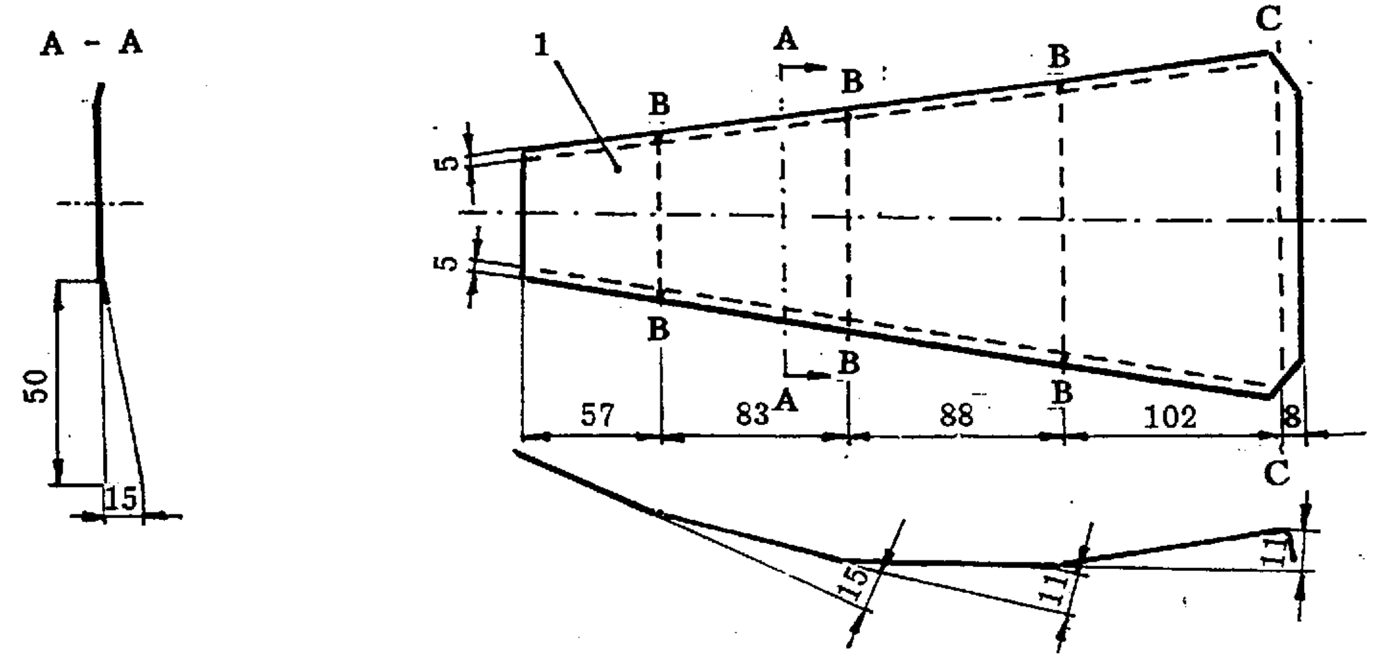
V-4: The cooker with bright aluminium reflector sections.
Recommended, if the material is available.
(Recycled material, as used in mirrors of fluorescent lamps, is highly recommended!)

Receiver

Following the drawing cut 16 pieces for the mirror sections.

Drill 4 mm. holes according to the drawing. Use template!





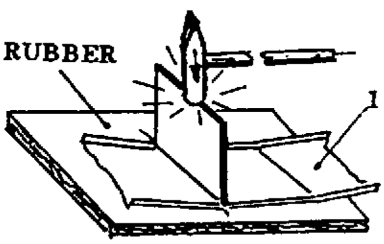
Mark the bending lines as shown in the drawing.

Then make cuts 5 mm in from the edge on the long sides along every bending line (B).

A simple hand machine for bending is necessary.

First bend the long sides up (about 15°, see A-A).

Second, bend the outher side down 90°. (C-C).



Finally bend the three lines (B-B) exactly along the lines. It happens easiest to hammer down 1-2 mm thick steel plate over a piece of rubber carpet.

For assembly work use 4 x 8 mm screws. If you have done accurate work, the receiver will surely be fine!

For the V-3 receiver cut the foils exactly as the mirror sections and glue with whiteglue.

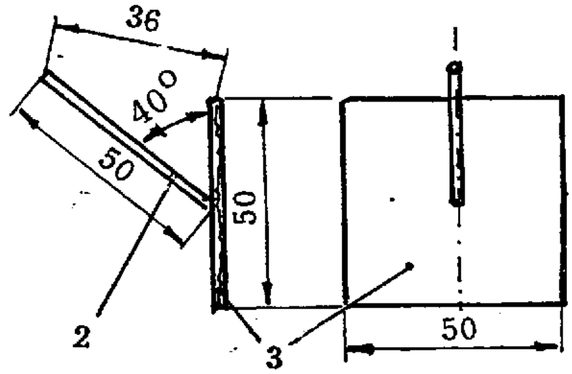
For aiming an adjusting pin is necessary.

The base plate **3** can be made of plywood.

The pin (**2**) can be made of a nail or a round 3-5 mm bar.

The base plate schould be painted white.

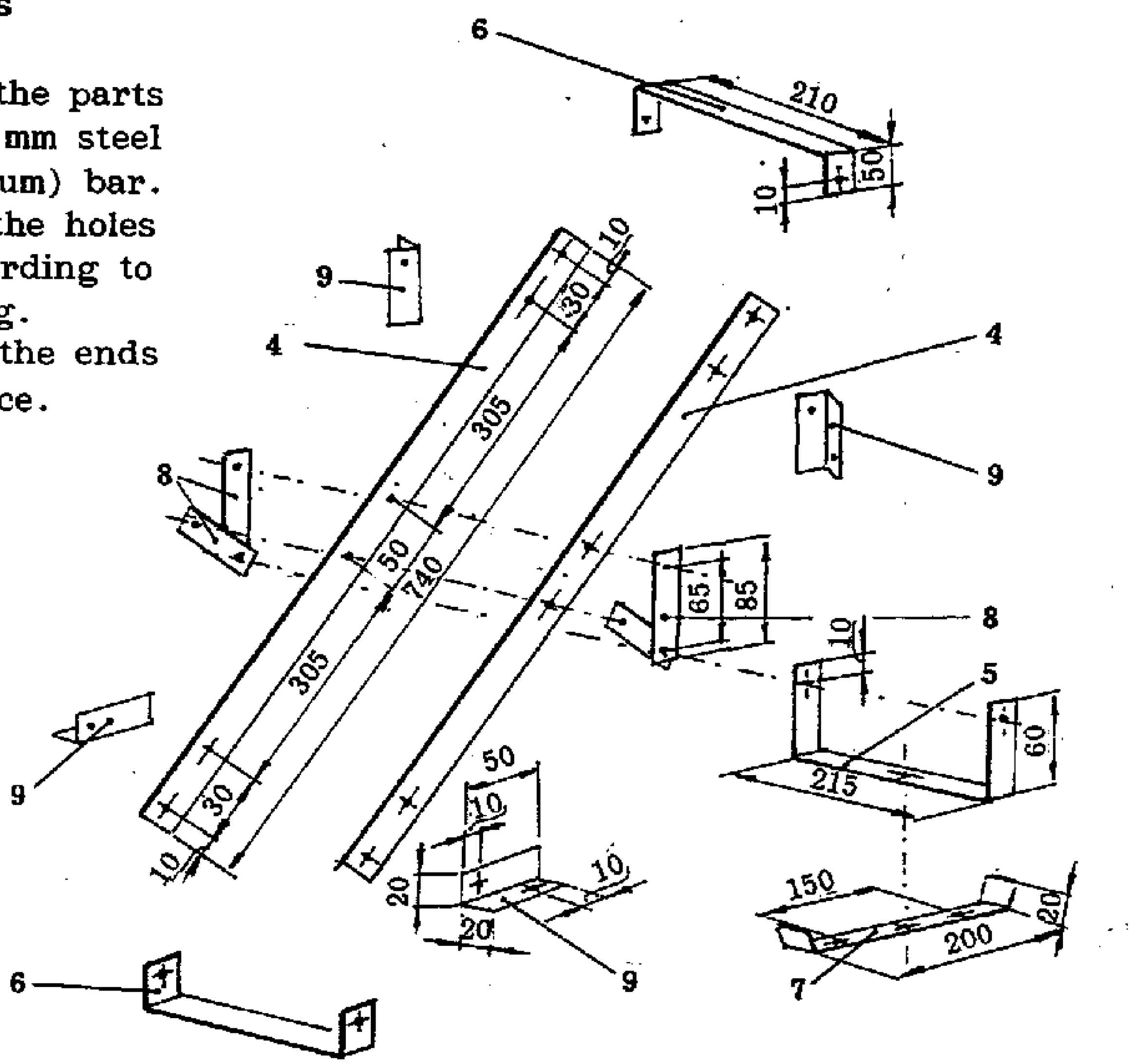
Fasten in the top with screws.



Stands

Cut the parts of 3 x 20 mm steel (or aluminium) bar.

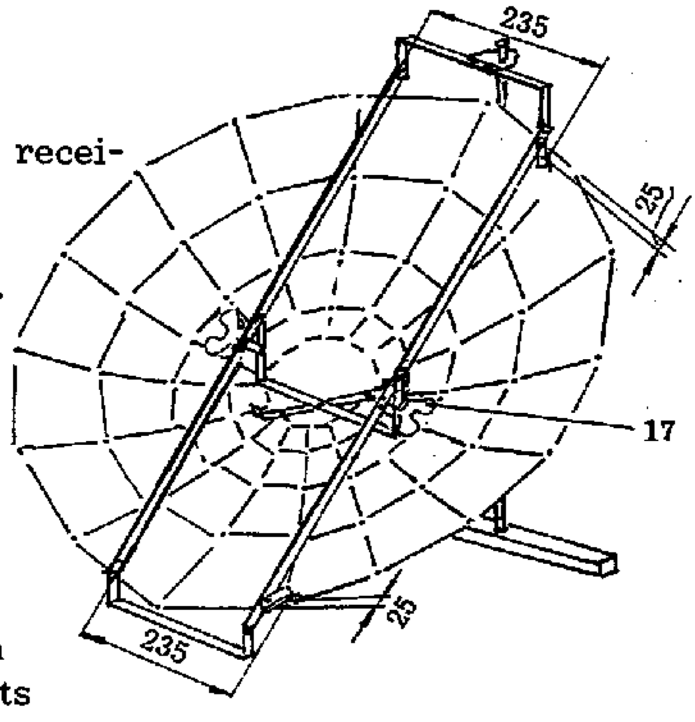
Drill the holes 5 mm according to the drawing. Then bend the ends in filing vice.



Make the fastenings (9) of 1 mm steel or aluminium sheet.

Drill four 5 mm holes on the receiver as shown in the drawing. Fasten the long supporters (4) together with end supporters (6). Then fasten them together with the receiver fastenings (9).

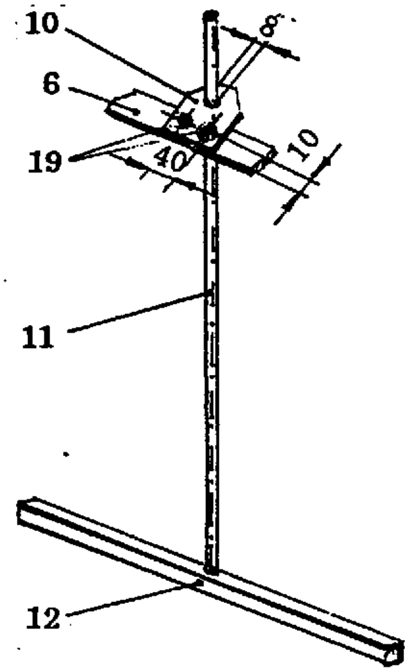
Screw the pot supporters (5) and (7) together and then these with 5 mm screws together with the bars (8) with the long supporters (4). Put a spring washer (18) between the bars and tighten the wing nuts (17) on both ends.



Prepare the upper supporter bar with 3 x 60 x 60 mm rubber plate (10).

Drill two 5 mm and one 8 mm hole and screw it together with the upper supporter bar (6) with 5 mm screws.

Least make the supporting tube (11) (or use a wooden stick) at the rear of the receiver.
Drill the hole in the middle of 25x25 x 500 mm wooden batten (12) and glue the tube or stick together with the batten.



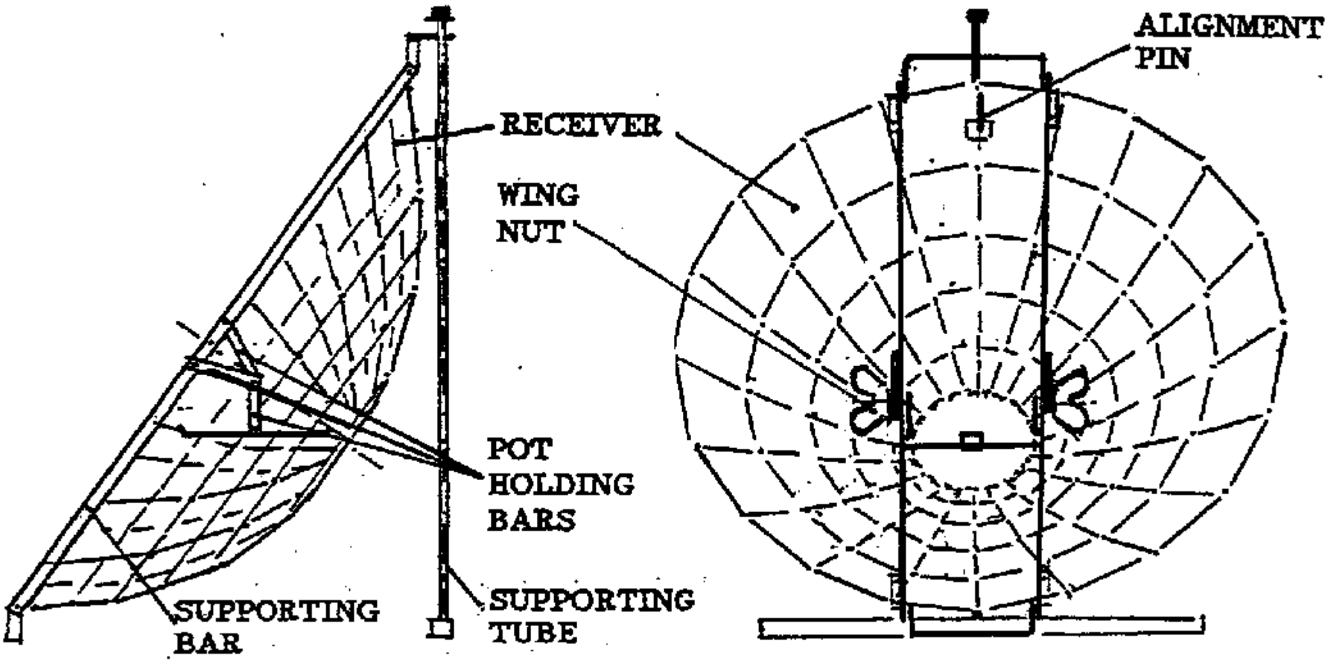
Materials for the cooker	V-3		V-4	
	Amount	Price	Amount	Price
1. Reflector sections m2				
Bright alum.0.7mm (as ANOFOL)	-	-	0.6	8.40
or steel sheet, 0.5 mm	0.6	1.80	-	-
2. Nail 60 mm	1	-	1	-
3. Plywood 8-10 mm	1	-	1	-
4. Steel bar 3x20 x 740 mm	2	0.70	2	0.70
5. -"- x 335 mm	1	0.20	1	0.20
6. -"- x 310 mm	2	0.30	2	0.30
7 -"- x 240 mm	1	0.10	1	0.10.
8. -"- x 85 mm	4	0.20	4	0.20
9. Steel fastenings 1x20x20x50 mm	4	0.20	4	0.20
10. Rubber plate 3-4x60 x60 mm	1	0.10	1	0.10
11. Steel tube 8-10x700 mm	1	0.40	1	0.40
12. Wooden batten 25x25x500 mm	1	0.20	1	0.20
13. Aluminium foil m2	0.7	1.50	-	-
14. Whiteglue l.	0.2	1.50	-	-
15. Screws 4 x 8 mm	80	1.60	80	1.60
16. -"- 5 x 15 mm	15	0.50	8	0.50
17. Wing nuts 5 mm	2	0.50	2	0.50
18. Spring washer	2	0.10	2	0.10
19. Washer 5 mm	4	-	4	-
Total		**9.90**		**13.50**

Prices are estimates given in US-dollars.

HOW TO BUILD A STILL BETTER PARABOLIC SOLAR COOKER

TFL / P-1000

The idea for a new parabolic cooker based on the possibility to use a thinner reflector material and bend the reflector sections. The expected life time with bright aluminium reflector is very long, (V-4), the weight only 4.5 kg and the assembly work will be very easy. **You can cook 2 litres in 45 minutes!**



The 2 versions presented here are:

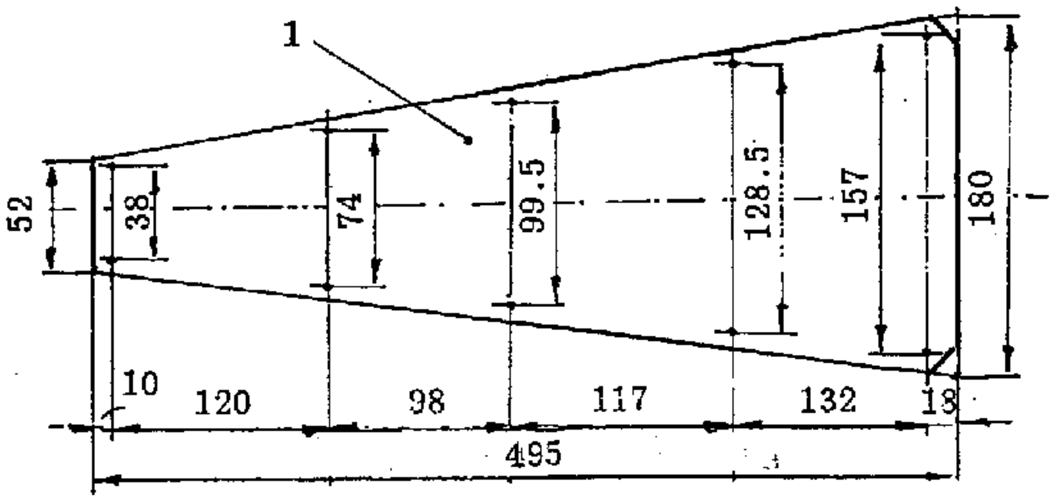
V-3: The cooker with glued foil reflector sections

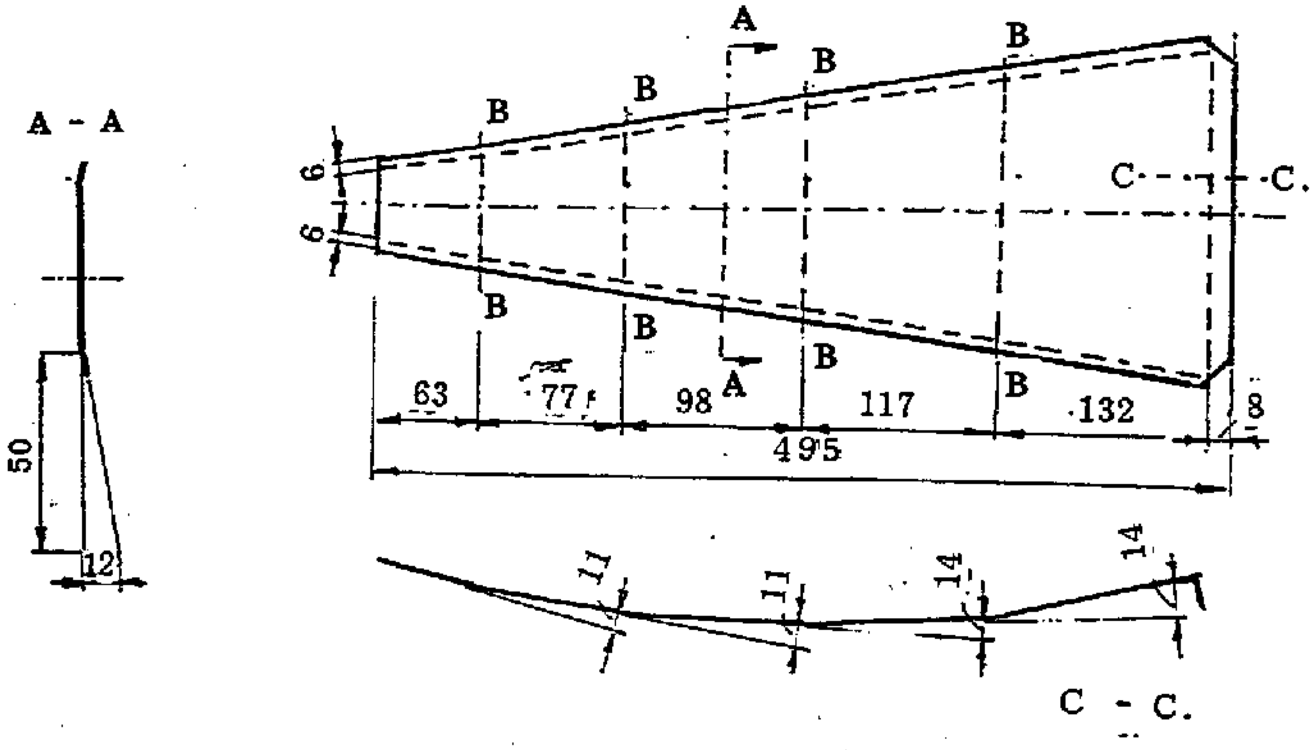
V-4: The cooker with bright aluminium reflector sections. Recommended, if the material is available. (Recycled material, as used in mirrors of fluorescent lamps, is highly recommended!)

Receiver

Following the drawing cut 20 pieces for the mirror sections.

Drill 4 mm. holes according to the drawing. Make first a template !





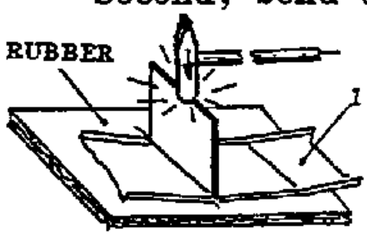
Mark the bending lines B-B as shown in the drawing.

Then make cuts 6 mm in from the edge on the long sides along every bending line B-B.

A simple hand machine for bending is necessary.

First bend the long sides up (about 12° , see A-A).

Second, bend the outher side down 90° . (C-C).



Finally bend the three lines (B-B) exactly along the lines. It happens easiest to hammer down 1-2 mm thick steel plate over a piece of rubber carpet.

For assembly work use 4 x 8 mm screws. If you have done accurate work, the receiver will surely be fine!

For the V-3 receiver cut the foils exactly as the mirror sections and glue with whiteglue.

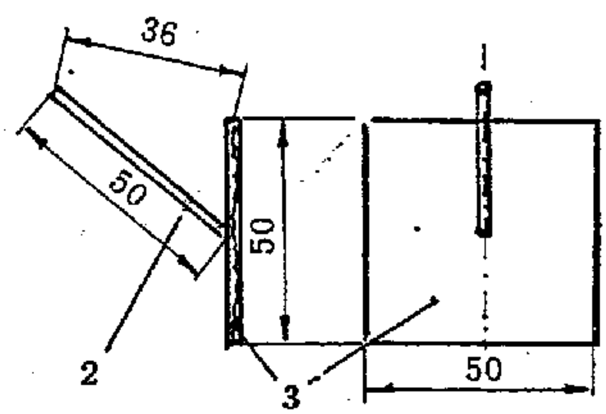
For aiming an adjusting pin is necessary.

The base plate 3 can be made of plywood.

The pin (2) can be made of a the nail or a round 3-5 mm bar.

The base plate schould be painted white.

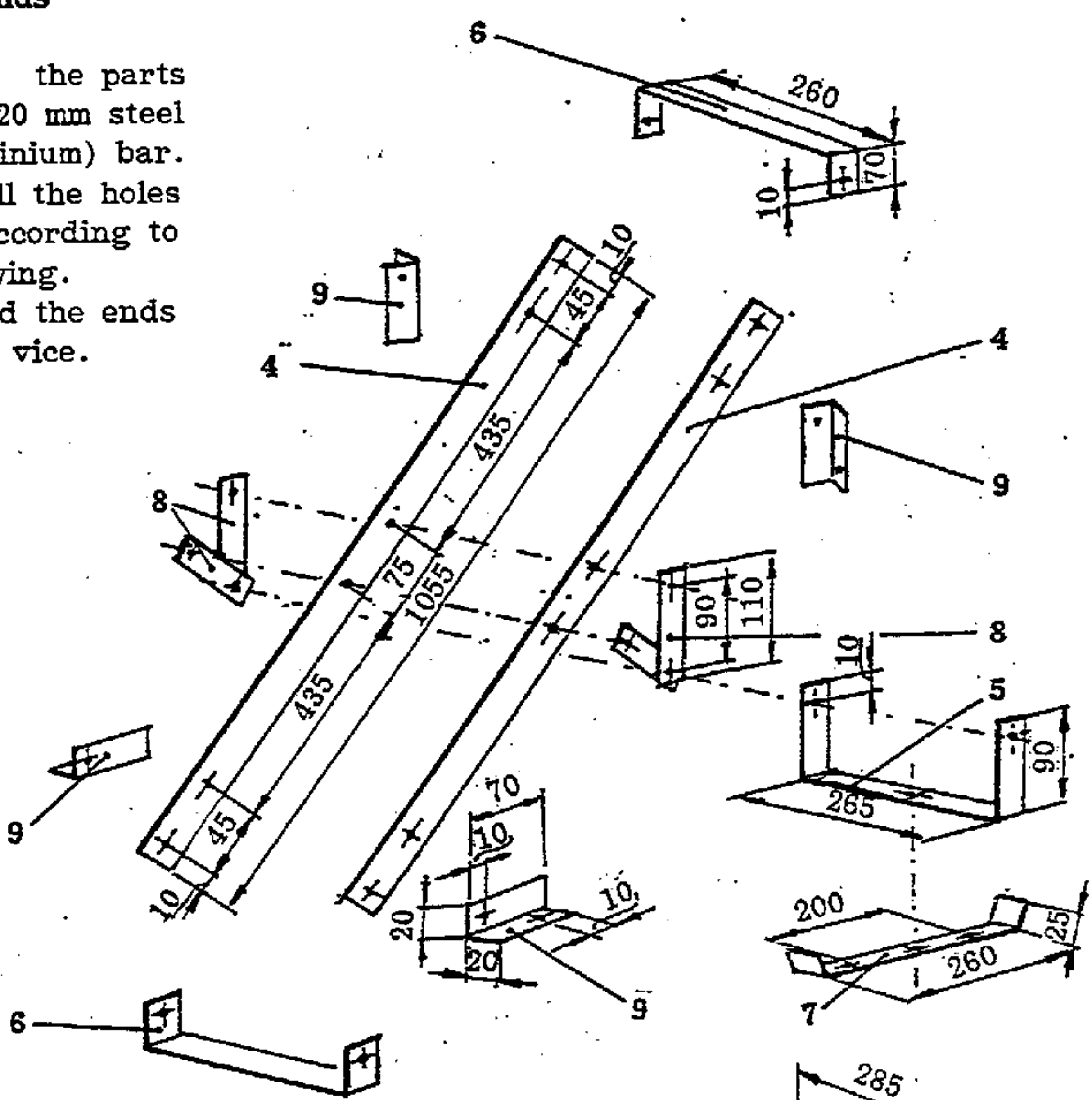
Fasten in the top with screws.



Stands

Cut the parts of 3 x 20 mm steel (or aluminium) bar.

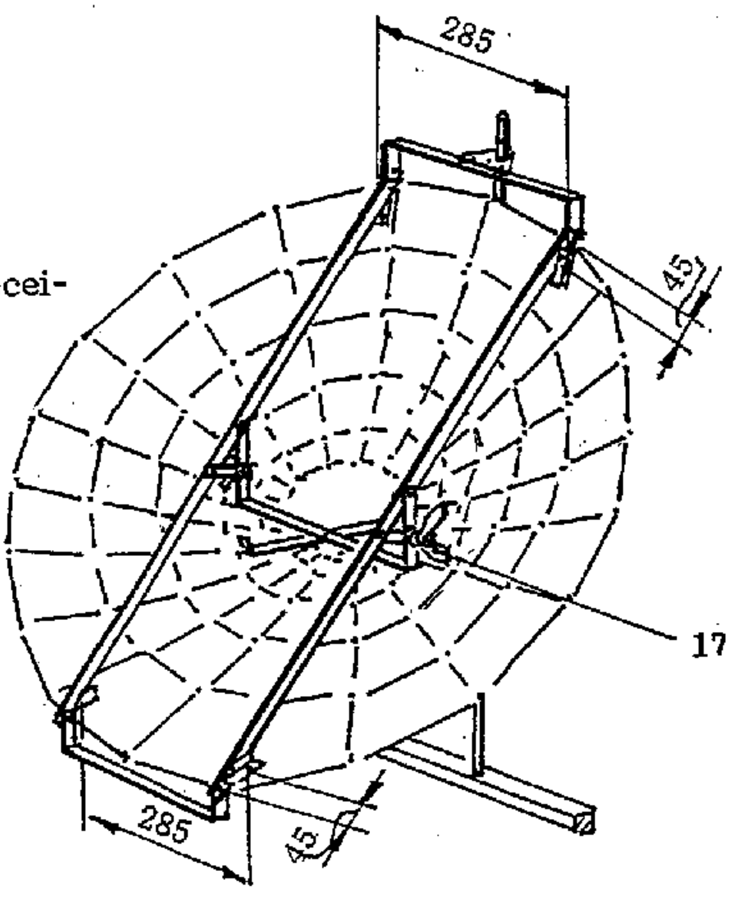
Drill the holes 6 mm according to the drawing.
The bend the ends in filing vice.



Make the fastenings (9) of 1 mm steel or aluminium sheet.

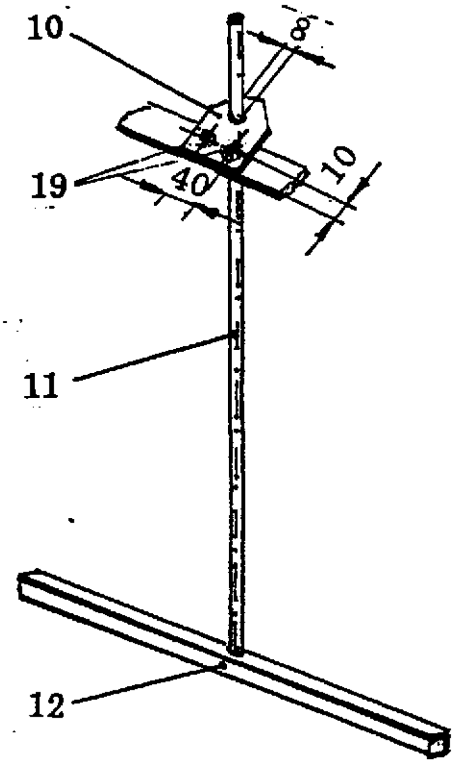
Drill four 6 mm holes on the receiver as shown in the drawing.
Fasten the long supporters (4) together with end supporters (6).
Then fasten them together with the receiver fastenings (9).

Screw the pot supporters (5) and (7) together and then these with 6 mm screws together with the bars (8) with the long supporters (4).
Put a spring washer (18) between the bars and tighten the wing nuts (17) on both ends.



Prepare the upper supporter bar with 3 x 60 x 60 mm rubber plate (10). Drill two 6 mm and one 8 mm hole and screw it together with the upper supporter bar (6) with 6 mm screws.

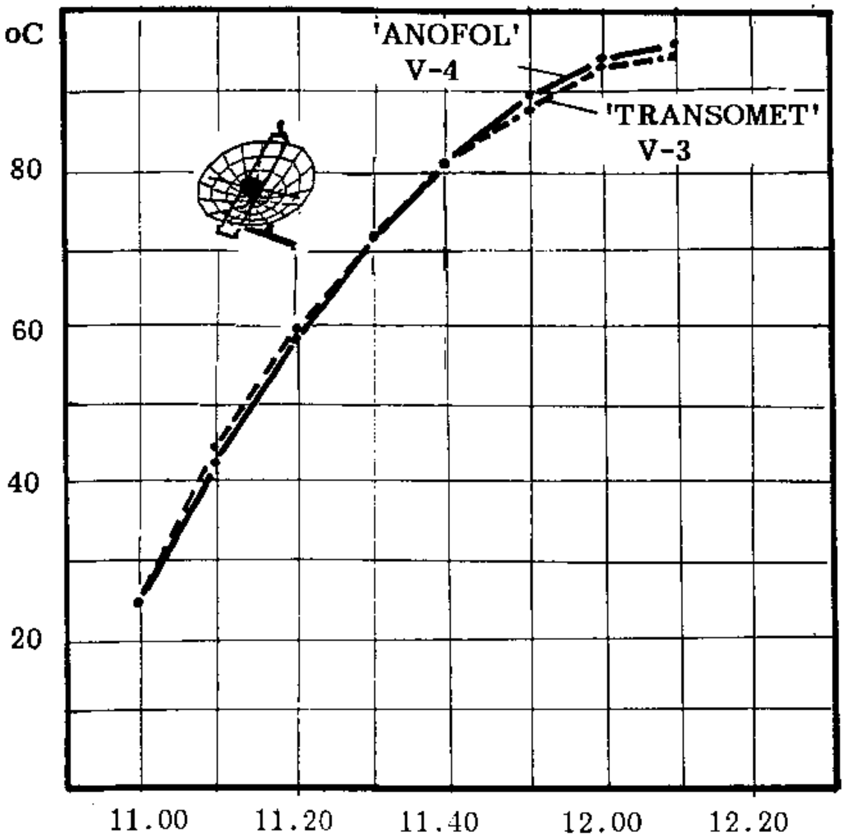
Least make the supporting tube (11) (or use a a wooden stick) at the rear of the receiver. Drill the hole in the middle of 25x25 x 1000 mm wooden batten (12) and glue the tube or stick together with the batten.



Materialas for the cooker	V-3		V-4	
	Amount	Price	Amount	Price
1. Reclector sections m2				
Bright alum.1.0mm (as ANOFOL)	-	-	1.2	21.0
or alum/steel sheet, 1.0/0.75 mm	1.2	4.20	-	-
2. Nail 60 mm	1	-	1	-
3. Plywood 8-10 mm	1	-	1	-
4. Steel bar 3x20 x 1055 mm	2	1.00	2	1.00
5. -"- x 445 mm	1	0.30	1	0.30
6. -"- x 400 mm	2	0.40	2	0.40
7 -"- x 310 mm	1	0.10	1	0.10.
8. -"- x 110 mm	4	0.30	4	0.30
9. Steel fastenings 1x20x20x70 mm	4	0.20	4	0.20
10. Rubber plate 3-4x60 x60 mm	1	0.10	1	0.10
11. Steel tube 8-10x1000 mm	1	0.60	1	0.60
12. Wooden batten 25x25x1000 mm.	1	0.30	1	0.30
13. Aluminium foil m2	1.4	3.00	-	-
14. Whiteglue l.	0.4	3.00	-	-
15. Screws 4 x 8 mm	100	2.20	100	2.20
16. -"- 6 x 15 mm	15	0.70	15	0.70
17. Wing nuts 6 mm	2	0.70	2	0.70
18. Spring washer 6 mm	2	0.20	2	0.20
19. Washer 6 mm	4	0.10	4	0.10
Total		**17.40**		**28.20**

Prices are estimates given in US-dollars.

COMPARISIONS BETWEEN DIFFERENT REFLECTOR MATERIALS
IN TFL-PARABOLIC COOKERS



WATER TEMPERATURE
IN THE POT

Reflector area:
0.8 m2
Amount of water:
2 liter
Ambient temperature:
23 oC
Weather:
Bright sunshine,
mild wind.

Helsinki, 16.6.1999.

Low-cost "ANOFOL" - reflector foil can be obtained from:

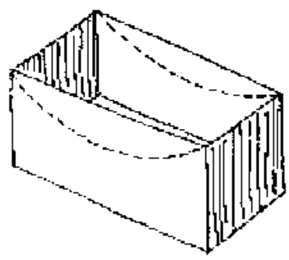
Åkerlund and Ramsing Ltd.
Post Box 100
27501 Kantria, Finland

Using Parabolas to Design a Solar Hotdog Cooker

Download from Internet. Infoseek => Solar Cookers.

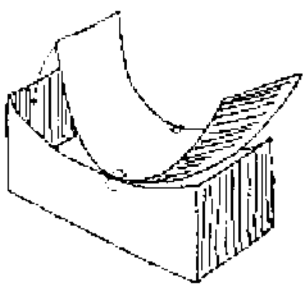
Energy and Science Projects For Students

Solar Hot Dog Cooker



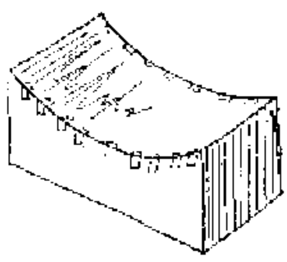
This project is for older students or for younger students with adult supervision.

A reflective hot dog cooker can be built from a cardboard box, tin foil, and posterboard. Sunlight hits the reflective surface and focuses on the hot dog held in the center. Students can work in pairs or individually if there are enough materials.



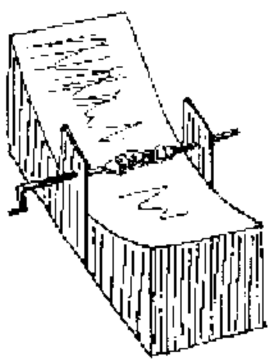
1. Select a long narrow box; the longer the box the more heat collection is possible. Choose a focal length between 5" and 10" and design a parabolic curve as seen in the picture. One template could be used for all the cookers. Trace the curve on the open end of the box so that it is centered and straight.

2. Cut out the curve with a utility knife. Stress the importance of being exact. Measure and cut a piece of posterboard that will fix flush against the opening to the box. Attach this with tape beginning at the center and working toward to edges.

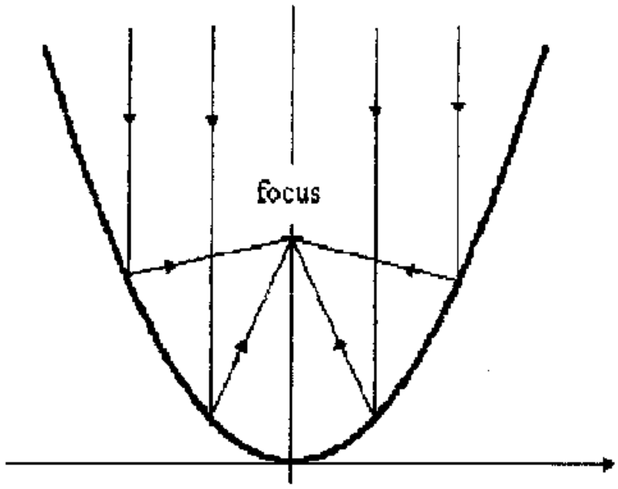


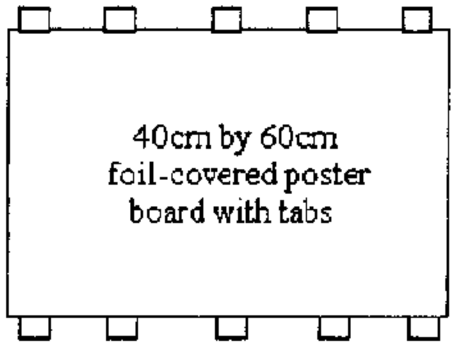
3. Cover the curve with white glue and apply aluminum foil shiny side out. Start in the middle and smooth toward the edges. Try not to wrinkle or fold the foil; you want it as smooth as possible.

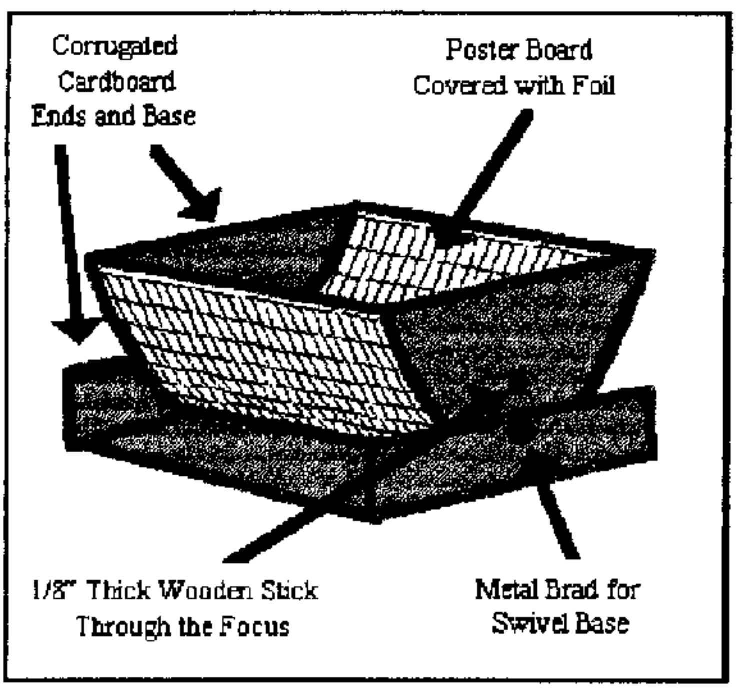
4. Use two scraps of cardboard taped to each side as supports. Using the sun or a projector light, test the focal point. There should be a bright spot where light is concentrated; mark this spot and punch a hole for the skewer. Use a section of a coat hanger from which the paint has been removed for a skewer.



5. Enjoy your hot dog!







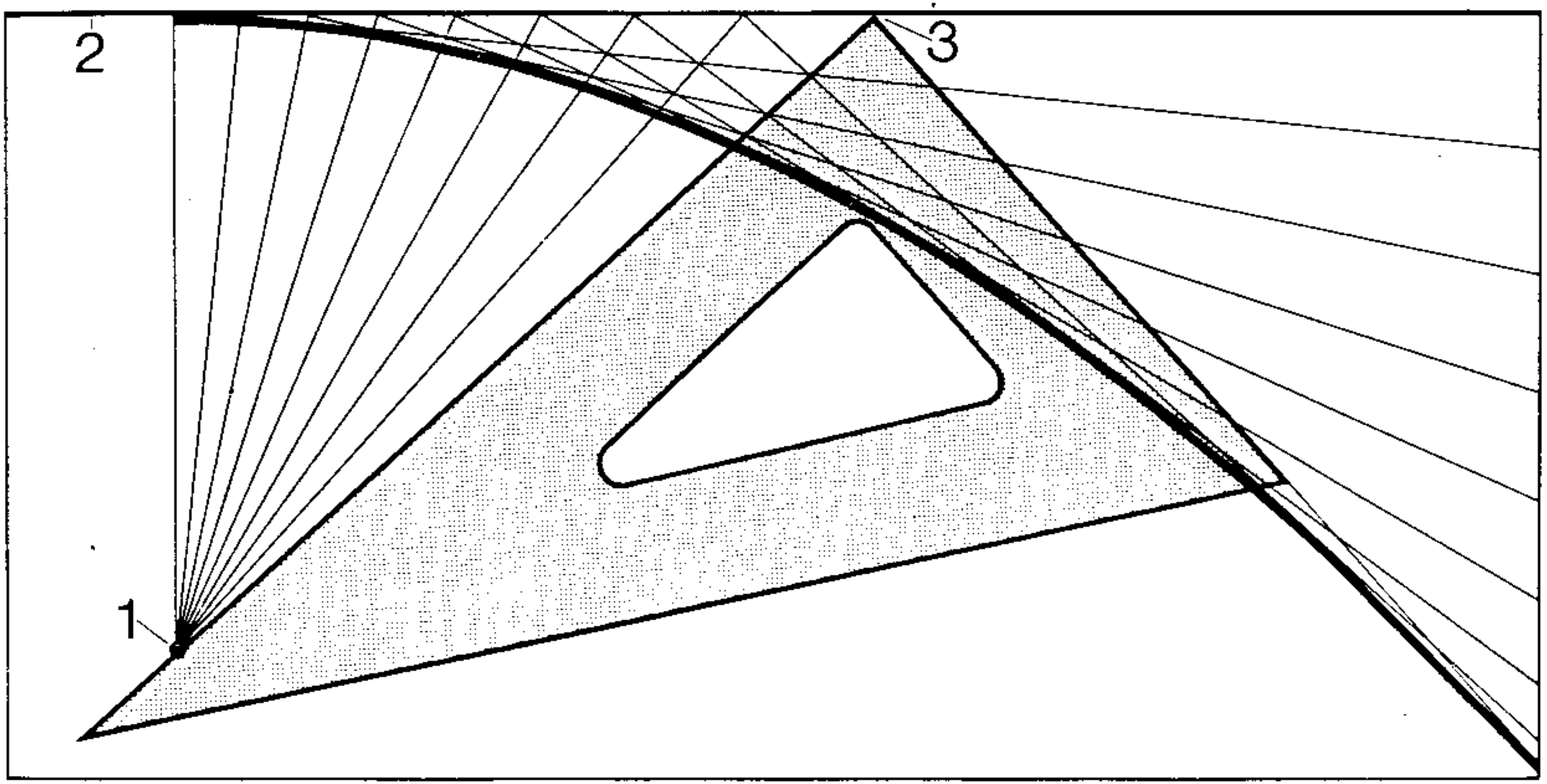
Here are the basic design instructions. You will need some poster board, some aluminum foil, a skewer (get a 1/8" diameter wooden stick from a craft store), some glue, a handful of metal brads and a sheet of corrugated cardboard (we used a cardboard T-shirt pattern from a craft store). The total cost of the materials should not exceed $2.00. The corrugated cardboard is used to make 2 ends which are shaped like parabolas, and a swivel base. We used the equation $y = \frac{1}{20}x^2$ to create the parabola. (If you are wondering how you can make an accurate sketch of this parabola on the cardboard, then read the article below.) Units were measured in centimeters and a sketch was made for $-20 \leq x \leq 20$. We then cut out the region determined by $\frac{1}{20}x^2 \leq y \leq 20$ for $-20 \leq x \leq 20$. These ends were attached to a 40cm by 60cm sheet of poster board which was covered with aluminum foil. The foil can be fixed to the poster board by spreading a very thin layer of wood glue over the poster board and then attaching the foil. Try to keep the foil as smooth as possible. The cardboard ends can be attached to the poster board in a variety of ways. The easiest of these is to cut the poster board a little wider than 40cm, and then cut tabs in the ends which can be folded over the cardboard sides and attached with glue and metal brads. Of course, it is the long sides of the poster board which attach to the cardboard ends. You might also find that the 40cm lengths of the poster board will be more sturdy if a 40cm stick is attached along each end with masking tape (try a 1/8" diameter wooden stick).

Once the poster board is attached to the cardboard ends, the only remaining work is placing a wooden rod through the focus at each end (5cm above the vertex) and attaching the structure to a swivel base (as indicated in the picture).

Cooking is fairly simple. Simply back the stick out of one focus and skewer a hotdog. Then place the stick back in the hole. Put your cooker in the sunlight and use the swivel to point the foil-lined parabolic cylinder directly towards the sun. If the cooker is properly aligned then the lower portion of the hotdog will be brightly illuminated. Your cooking time may vary. We recommend that you try this in hot weather.

We tested 30 cookers in August during a summer math/science summer camp, and the average cooking time was 20 minutes. The students were amazed that the cookers actually worked!

- **Download from Internet. Infoseek => Solar Cookers.**



Konstruktion af en parabolkurve til et solkogeapparat. En ret linie tegnes på et stykke spånplade (2), og et søm (1) slås i spånpladen i en afstand, som svarer til brændpunktslængden. (Afstanden 1-2, som skal være 40-50 cm). Dernæst tager man en tegnetrekant (eller et bræt) og flytter dens ene hjørne langs stregen, idet man tegner en linie, som vist på tegningen hver gang man har flyttet den et lille stykke. Linierne vil tilsammen danne en parabolkurve med den ønskede brændpunktslængde. Kurven tegnes op og skæres ud med en løvsav.

Bogen om Alt. Energikild. E-Lura. Politikens Forlag. DK 1977. 87-567-2741-0.

108. Graph of a function of second degree.

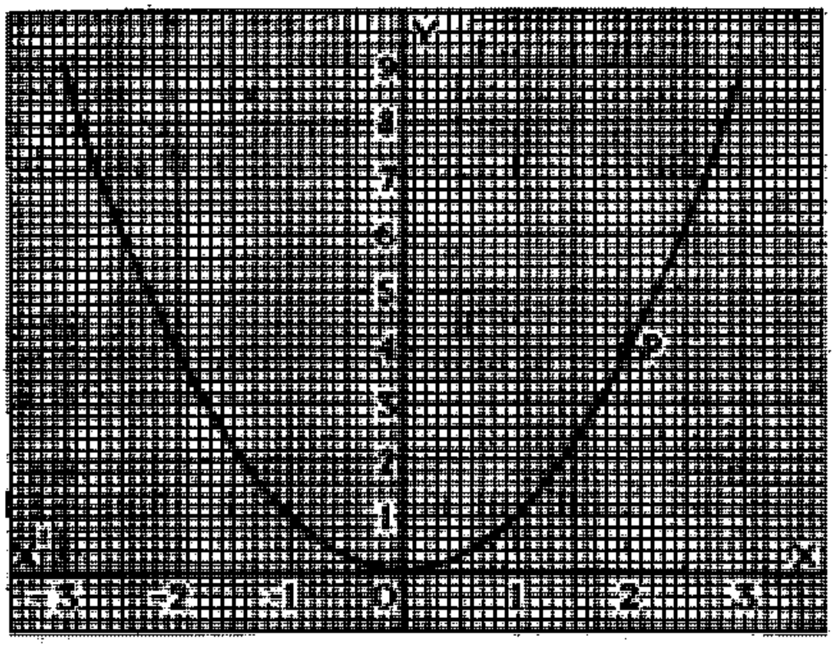
The simplest form of a function of the second degree is that which is expressed by $y = x^2$. This is called a **quadratic function**, from the Latin **quadratus** (squared). The area of a circle, $A = \pi r^2$, is a special form of this.

To plot the curve of $y = x^2$. We first assign values to x, calculate the corresponding values of x^2, or y, and tabulate them as follows:

x	−3	−2·5	−2	−1·5	−1	0	1	1·5	2	2·25	3
y	9	6·25	4	2·25	1	0	1	2·25	4	6·25	9

As wide a range of values is taken as the size of the paper will allow to be plotted. Since the values of y increase more rapidly than those of x, more room is needed on the y axis, but as the square of a number is always positive, no negative values of y are necessary. The x axis is therefore drawn near the bottom of the paper, as shown in Fig.

It will be seen that these points apparently lie on a smooth regular curve. This must be drawn by the student. It is a reasonable inference from the form of the curve



Parabola

FIG. 112.

that all points on it, besides those plotted, will satisfy the condition $y = x^2$. This can be checked by taking points on it, finding the corresponding values of x and y and seeing if they do satisfy the condition. Further, it will be clear that there are no points on the plane, not lying on the curve, which satisfy the condition $y = x^2$.

For convenience, different units are employed for x and y.

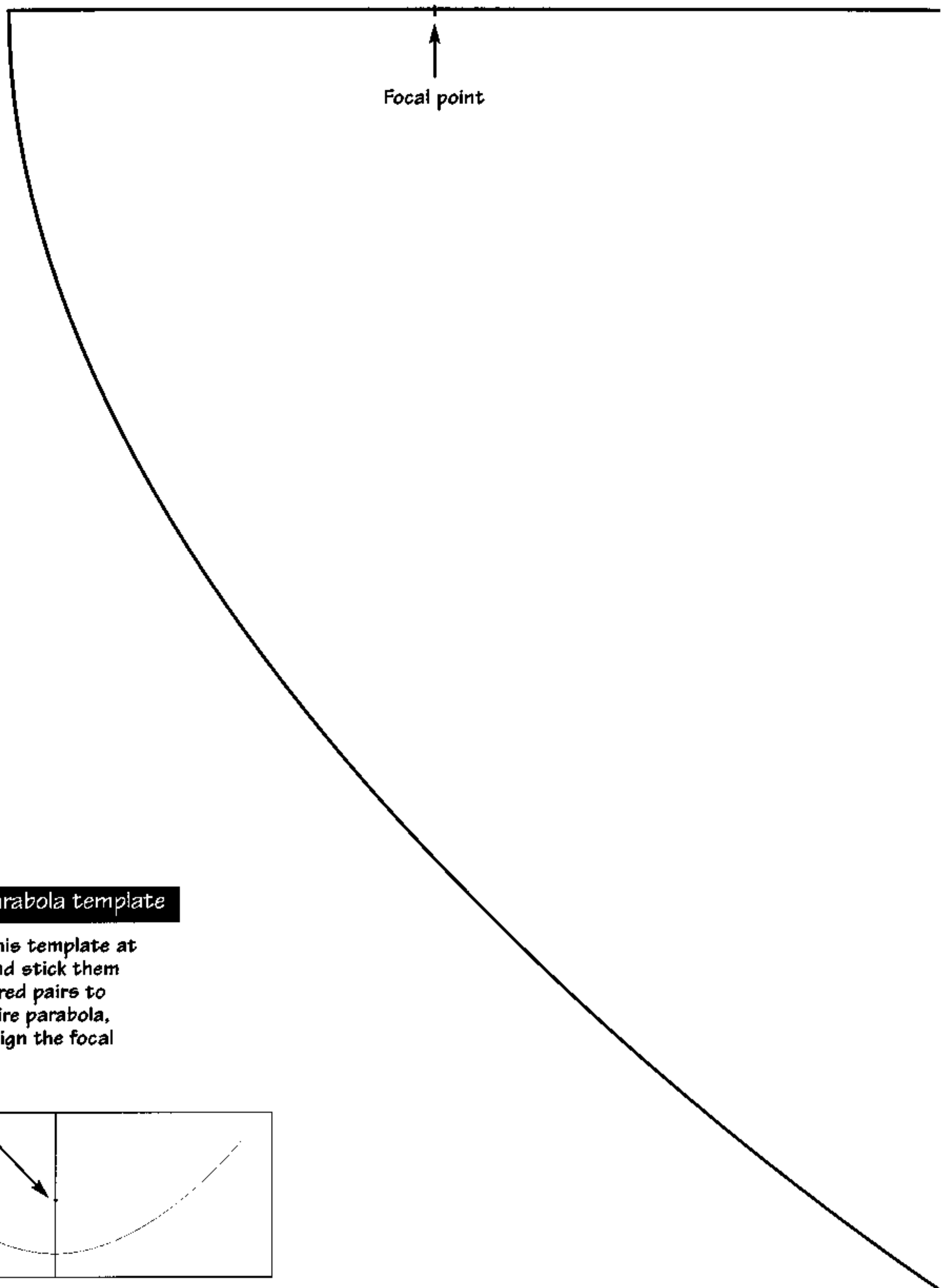


Fig 14. Half parabola template

Make copies of this template at 100% or larger, and stick them together in mirrored pairs to complete the entire parabola, making sure to align the focal points

More or less this same as one pdf-file made by linux-programs..

Designing and Building Home Made Focusing Solar Cookers

I would appreciate, if this web-address, my name and my e-mail address would be mentioned as references:

http://www.jyu.fi/~hvirtane/cooker/
Hannu Virtanen
hvirtane@cc.jyu.fi

Note: comments would be especially appreciated to the above e-mail address!

1. General Remarks

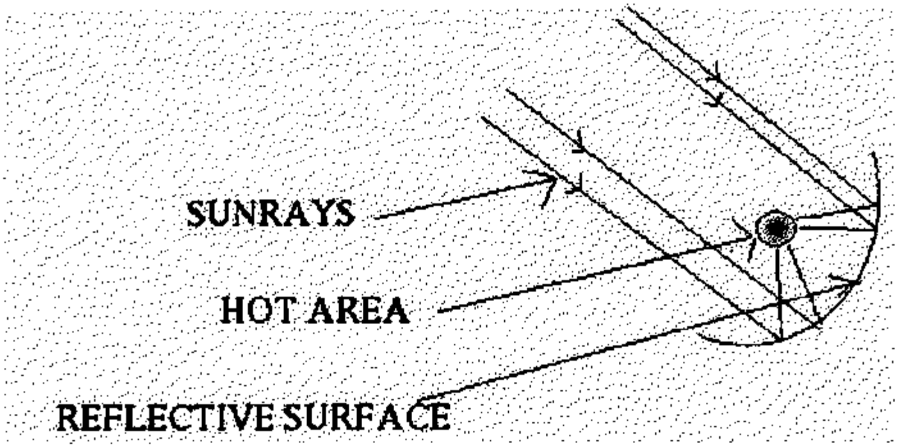
Due to the advance of knowledge gained by various independent designers it is basically easy to build Parabolic Solar Cookers, which can boil water, cook soup, make fried foods or even bake bread. What is needed is general workman's skills like

some carpenter's skills
and/or some construction worker's skills,
about 10-50 USD/ED money to buy materials,
(and possibly some elementary knowledge of mathematics and physics,)
but mainly a lot of common sense!

2. The General Principle: How Does it Work?

A focusing solar cooker works by reflecting solar radiation to a small area, where your cooking or baking pot is located.

The principle is shown in the next picture:



Under cloudless bright sky during day time **the power of sun radiation is about 1 kW/square m(!)**. If all that energy could be reflected and transformed into heat in a kettle holding 1 liter cold water, the water would boil in 5-10 minutes depending on the starting temperature of the water.

NOTE:

IF A GOOD REFLECTIVE SURFACE IS USED FOR THE CONCENTRATOR AND IT WILL BE WELL MADE, THE FOCUS POINT WILL BE VERY HOT AND MORE DANGEROUS THAN A FIRE ESPECIALLY FOR EYES. SO THESE INSTRUCTIONS ARE MADE FOR EXPERIENCED AND CAUTIOUS PERSONS ONLY. AS A DESIGN PRINCIPLE IT IS BEST TO KEEP THE FOCUS POINT INSIDE 'THE MIRROR CUP' TO AVOID THE DANGER OF ANYTHING ELSE BESIDES YOUR COOKING POT OF GETTING IN TOUCH WITH THE HOT SPOT.

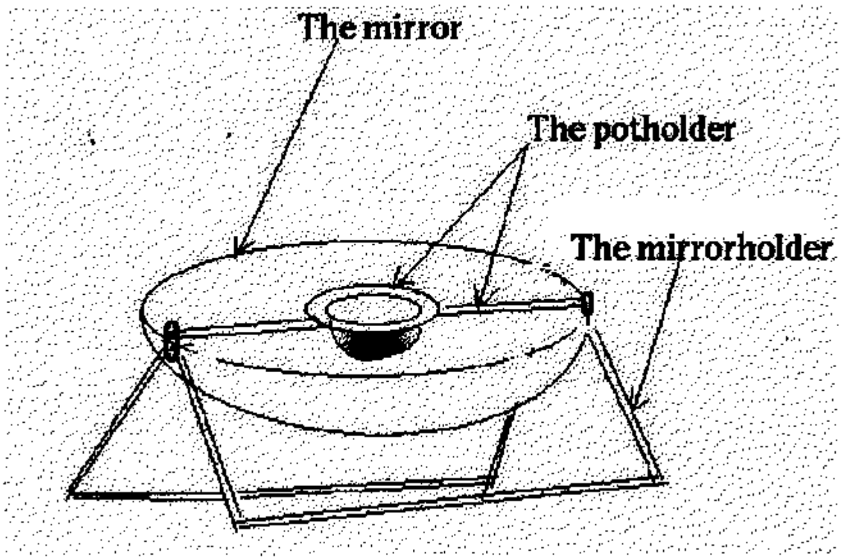
In practice not all of the sun radiation is reflected from our 'REFLECTIVE SURFACE' and not all of the reflected energy is absorbed by our kettle or baked bread and transformed into heat and so the efficiency of our cooker is not 100% and we need in general more power and thus area for our mirror.

In general good focusing solar cookers have got about 1,5- 2 square m reflective area.

3. The Basic Parts and Materials of the Cooker

To build a cooker we need something to build:
the mirror base for the reflective material,
the reflective material itself,
the adjusting and holding construction for the mirror,
the pot holder and the cooking pot.

In the next picture the parts are shown for a model cooker.



The mirror base can be made of various materials including
paper mass,
concrete,
plywood,
bamboo-clay,
metal.

For the reflective surface
small mirror pieces,
aluminium foil,
polished metal plates
can be used.

The mirror holding and the potholding systems can be made of
metal,
wood,
plywood
bamboo.

4. The Parts in Detail

4.1. The Mirror Base

4.1.1 The Shape of the mirror

Basically the perfect shape for our mirror is a parabolic shape.

The mathematical formula for a parabola is

Y = (X*X)*(1/4F)

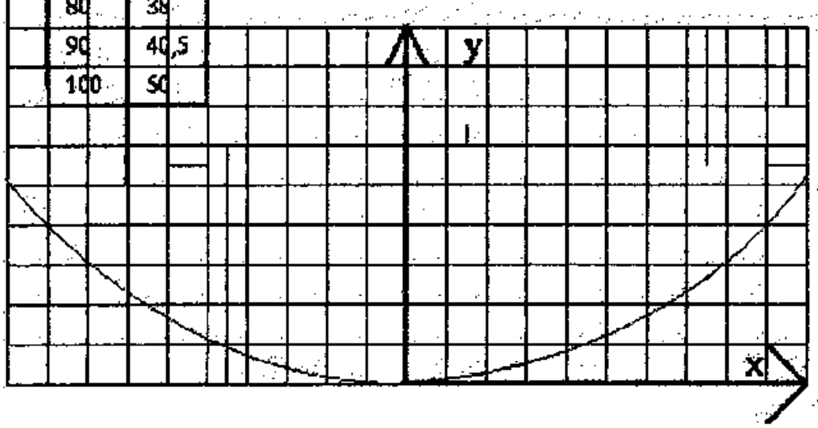
where F is the distance of the focus point from the bottom.

If in the formula F = 50 cm calculations become very easy and our mirror base will have quite satisfactory shape. We can count first points for each 10 cm distance from the centre and then some points in between. It will be quite easy to get a satisfying curve drawn using a bent metallic or plastic ruler to interpolate all points in between. And the curve will look as follows and the points calculated are in the table.

1) The following picture and the table will show the curve for a parabola with F=50.

x	y
10	0,5
20	2
30	4,5
40	8
50	12,5
60	18
70	24,5
80	38
90	40,5
100	50

Here is a picture of the parabola needed.
The table on the left is correct, but the line itself is not really accurately drawn because of limitations of the computer program, which was used.
You can first calculate and draw points after each ten cm, and then some points in between.
You might use a flexible plastic or metal ruler to draw the line.

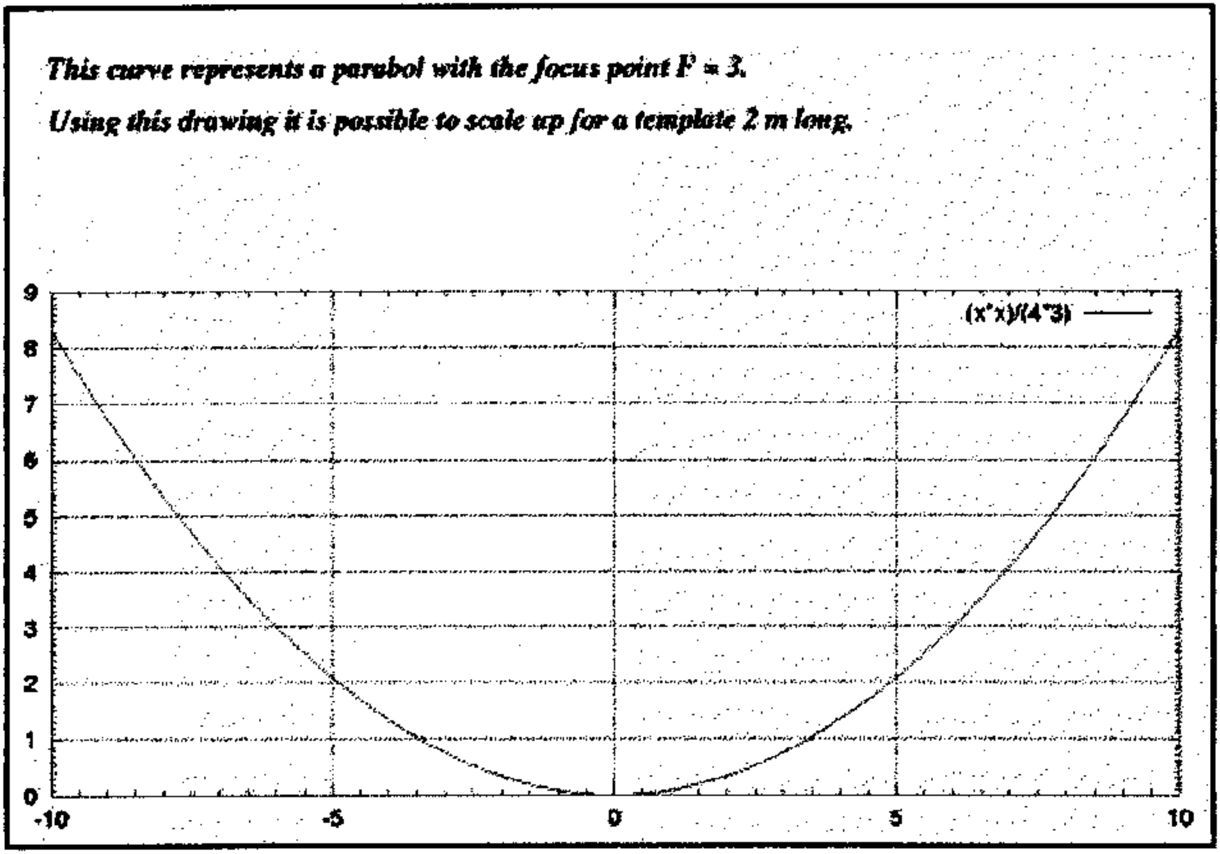


2) The shape for F=30 is as in the following graph:

For most constructions it is better to use F=30 cm

BECAUSE IT IS IMPORTANT TO GET THE FOCUS POINT INSIDE 'THE MIRROR-CUP' TO AVOID GETTING DANGEROUS REFLECTIONS ON YOUR EYES!

I've used a computer program 'Gnuploth' to draw the following curve:

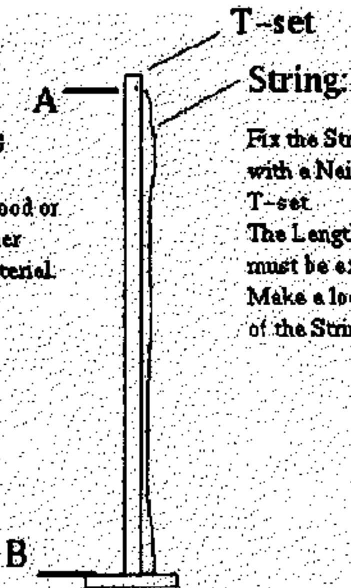


3) How to draw a parabolic curve without any knowledge of Mathematics:

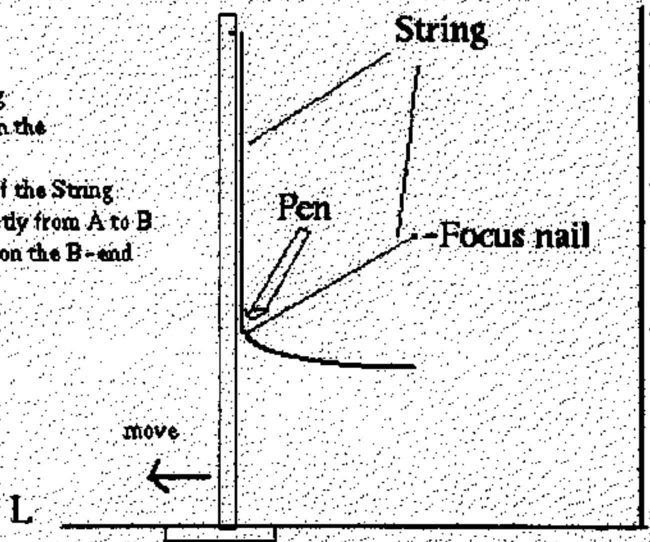
You can use other methods besides calculations to draw parabolic curves.
Here is an easy method, which will make perfect curves:

T-set:

Make a BIG T-set of wood, plywood or of some other suitable material.



Fix the String with a Nail on the T-set.
The Length of the String must be exactly from A to B.
Make a loop on the B-end of the String.



Take a piece of plywood, a pen and one more nail.
Fix the B-end of the string by the nail on The Focus Point.
Move the T-set on the edge of the plywood piece and keep the String tight on the T-set by the Pen.
The parabolic line will be drawn by the Pen as you move the T-set on the line L and keep the Pen on the long edge of the T-set keeping the String tight all the time.
A note: as You see, Your T-set must be quite long to make big drawings. The Focus Nail fixes the Focus Point of Your mirror.

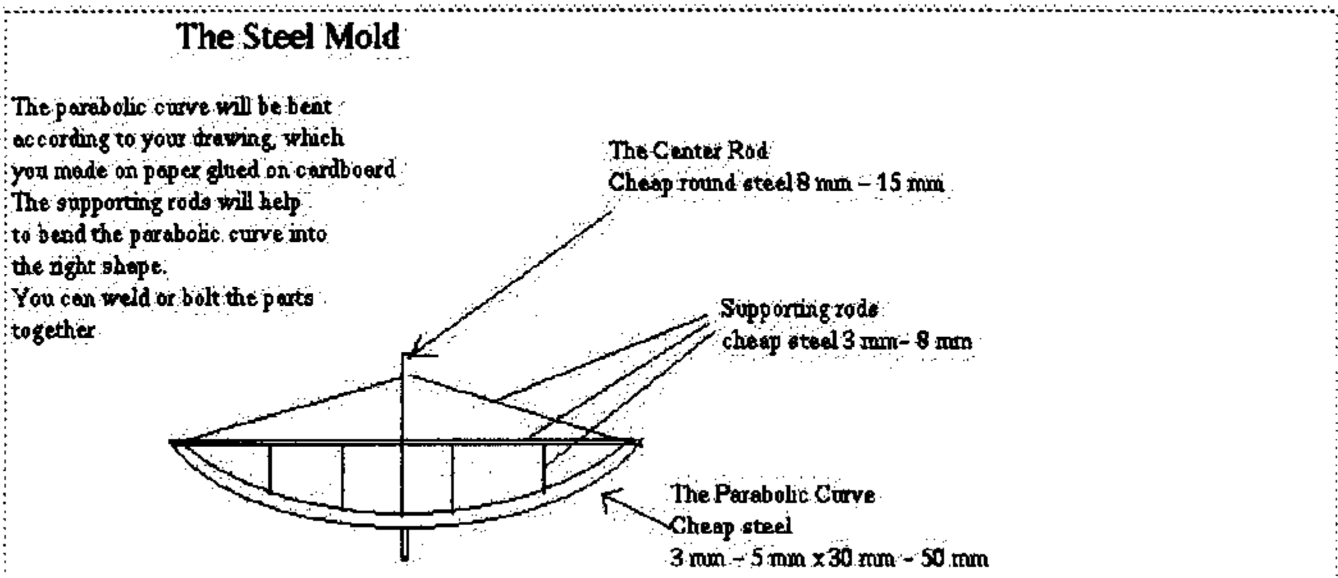
4.1.2 Mirror base materials and construction ideas:

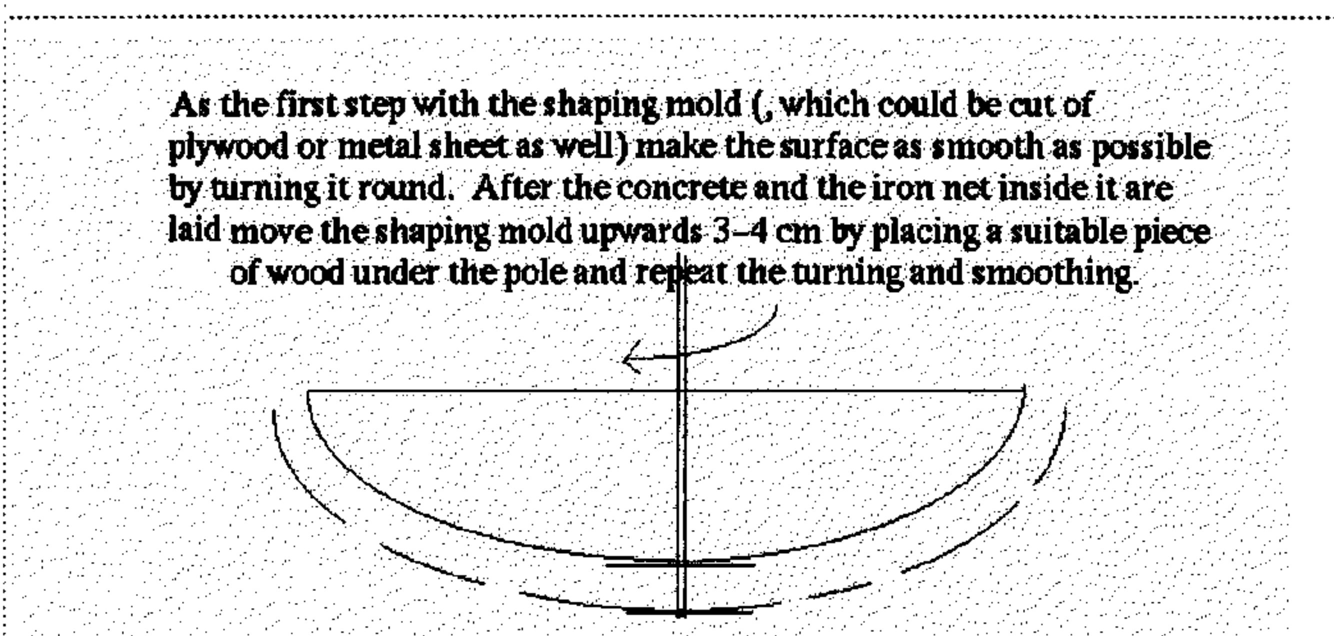
It is best to use materials, which are cheapest or easiest locally available. The local traditional handicraft skills should be taken into the construction consideration as well!

a) Paper mass, clay or concrete construction:

a1) Making the mold inside the ground

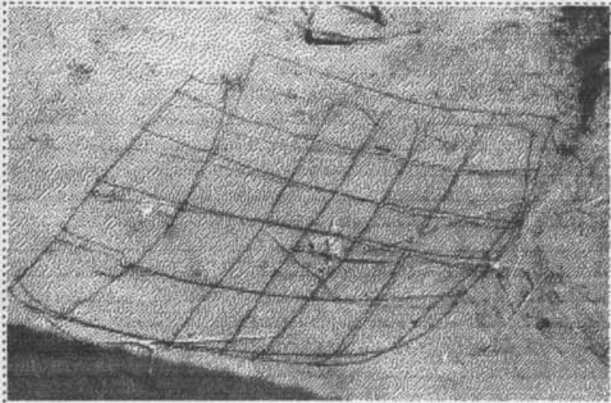
If you will use paper mass, clay or concrete, it is best to make first a mold. That can be then used to make as many mirror bases as you want. The concrete mold can be made by casting inside the ground, if the ground is easy to dig and to make smooth. Using this method you will first make a steel mold as follows. The steel mold can be made of cheap steel. For construction you can use welding or bolts to join the parts





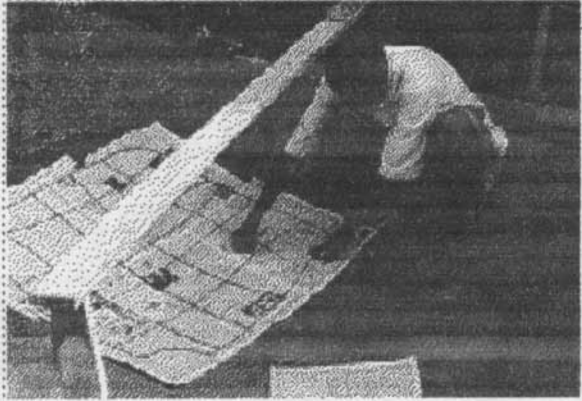
First dig a parabolic hole.

t



You need an iron net.

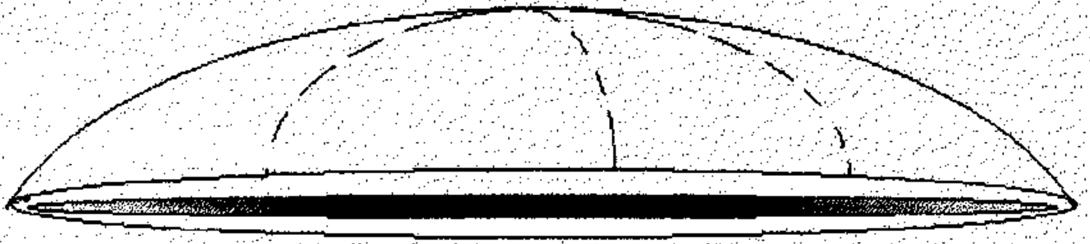
And



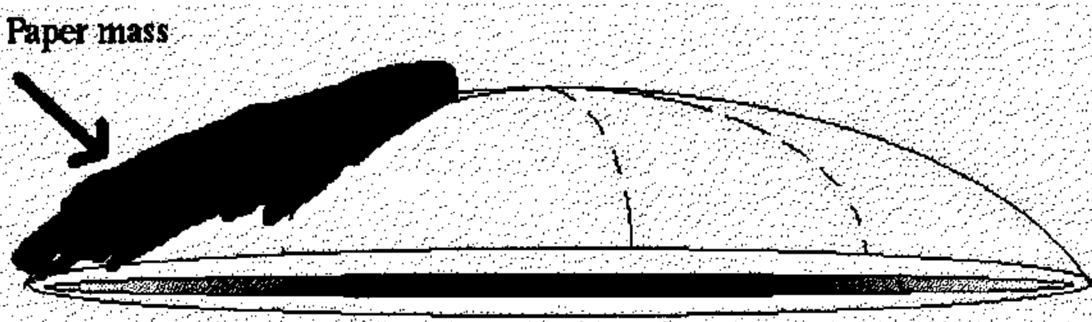
newspapers.

Then You'll make your thin

casting.



As the result You'll have a negative hollow concrete mold as shown. The small possible imperfections on the surface are easy to fix using concrete.

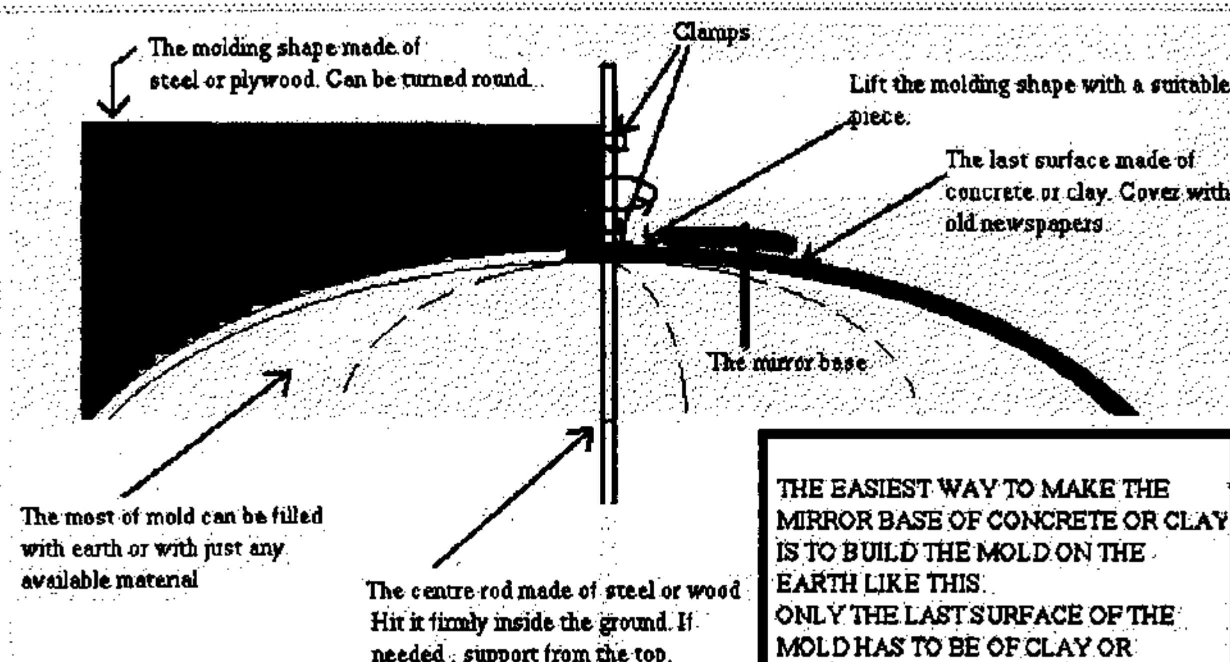


Put old newspapers on your mold and plaster 4–5 cm thick surface of paper mass on the top. Inside that paper massa put similar iron net as was put inside the concrete mold. Let it dry some 3–5 days until it is dry. Lift the shell off. Here you have it. Glue shining surface inside...

You can use an exactly similar mold to make your mirror base of clay as well (put inside a net made of bamboo for example) or of concrete (put inside an iron net)

a2) Making the mold on the ground

You can often make the mold easier by building the mold on the ground.



THE EASIEST WAY TO MAKE THE MIRROR BASE OF CONCRETE OR CLAY IS TO BUILD THE MOLD ON THE EARTH LIKE THIS.
ONLY THE LAST SURFACE OF THE MOLD HAS TO BE OF CLAY OR CONCRETE TO SAVE MATERIAL.

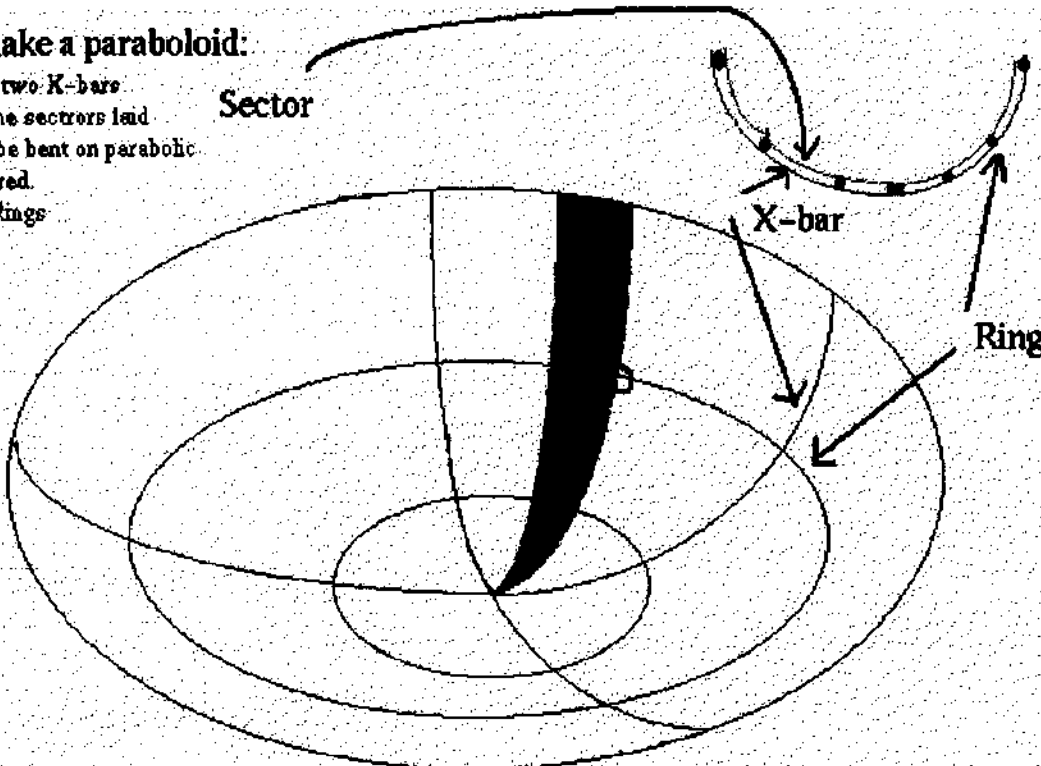
When the mold is dry after a few days, put on it old newspapers and cast your mirror basemade of concete (use an iron net inside) , papermass (use an iron net inside) or clay (use for example bamboo basket inside) on the top of the mold. The thickness of your mirror base must be adjusted according to your material. For a concrete mirror base 2-3 cm is enough.

b) other methods how to make the mirror base:

The first construction below is for a blacksmith, the second for a carpenter. The second plan can be used to make the mirror base of cardboard as well:

How to make a paraboloid:

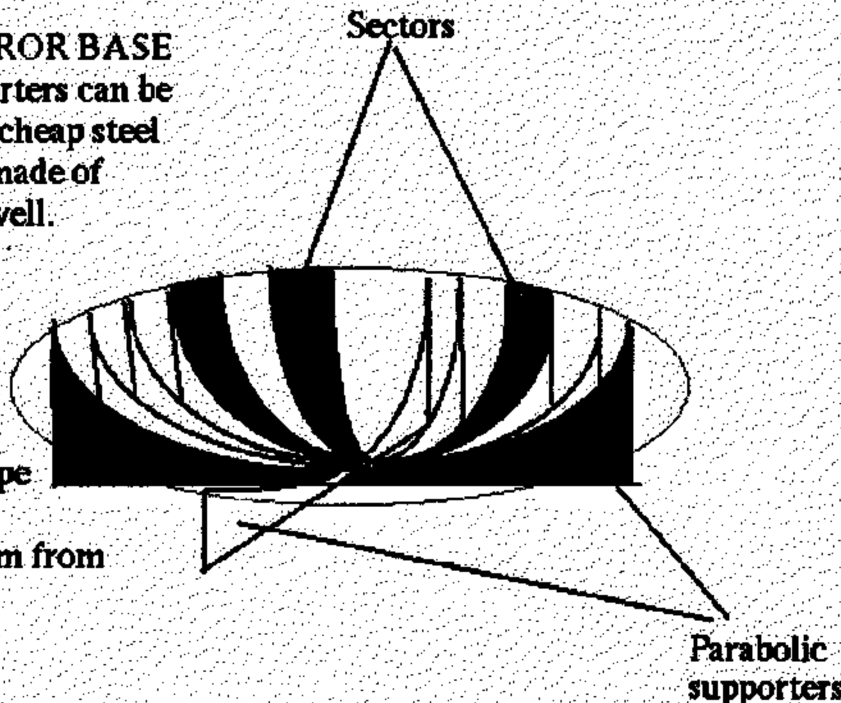
1) First make two X-bars bent so that the sectors laid on Rings will be bent on parabolic shape as desired.
2) Make the Rings



For X-bars use suitable iron. For rings (they must be perfectly circular) use suitable steel. For sectors use suitable cheap steel and glue reflective foil on top. Fix sectors with electric cord on the rings.

PARABOLIC MIRROR BASE
The parabolic supporters can be made of plywood or cheap steel
The sectors can be made of plywood or steel as well.
Glue reflective foil or small mirror pieces on the top.

Use for the supporters such shape that it will give the focus point 30 cm from the bottom.



Note1:
If you are best with plywood or plywood is the material, which is easiest and cheapest availabe, it is probably best and easiest to use the above design ideas combined. Just make only two 'supporters' like in the picture above and use them as 'the X-bars' as in 'the steel construction'. Make 'the rings' (of 'the steel construction') as well of narrow strips of plywood. Fix the sectors on 'the rings' using for example thin rope through holes on sectors like in 'the steel construction' (to make them easily changeable as well).

Note 2:
The sectors have no need to continue to the middle of the mirror base, because there will anyway be the shadow of the kettle. You can leave a hole in the middle.

Note 3:
It is far easier to glue some kind of foil on the top of plywood than on the top of metal sectors or on the clay. If clay is used as the material for the mirror base, it is best to glue some paper in between the foil and the clay surface.

An Affordable Parabolic Solar Cooker

by Ari Lampinen and Rajesh Sharma

Most of the solar cookers used in the developing world are box type. The higher performance parabolic cookers are extensively used by households only in Tibet (mirror area about $2m^2$). Elsewhere, they are most often used in large configurations in schools and other community kitchens where big mirrors can be used to cook tens of litres of food at once (eg ULOG solar hybrid community kitchen with mirror area of about $7m^2$).

The price tags of the Chinese/Tibetan cookers exceed $100 and the ULOG cookers exceed $1000 and so are not affordable by ordinary people. This paper describes a design that can be fabricated by rural people with their existing skills. Its performance is not so good as the Chinese and ULOG models but is considerably better than box cookers which cost more because of the high cost of glass.

A working model has been made by rural, illiterate Nepalise women belonging to the untouchable caste. Participants for this project and a larger project including other types of solar cookers were chosen, based on their skills, by local women's committees set up with support from a Plants for Life (a Nepalese NGO) integrated rural development programme.

A local, skilled bamboo weaver wove two parabolic baskets about 1m diameter each, ie $0.8m^2$ using a metal former. A mixture of clay, cow dung, mustard oil cake and paddy husk was pasted on to the parabolic baskets and left to dry for a day. Next day, this was smoothed with fresh mustard oil cake and left for another day. On the third day the surface was polished with sandpaper, and aluminium, reflecting paper was glued on. (See figure 1)

A supporting frame was made with the help of a local carpenter using bamboo to hold the baskets and also to move them vertically from about 30 to 90 degrees. Using a mirror, the two reflecting baskets were focused on an oven plate and the cooking pot.

During cooking, adjustments were made every 12 to 15 minutes. Vertical adjustment was done by using a moving bamboo mechanism.

The material cost of the 60kg cooker was US$3 and labour for the prototype was 18 hours. Cooking time was 35 minutes for 0.5kg of rice and 40 minutes for 0.5kg of potatoes.

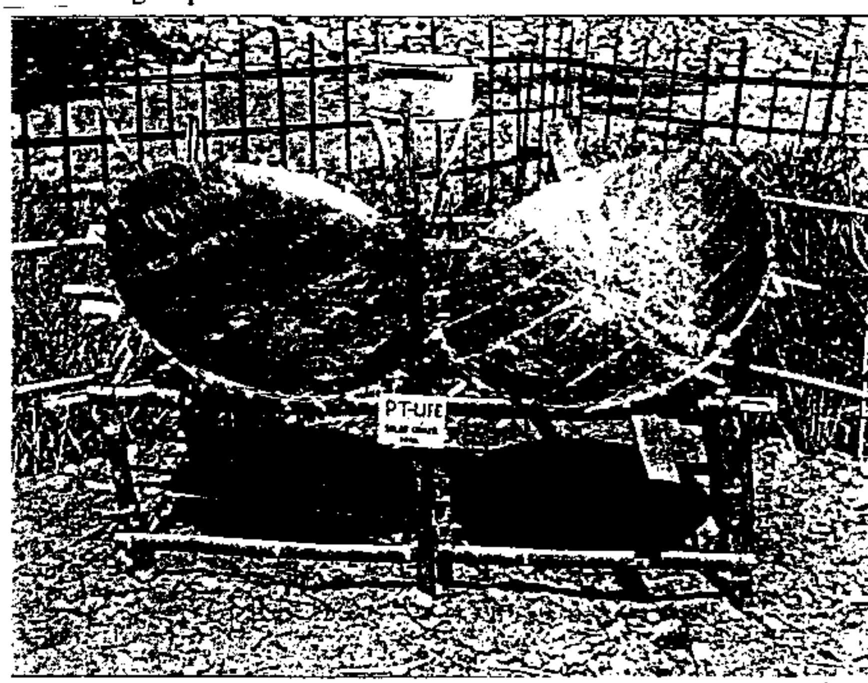


Figure 1

This work was financed from FINNIDA NGO funds.

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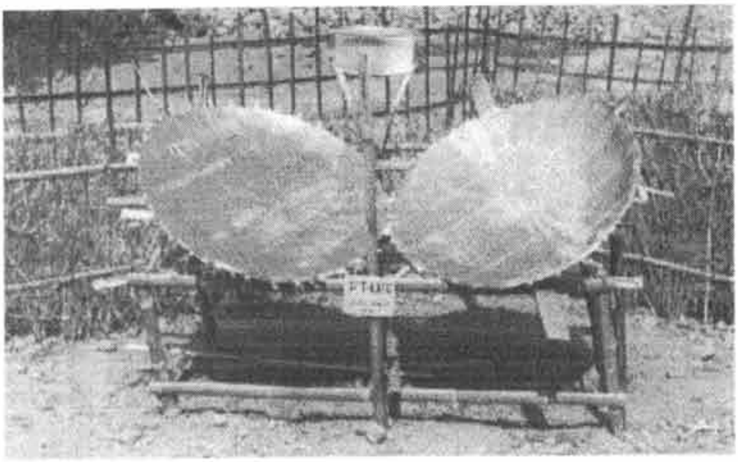
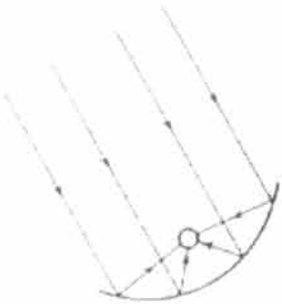
DO-IT-YOURSELF A PARABOLIC SOLAR COOKER FOR $3



A Pictorial Guide by

Plants for Life, Nepal
and
Technology for Life, Finland (TFL)



Solar radiation hitting the ground does not have high enough density for cooking. But if radiation is concentrated into a small volume then cooking temperatures can quite easily be reached, see the figure. CAUTION: do not move your eye into the focus because the HIGH ENERGY DENSITY AT THE FOCUS MAY BLIND YOU! A concentrating mirror as small as a few centimeters in diameter can be dangerous if caution is not taken. Of all solar cooker designs (e.g. box and panel) a parabolic model offers the highest potential performance. Very large parabolic mirrors can even be used to melt metals. Still, a parabolic cooker can be fabricated at extremely low cost by using local materials.

In the following series of figures women and men of Khojpur village in Eastern Nepal show ***how to make a cooker costing only $3 but able to cook a meal in half an hour with free and abundant fuel*** . This model is constructed mainly of bamboo and clay-dung mixture. However, there are many other possibilities that you may think of after following how the Nepalese do this one.

Figure 1. If you can weave bamboo you can fabricate a cooker very cheaply.

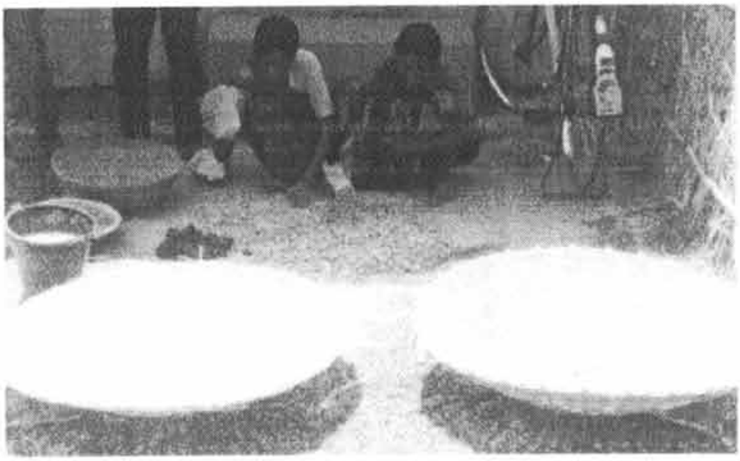


Figure 2. Parabolic shape bamboo baskets. Instead of bamboo you can use e.g. cardboard or put a satellite transceiver dish into a better use. These baskets are about 1 m in diameter. The larger baskets you make the higher will the potential performance be.

Figure 3. Clay and dung are mixed together with mustard oil and rice husk.

Figure 4. Fresh mixture is pasted on the surface of a bamboo basket. A wooden mold (not shown on the pictures) can be used to shape the mixture as parabolic as possible. It is especially necessary in this model that has two mirrors, to approximately match their focus length.

Figure 5. The surface is being smoothed and then left for drying for 1 day.

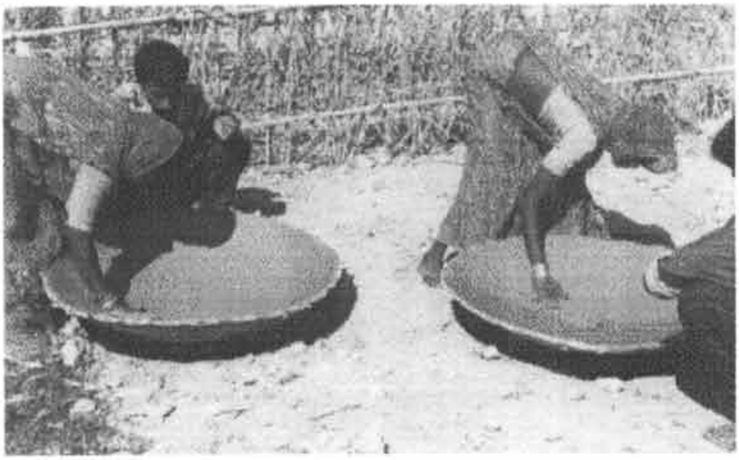


Figure 6. On second day, dry dishes are repasted with mustard oil cake that gives a very smooth surface. After rechecking the shapes with the wooden mold the dishes are left for drying for another day.

Figure 7. On third day, the surface is grinded with sandpaper. The smoother surface you make the higher will the performance of the mirror be.

Figure 8. Aluminium paper is glued on the surface. From this point on men are getting very excited about the project.

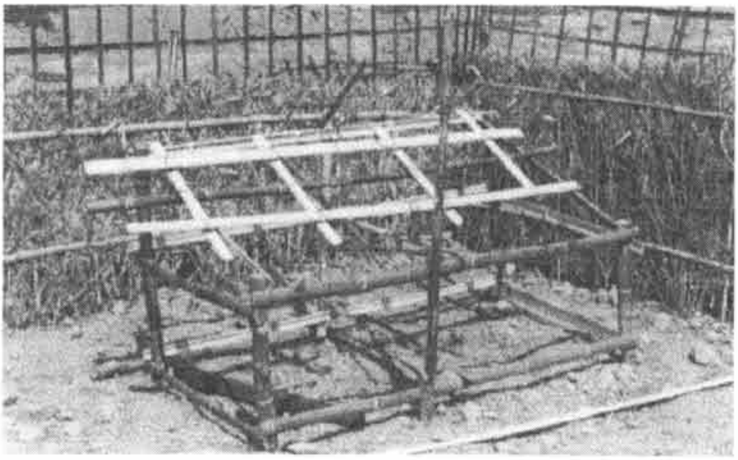


Figure 9. While the dishes are drying a support system for the mirrors are constructed. This one is made of bamboo. The loose horizontal stick on the picture is used for moving the mirrors vertically from about 30 to 90 degrees to be able to follow the sun.

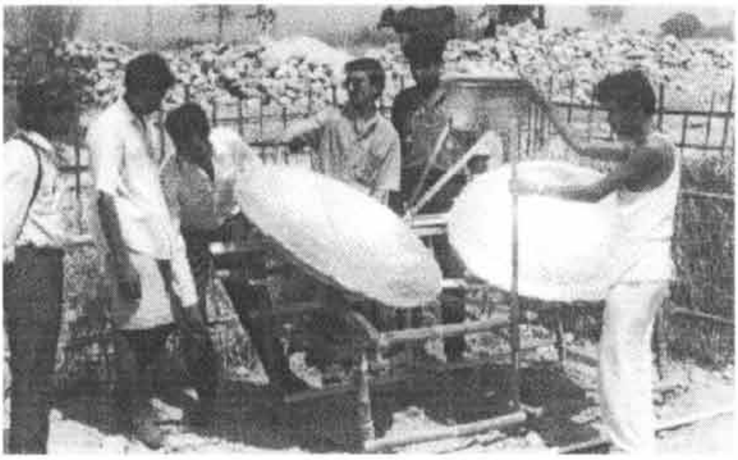
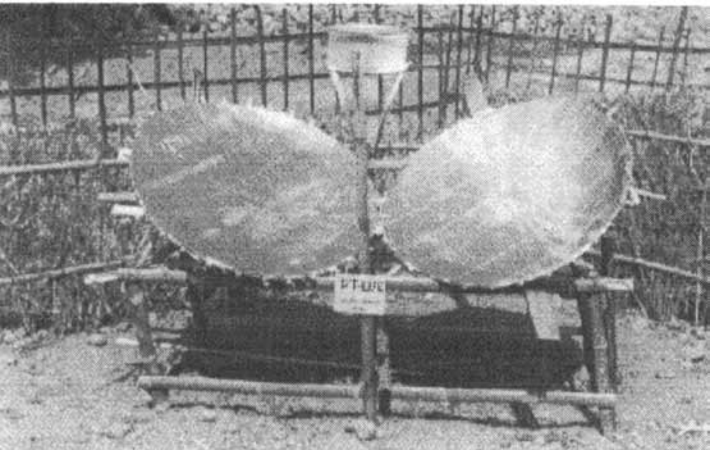


Figure 10. The focuses of the two mirrors are being adjusted to hit the cooking pot. It is important to keep the focus on the pot during cooking so about every 15 minutes you need to readjust the mirrors and the crate.



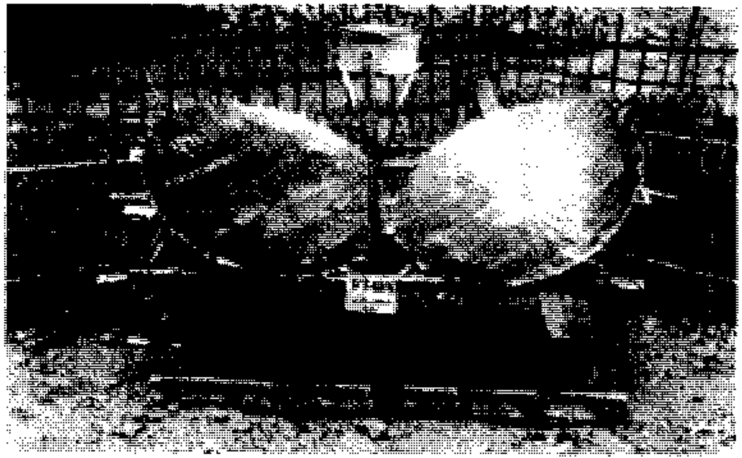


Figure 11. The ready-made double mirror parabolic solar cooker with about 1.6 square meters of reflecting surface, i.e. about 1600 Watts of input power. In this particular device the actual cooking power is approximately 400 Watts. It is enough to cook about half a kg of potatoes or rice in about half an hour.

The performance can be increased by making the surfaces smoother and the shapes more parabolic. But the focus does not need to be sharp like e.g. in satellite receivers because it is enough that the sun's energy is concentrated into the bottom of the cooking pot. If the focus is too sharp it can even melt the bottom of the pot! And the sharper the focus the more dangerous it can be for your eyes. REMEMBER TO KEEP YOUR EYES AWAY FROM THE FOCUS!

The construction manpower is about 18 person-hours and the cost of material (principally the aluminium foil) is about $3.

There are many ways you can modify this model. You could e.g. use only one mirror, or maybe five. You could add a tracking system to automatically follow the sun. Or instead of parabolic mirror you could use so called Fresnel mirror for the same result. Litterature offers many ideas of design and use of parabolic solar concentrators, beginning from the war machines of ancient Greece.

We call this particular design a PT-LIFE cooker due to the names of our organizations (we are non-profit NGOs). You are free to use this concept just for yourself or commercially. If you do ..... we would be happy to hear about it.

For more information, please contact:

Technology for Life, Kauppakatu 12 A 1, FIN - 40100 Jyvaskyla, Finland,
email ala@jyu.fi, WWW http://www.kaapeli.fi/~tep/
or
Plants for Life, P.O. Box 21, Hetauda 5, Makwanpur, Nepal

Construction of a Simple Solar Cooker

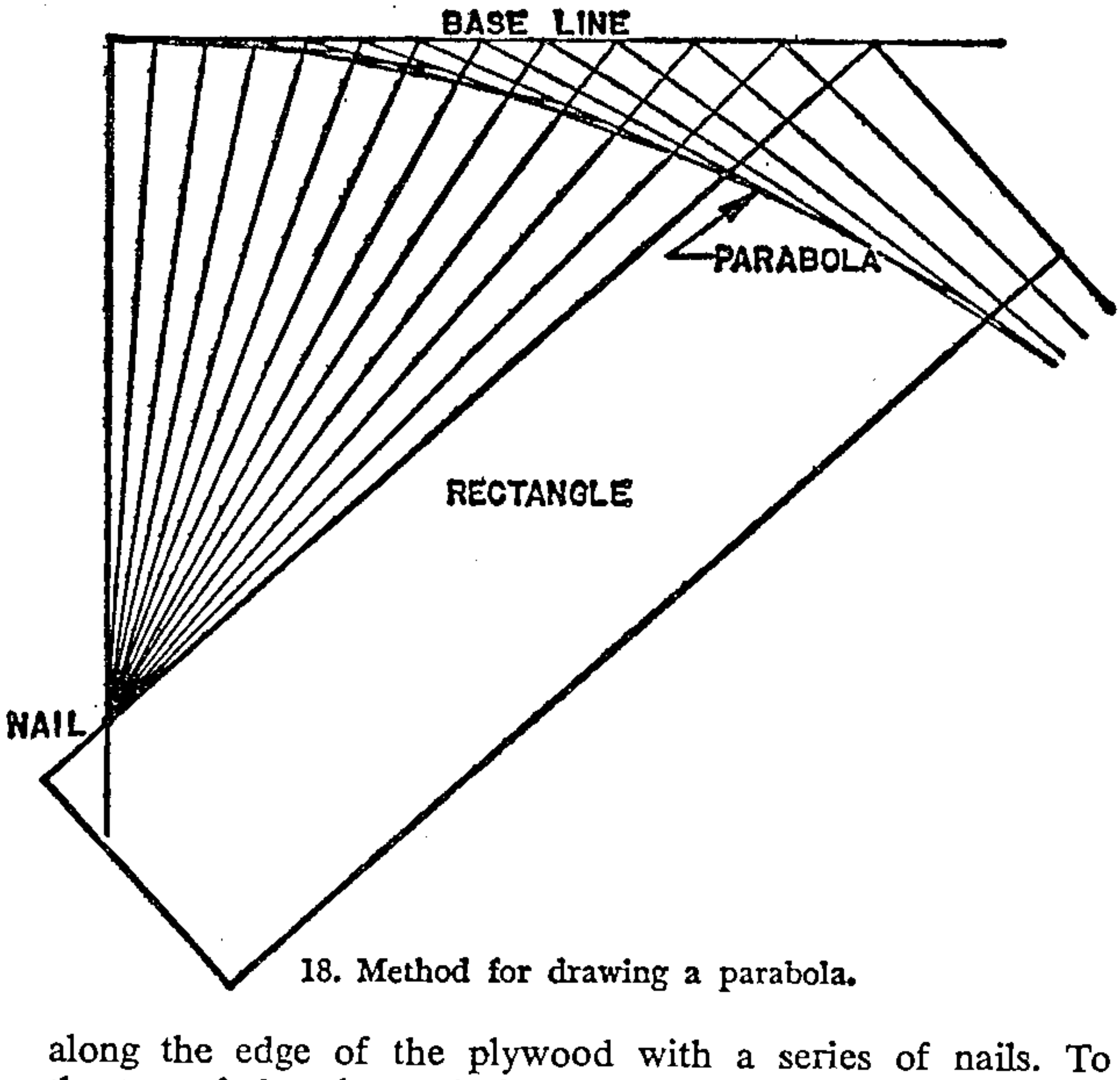
The solar cookers described so far have involved electric power and machine tools. The costs of manufacture in an industrialized country and shipment to a nonindustrialized country are high. Accordingly, efforts have been made to develop simple designs and methods of manufacture which will permit local production and require the importation of a minimum of special material. Some of these designs have involved paper and aluminum foil, which will not withstand long exposure to outdoor weather.

An experiment in southern Mexico used local materials and labor, where no electricity for power tools was available. Effective cookers were made as shown in Plate 4 and their acceptance tested in a small village.[13]

The shell for this type of solar cooker is made with plastic on a hoop laid over a parabolic concrete mound. It is lined with a mosaic of 1-inch mirrors. The adjustable U-frame made of water pipe rotates around a pipe driven into the ground, and the reflecting shell is suspended from the horizontal pipe which supports the small circular grill for holding the cooking vessel. The frame is rotated, and the reflecting collector is tilted to bring the shadow of the kettle to the center of the collector by pulling a chain which can be caught over a protruding bolt in the frame.

For the parabolic mound (see Plate 5), on which an indefinite number of plastic shells can be made, a parabolic edge is sawed in a piece of plywood with a keyhole saw and rotated around a vertical pipe driven into the ground. The parabola is drawn with a square, as illustrated in Figure 18. A straight line is drawn on the plywood and below it a nail is inserted at the desired position of the focus (18 inches). The square is then rotated by small degrees around the nail sliding past it so that the corner of the square is always just touching the straight line. A pencil line is drawn along the edge of the square in each position. At first these lines nearly coincide with the original straight line but as the corner of the square is moved out the lines make increasingly sharper angles with the original straight line. This collection of many straight lines gives a figure with a true parabolic edge, as shown. A reflector diameter of 4 ft is convenient, requiring a rotating parabola a little longer than 2 ft.

It is difficult to get a perfectly smooth edge with the hand saw. Accordingly, a ⅜-inch copper tube is attached



18. Method for drawing a parabola.

along the edge of the plywood with a series of nails. To the top of the plywood shaping tool are attached two protruding strips of wood, one on each side, for straddling the vertical pipe. A wooden plug is inserted between the ends of the two strips to give a square hole. The shaping tool is then mounted by slipping the hole over the pipe so that the whole plywood board can be easily rotated around the vertical pipe.

A shallow circular platform of concrete is laid on the ground around the vertical pipe and smoothed and leveled with a hand level. This gives a flat track on which the lower end of the parabolic board rotates. A mound of wet sand is packed down on the concrete platform around the pipe and rounded off smoothly with the rotating edge to make a parabolic mound. A smooth piece of metal is nailed to a wood block attached to the bottom of the outer rim of the rotating plywood to raise the parabolic edge about ¾ inch. The center of the shaping tool is then raised until the top is exactly level, and it is kept in this position by winding a bulge of string around the pipe at the proper height.

A thorough mixture of three parts sand and one part Portland cement with water is then laid over the sand mound like frosting on a cake and the parabolic tool rotated carefully to give a smooth parabolic mound. The consistency of the cement must be just right, without too much water, so the copper tube will give a smooth surface. The cement layer on the sand mound must be high enough to be in contact everywhere with the rotating parabolic copper tube. After setting for a day the surface of the mound is still rough because of the sand, but it is smoothed with liquid plastic available from the manufacturer, from large mail-order companies, or from suppliers of motorboat building materials. A thick coat, mixed with an accelerator so it will harden in a few hours, is painted on with a brush. After setting over night the plastic surface is rubbed with steel wool to give a smooth surface. It is then rubbed vigorously with a "separation wax" so it can be used as a convex master mold to make plastic concave shells. Butcher's wax or other floor or automobile-body wax is suitable if thoroughly rubbed in to give a smooth shining surface.

Then the waxed mold is painted with liquid plastic and covered smoothly with a circular disc of cloth or preferably fiberglass cloth. A hoop of thin-walled conduit tubing, made with a pipe bender, is placed around the circumference of the mound and the plastic-coated cloth is tucked in. Reinforcement strips of cloth are added to the cloth shell. After hardening for a day the shell is pried off the parabolic mound.

The inside of the plastic shell is smoothed and covered with fresh liquid plastic, a narrow strip at a time. Several hundred square glass mirrors, rubbed with wax on the glass fronts, are quickly and carefully laid in the plastic covering to make a close-packed mosaic which sets within a few hours. Surplus plastic that oozes up in cracks between the small mirrors can be scraped off the waxed surface with a sharp knife. The mosaic mirror is then cleaned completely by rubbing it with medium steel wool and washing with a detergent.

Using another technique, strips of aluminized plastic 3 inches wide are placed over the parabolic mound with overlapping edges, like shingles. The aluminized surface is up, and the plastic surface is made to cling to the mold by painting it with glycerine. The strips are covered with a layer of plastic and later with the cloth and plastic shell.

The reflecting parabolic shell is arranged to hang about 10 inches below the central grill by means of two wooden or metal strips bolted to the hoop (see Plate 4). The crossbar holding the central circular grill is put through holes in the ends of the strips and set into vertical slots at the top of each arm of the U-frame. The grill and supporting crosspiece is made of conduit tubing with a flattened semicircular bend in the middle, which is bolted to another semicircular section to give an 8-inch ring. Round-bottomed clay or metal vessels are set into this ring at the focus of the light. A coarse wire screen is set into the ring when smaller or flat-bottomed vessels are used. Suggestions for collectors and cooking vessels are given by Jenness,[14] and Stam[15] discusses certain aspects of solar cooking.

An evaluation of solar cookers has been carried out by the Volunteers for International Technical Assistance, Inc.[16] Twelve different solar cookers are described and illustrated with photographs. Appropriate weights, sizes, and costs are given when available. Of these twelve cookers four are rated very good, including the Wisconsin cooker and the Telkes oven. A solar cooker of the Fresnel type, developed by the Volunteers for International Technical Assistance, Inc., consists of a set of annular rings of Masonite, covered with aluminized plastic or aluminum, each ring slanting to focus on the bottom of a cooking vessel. Detailed directions for construction are given.[16]

Vita Report no. 10

Washington DC / Schenectady NY.

08: App. Technology Sourcebook. Darrow, Pam. VITA. USA 1976 0-917704-00-2.

Solar Cooker Construction Manual, leaflet with complete construction and assembly information, 18 pages, VITA, 1967 (reprinted 1975), Spanish and French editions also available, $2.00 from VITA.

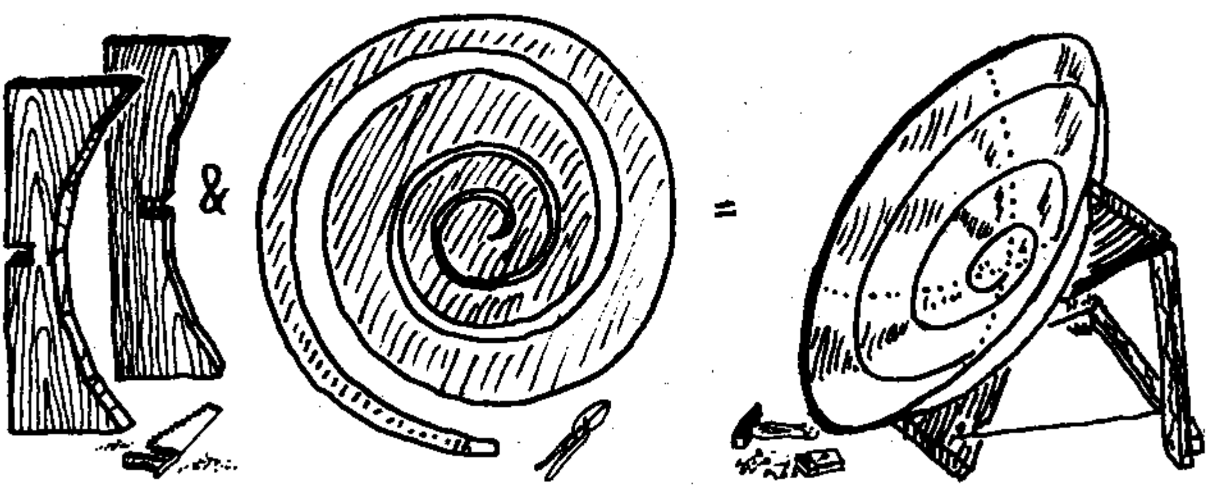
MATERIALS: plywood, aluminum foil or aluminized Mylar, wood, iron strip

PRODUCTION: simple handtools; attaching the foil or aluminized Mylar is a delicate operation

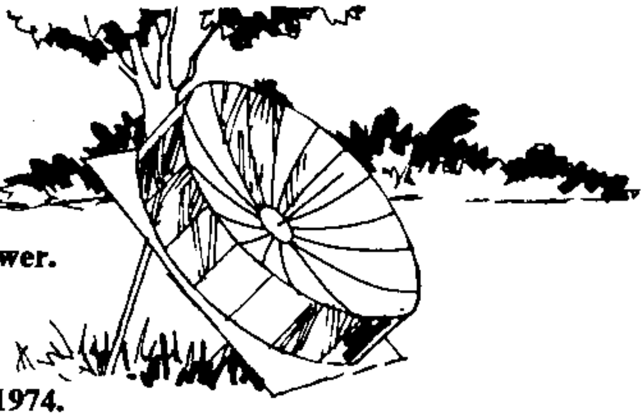
This is a concise, complete guide to the construction of a cheap and effective solar cooker. It is designed to give enough heat for the cooking needs of a family with 3-5 children under bright, sunny conditions. However, it cannot eliminate the need for other means of cooking. A broad area the size of the cooking pot is heated, rather than a sharply-focused point. A system of concentric rings rather than a parabolic dish is used. The cost of materials is estimated to be $3.00.

Limitations: "The cooker is not useful for cooking meals in early morning or late afternoon. The cooker must be frequently shifted in position during use to take advantage of the sun's position." It takes some time to learn how to cook effectively using the cooker. Because the application of the foil or Mylar to the plywood is a rather delicate task, the authors suggest that 10 or more cookers be built at one time so that an effective method for this can be developed.

- Einfälle statt Abfälle. Verlag - Ch. Kuhtz. Kiel Germany 1985 3-924038-11-2.



09: **Handbook of Homemade Power. Shuttleworth.**



Mother Earth News. USA 1974.

HOW TO BUILD—AND USE!—A REFLECTOR COOKER

MATERIALS

- Cardboard (as required)
- Poster board (two sheets)
- Aluminum foil (one roll)
- Plywood (one piece, 18 by 24 inches)
- 3/4-inch aluminum tubing (approximately 64 inches)
- 3/4-inch mounting flange (one)
- Grill (one)
- Curtain rod (one)
- Broomstick (four feet)
- Clothesline (one foot)
- Glue (as required)
- Masking tape (as required)
- 3/16-by-1-inch bolt with wing nut (one set)

A stove made of paper sounds about as practical as a pitcher carved from ice, but this reflector cooker—constructed almost entirely of cardboard—will broil steaks, grill hot dogs, fry bacon and eggs and make hotcakes and coffee. It will also heat water for doing the dishes. All that's necessary to make it work is clear weather, because this stove cooks with sunshine!

Stop to think about it for a minute and you'll remember that every time we cook—be it with gas, electricity or charcoal—we indirectly use the sun's energy, which has been stored up and reconverted to heat. Basically, then, our solar stove's fuel is nothing really new. Even the use of direct sun heat for cooking goes back many years. Sun-dried foods have long been eaten, and crude solar stoves were built a century ago. Besides, who hasn't heard of cooking an egg on the sidewalk on a really hot day?

In recent years, however, many advances have been made in the design of solar cookers. Today there are commercial models on the market that are fine for campers or for patio use. One umbrella-like design folds up for easy carrying and storage and also provides an answer for the skeptic who wants to know what you do when it rains! Such a cooker is just the thing for trips. If you're dubious about how well the sun can cook a meal, or if you don't have the cash to buy a ready-made stove, get busy and build the one described here. At most, it will cost five dollars. If you use discarded cartons and other salvage material, the outlay will be only a fraction of that.

The reflector framework is cut from fiberboard, approximately 3/16 inch thick, the kind large cartons are made from. Some poster board and aluminum foil will complete the cooker itself. A grill (for hot dogs, hamburgers or pans) is made from plywood, some tubing and an inexpensive hand grill that costs about 50 cents.

Study the plans first to get the overall picture, and to see how much material will be needed. If you want to buy new fiberboard, two sheets 4 by 8 feet will be plenty. These cost about 80 cents each at a box factory or supply house. The other items will be easy to find. Get everything you'll need together and then begin construction. An eager beaver can do the job in a day or so and begin sampling outdoor cooking à la sun right away.

First, cut a base piece 4 feet square from the 3/16-inch cardboard. We'll mark the layout of the reflector ribs right on this base. With a pencil and a piece of string, draw a 48-inch-diameter circle. This is the size our finished cooker will be. Next draw two lines through the center of the base, perpendicular to each other as shown on the plans. These mark the location of the main ribs, which we will make next.

A word about the principle of our reflector cooker will be helpful before we proceed any farther. The sun stove simply focuses all the sun's rays that strike its surface onto the bottom of the grill. Even on a clear winter day the 12 square feet of area in our cooker collects a lot of "warmth", which when shrunk into the 1-foot area at the grill becomes concentrated "heat" (see Fig. 1).

The giant solar furnaces used by some research labs (such as the Mont Louis installation high in the Pyrenees mountains of southern France) use curved reflectors too. They generate thousands of degrees of heat at their focal points, using the same principle. To do this they must be very accurately made and of parabolic shape. This specially shaped curve reflects all the rays onto one tiny spot and gives the furnace a concentration ratio of many thousands to one. Obviously we don't want such high temperatures, for they would melt our pans!

Our reflector will use a radius of 36 inches instead of a true parabolic curve. This results in a larger spot at the focal point.

Besides this, we will use a number of wedge-shaped sections instead of one bowl-shaped reflector. Thus our focal spot will be roughly the size of the cooking pan, which is ideal for our purposes.

Now that we know the why of what we're doing, let's draw two main ribs as shown on the plans (Fig. 1). Cut these carefully—using a sharp linoleum knife, pocketknife or modeler's razor knife—and be sure to plan ahead so as not to waste material. Each of the main ribs has a notch at the center. Notice that one is on the top and one on the bottom so that they'll interlock.

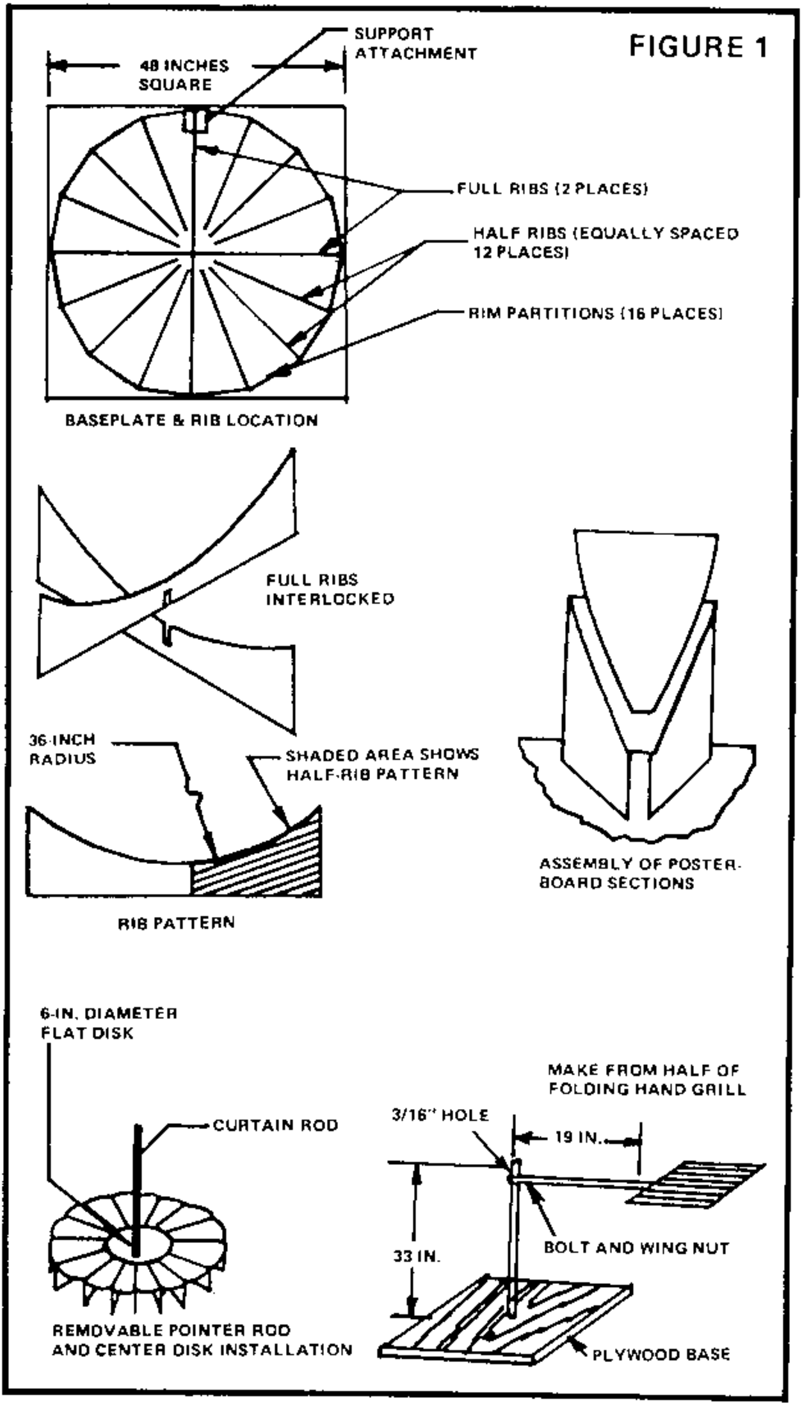
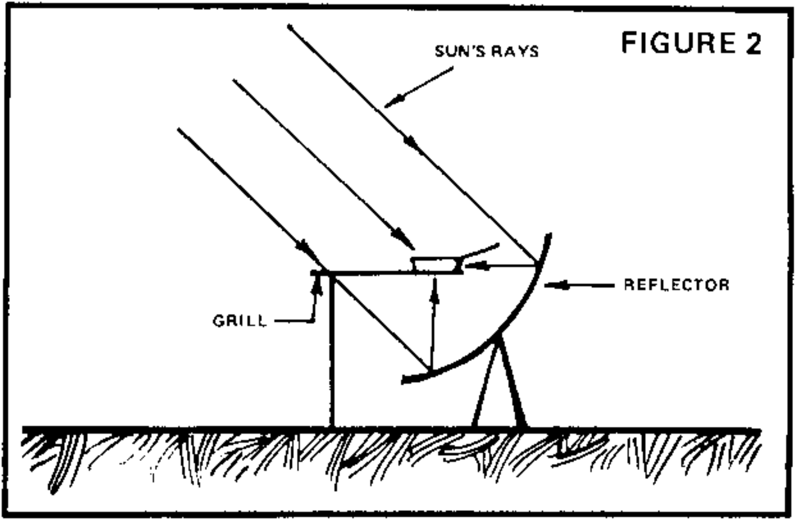
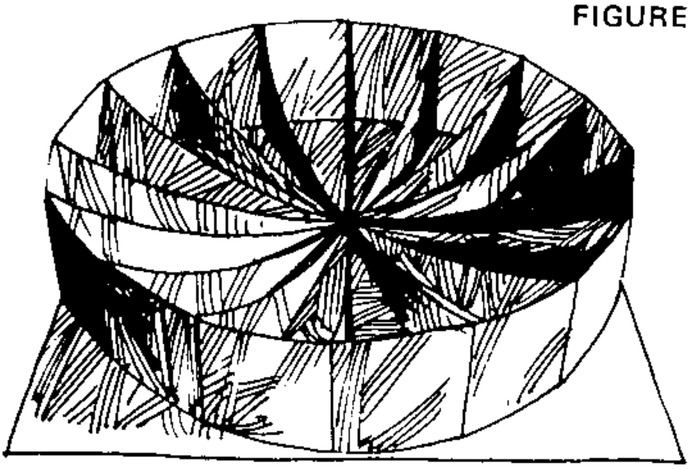


FIGURE 1. General plans for building the reflector cooker.



This illustration shows the operating principle of the reflector cooker.

FIGURE 3



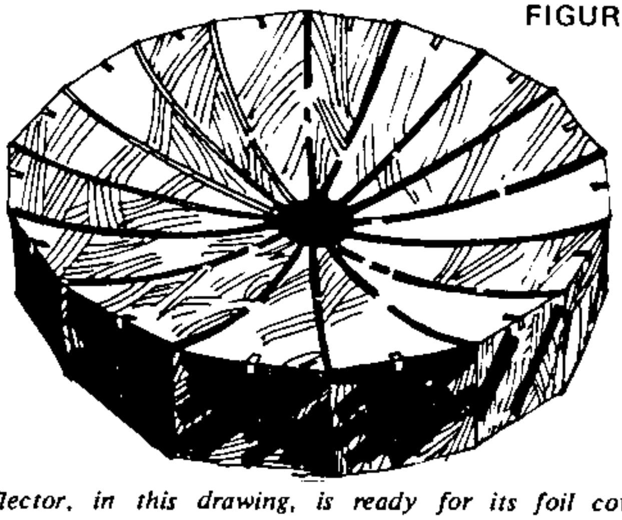
The above sketch shows the assembled framework of the reflector.

Using a full rib as a pattern, mark out 12 half ribs as shown on the plans. Before cutting these, cement the full ribs to the base plate on the lines previously drawn. Model airplane glue or a good household cement will work well. While the parts are drying, cut out the remaining ribs.

Three half ribs fit between each quarter section of the circle. Glue these in place, lining up the end of each one with the circle we drew on the base plate. While they're drying, cut the rectangular filler pieces of cardboard. As the plans show, these fit between the outer tips of the ribs to complete the framework (see Figs. 1 and 3).

When the framework is thoroughly dry, we're ready to put on the wedge-shaped pieces of poster board. Since these form the curve that will reflect the sun's rays, we must use poster board that is thin enough to bend easily, yet has sufficient

FIGURE 4



The reflector, in this drawing, is ready for its foil covering.

body to hold the proper shape. Lighter cardboard would have a tendency to ripple and wave.

By means of cut-and-try methods, trim one piece of poster board so that it covers the space between two ribs, with about 1/8-inch overlap all around. Do not cement this in place yet; it will be our pattern for 15 more pieces. Cut the additional sections carefully, making sure they will cover any of the spaces between ribs. (In spite of care, there may be slight inaccuracies in the framework.) It's better to have the poster-board pieces a bit too large than too small.

With all the pieces cut we can now begin to cement them in place. Since butting the joints smoothly against each other would be difficult, we will glue eight sections into alternate spaces first. Spread glue along the tops of two ribs and the intervening filler piece, then lay the poster-board wedge in place and carefully press down so that it touches the ribs at all points. The glue will dry well enough in a minute or two so that you can go on to the next piece. Don't forget to leave every other section open.

Now we can cover the remaining spaces with our second eight wedges of poster board. These will of course lap over the edges of the pieces already glued in place, thus making a strong joint. If you run into difficulty at the center where all the points come together, simply trim them off an inch or two. The hole left can later be covered with a separate piece of poster board.

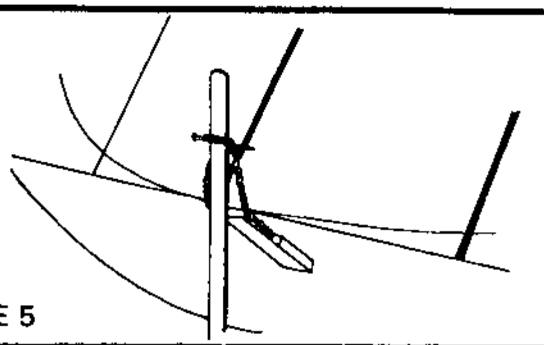


FIGURE 5

Detail of cardboard-clothesline-nail adjustable support bracket.

For added strength, seal all the joints with masking tape as shown in Fig. 4. While this isn't absolutely necessary, it will make a sturdier cooker. The reflector is now ready for application of the aluminum foil that will give it the mirror-like finish we need to collect heat for cooking.

Cut out 16 pieces of smooth-surfaced aluminum foil . . . the kind used in the kitchen for wrapping food. These should be slightly larger than the poster-board wedges to assure complete coverage of the reflector surface. Use rubber cement to stick the foil to the poster board, and be sure to place the shiny side up. Work carefully and try to keep the foil smooth, but don't worry if the finished job isn't perfect. The cooker shown in the illustrations has a few ripples but works well anyway.

We will now install a marker for the focal point of the reflector so that we'll know where to place the grill for the fastest cooking. This marker is simply a small, inexpensive curtain rod of the type used on kitchen doors. It consists of two tubes, one fitted inside the other. Cut a short length of the larger cylinder and insert it into a hole punched in the center of the reflector. Better still, use a drill the same size as the outside section of the curtain rod (or slightly smaller) to give a snug fit. Now cement the tube in place.

The smaller tube will fit into this "holder" and can be removed for easier handling when not needed. As we mentioned before, the proper place to mount our grill is one focal length from the reflector. With a spherical reflector that distance is half the radius or, in this case, 18 inches. As a double check, aim the reflector at the sun and adjust the tilt until there is no shadow visible from the pointer rod. Then hold a piece of wrapping paper with a small hole punched in it right at the tip of the pointer. Move the sheet toward the reflector and then away until the smallest spot of light is observed on the paper. This is the actual focal point, and our pointer rod should be trimmed to this length.

Cut out two squares and one rectangle of cardboard as shown in the detail of the adjustable support (Fig. 5) and cement them to the back of the cardboard base. The squares go first, and then the rectangle. After these are well dried, run a short length of clothesline through the slot and tie the ends in a square knot. Drill holes through a 48-inch length of 1-inch dowel (broomstick or tubing), spacing the holes about an inch apart halfway down the dowel. Insert a nail to engage the loop of clothesline. We can now set up our reflector so that it will stand alone.

To make the grill, first cut an 18-by-24-inch plywood base. Any thickness from 1/2 to 1 inch will do. Mark the center of this base and install a mounting flange for the 3/4-inch aluminum-tubing vertical support (which is 40 inches long).

The adjustable arm is also aluminum tubing, 24 inches long. Flatten one end and bend it around a piece of pipe or a broomstick to make the collar, which fits over the vertical support. Drill a 3/16-inch hole as shown and insert a bolt capped by a wing nut. The other end of the adjustable arm may now be flattened. Be careful to keep the flat area at right angles to the collar so that the grill will be horizontal when installed. Slide the grill in place and the solar cooker is complete.

Now that the work is done, the fun starts. Positioning the reflector is simple if you follow these directions. Stand behind the collector and face it right at the sun. Then tilt the reflector back until the shadow of the pointer rod vanishes as it did when we checked for focal length. This means that the collector is aimed perfectly and that all the sun's rays will be bounced right where we want them.

Holding the reflector in this position, slip the dowel or broomstick through the rope loop and put the nail through the hole just below the loop. With the collector standing on its own feet you can now put the grill in place. Loosen the wing nut on the adjustable arm and move it up or down until the grill rests just above the tip of the pointer rod. As a double check, pass your hand quickly just above the grill. It should be hot, ready for you to start cooking.

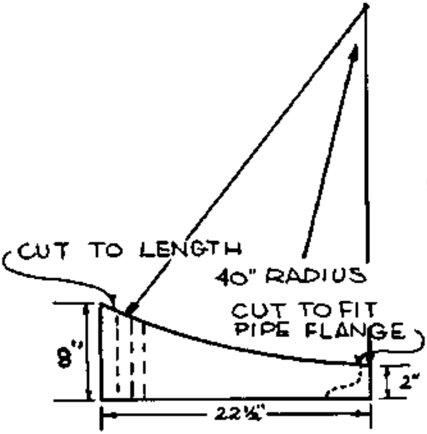
BUILDING THE SOLAR HOT PLATE

You'll find that your solar oven handles a great variety of cooking tasks. But how about coffee or hot chocolate? Bacon and eggs, hot cakes, or even a juicy steak? This kind of cooking requires much higher temperatures, focused onto a much smaller cooking area. In short, we need a solar hot plate. Years ago we heard about a reflector stove made of cardboard by a man named Max Flindt, and the idea appealed to us. Cardboard is inexpensive, easy to use, and lightweight. So we tried one and it worked very well. The solar hot plate described in this book is the latest in a variety of different designs, sizes, and shapes that we tried. We think it's the best.

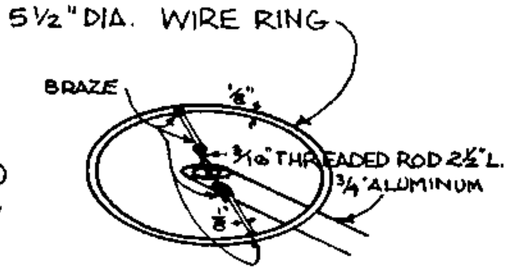
Our first reflector cooker was a giant, 48" in diameter. It cooked very well but was difficult to store and almost impossible to take anywhere unless we borrowed a pickup truck! After several generations of development, we realized that if the reflector was square instead of round it could be smaller in overall dimensions and still generate as much heat. This reflector stove is only 32" square but does an excellent cooking job.

List of Supplies Needed for Construction of Solar Hot Plate

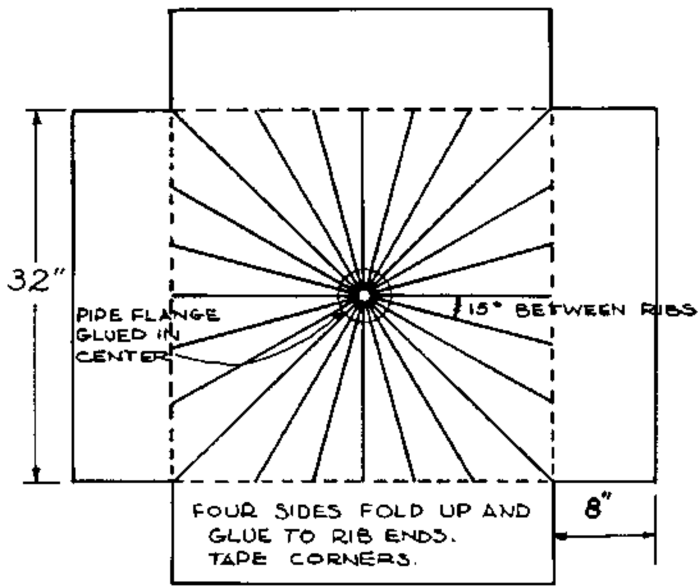
3 pcs. cardboard 1/8" x 4' x 8' (reflector box and cover)
1 pc. pipe flange 3/4"
1 pc. pipe nipple 3/4", 4" long
1 pc. aluminum tubing 1/2", 24" long
8 sq. ft. double-strength aluminum foil or aluminized mylar
1 iron lampshade ring 5-1/2"
1 pc. iron rod 1/8", 6" long
1 pc. threaded iron rod 3/16", 2-1/2" long
1 pc.wood 1" x 2" x 35"
1 bolt 3/16" by 1-1/2" long
3 nuts 3/16"
1 sheet poster board
1 finishing nail
1 pc. heavy string 12"



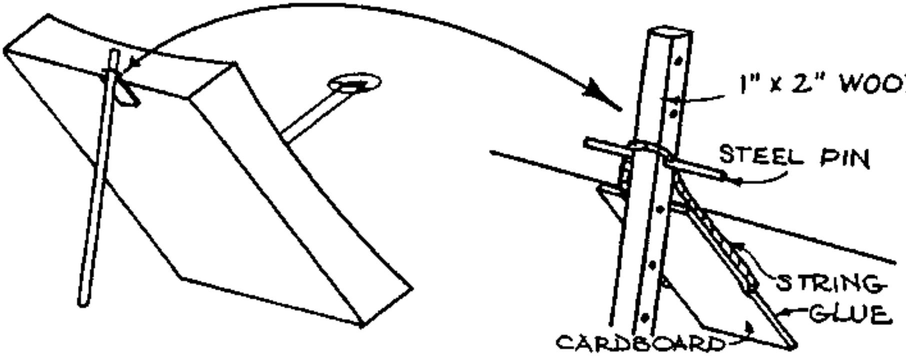
Rib pattern



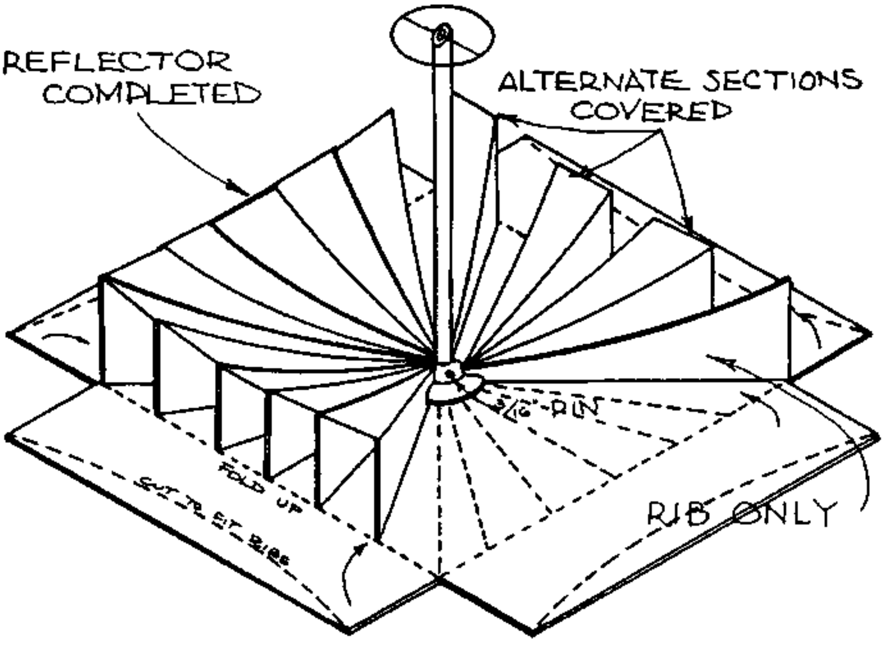
Grill



Layout of reflector box



Reflector cooker support.



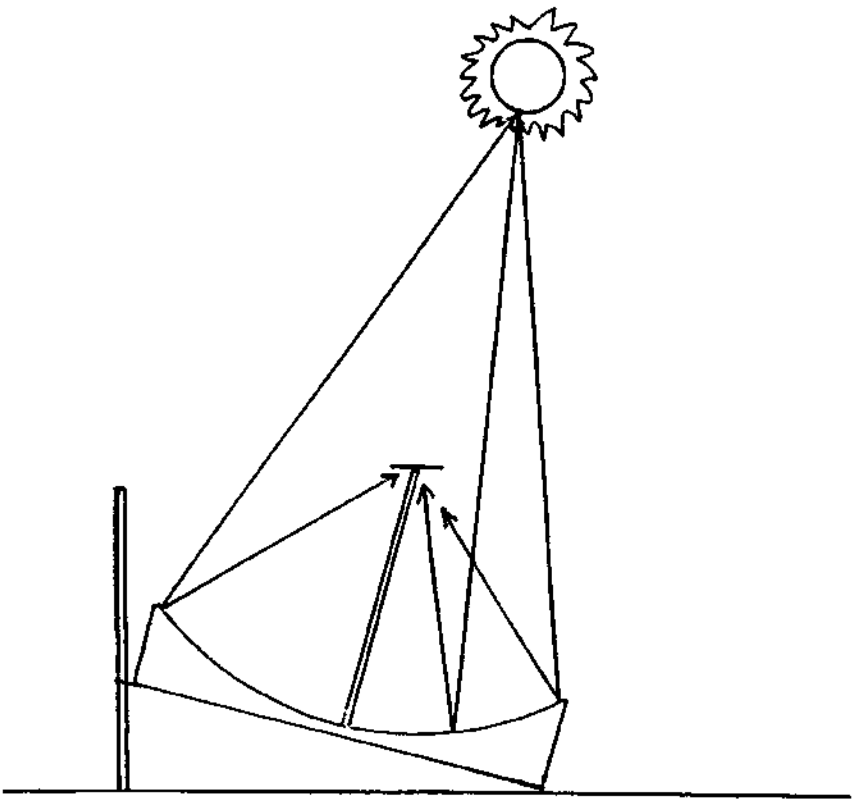
Hot plate assembly.

HOW THE SOLAR HOT PLATE WORKS

As kids, most of us used a magnifying glass to burn wood or leaves. A curved mirror does the same thing, concentrating all the sunlight that strikes it onto a tiny, very hot spot. Solar furnaces can be made in this way, and old searchlight mirrors are often put to such use. The parabolic curve of such a mirror results in very high concentration and temperatures of thousands of degrees! This would burn holes in a frying pan, of course, and we neither want nor need that powerful a mirror.

On our reflector we use the radius of a circle rather than a parabolic curve. We also form the mirror with a series of wedge-shaped pieces of flat reflective material instead of trying to mold them into a compound curve. This makes construction much easier and results in a hot spot about 6" square instead of a pinpoint. We've measured the grill temperature at more than 600 degrees F, so it really is a hot plate and must be treated with respect!

While the solar hot plate is easy to build, it does take some patience and care. Sloppy work will result in a solar cooker that won't get as hot as you'd like. So work slowly and accurately.



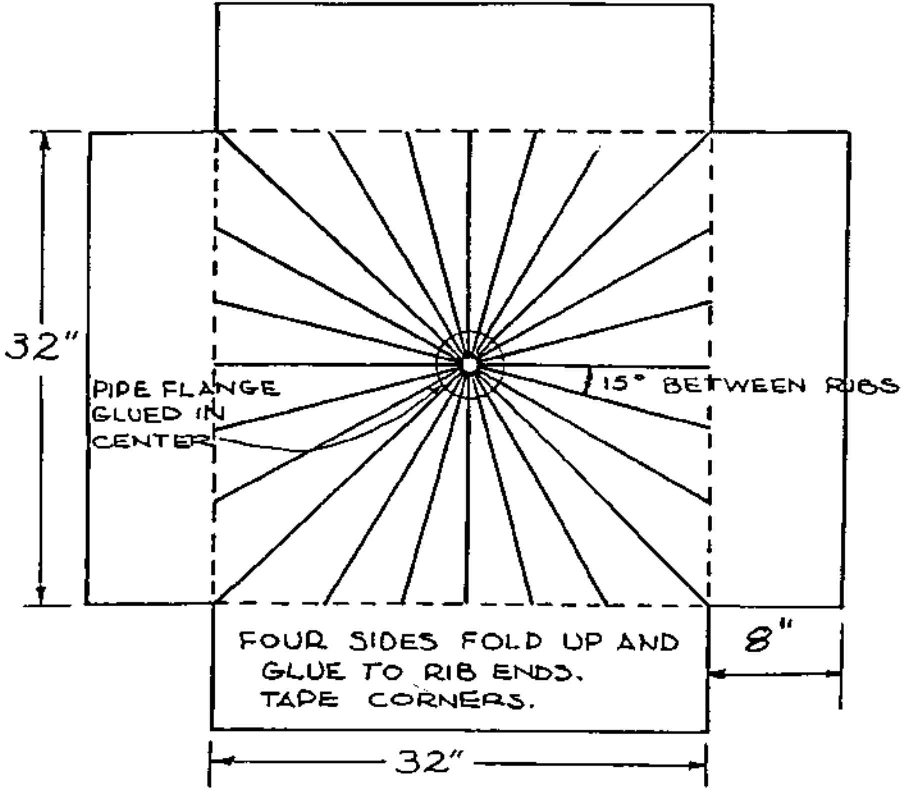
Solar energy reflecting to cooker hot spot.

CARDBOARD BASE

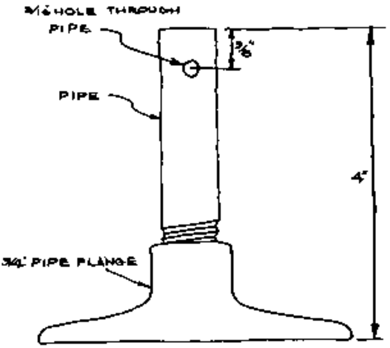
Start by carefully reading the directions and assembling the parts called for in the list of materials. You can buy 4-ft x 8-ft sheets of cardboard at a paper box factory, packaging store or scrounge used cardboard in sizes big enough for the cooker. Buy aluminum tubing at a hardware store, or search out bargains at a scrap metal place. Maybe you're even lucky enough to have the needed material right at hand.

Cut out the square cardboard base as shown in the drawing. Notch the corners and draw lines to locate the curve-forming ribs, making sure they intersect right at the center of the square. Draw the two diagonal lines first. Next, find the midpoint of each side piece and draw two more lines connecting them. With a protractor, divide each of the resulting 45° angles into three equal 15° angles. Twenty-four ribs times 15° equals 360°, a full circle. Draw all these lines, making sure they cross the center point.

Now turn the cardboard over and draw lines connecting the points of the corner notches. Very carefully cut through just one layer of cardboard, using a straightedge so the cut will be accurate. This makes it easy to bend the sides up when you reach that point in the construction—but don't cut all the way through!



Layout of reflector box.

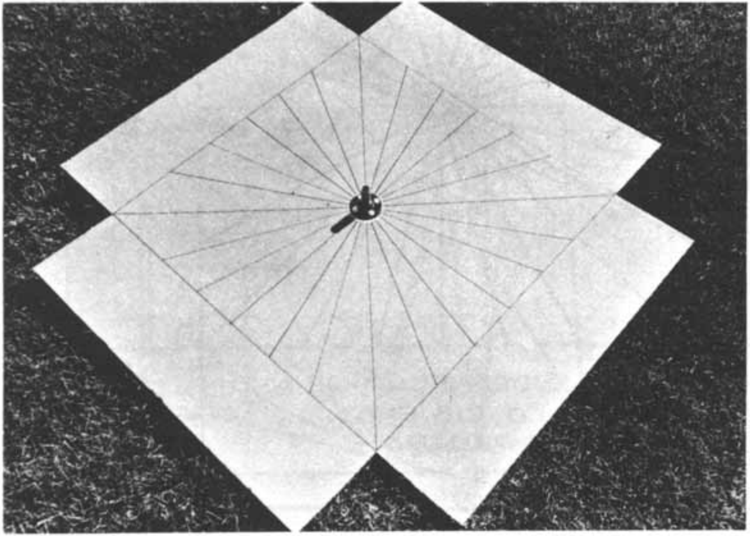


Detail of grill mount.

FLANGE ASSEMBLY

An important part of the cooker assembly is the flange that will support the cooking grill. Screw the 3/4" pipe nipple tightly into the 3/4" flange. Set the flange on a flat surface and measure up 4". Mark the pipe and then cut off the excess with a hacksaw, or have it done at the sheet metal shop. File the end smooth and clean out the inside of pipe so that the aluminum tubing will slide in easily. Now drill a 3/16" hole through the pipe as shown in the sketch.

The flange must be at the exact center of the reflector, so apply glue or epoxy liberally to its bottom surface and set it right over the intersection of the lines marking the rib positions. Make sure glue runs up out of the holes in the flange so that it will stick tightly to the cardboard.

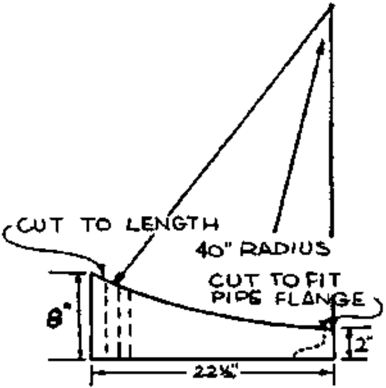


The reflector bottom has been marked for rib location and the sides have been trimmed. Note that the grill mounting flange has been secured with plenty of glue.

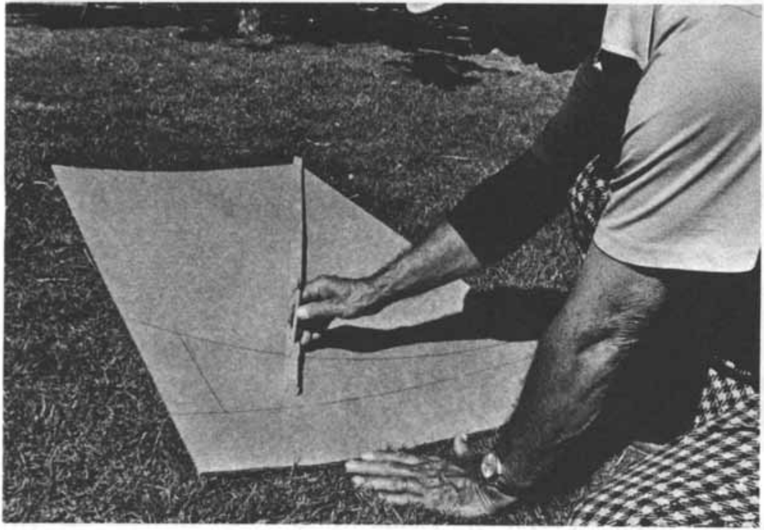
MAKING THE RIBS

Make the pattern for cutting the reflector ribs from the second cardboard sheet. As shown, draw a 40" radius beginning at a point 2" from the end of the cardboard sheet and right at its edge. Arrange the curve so that you will be cutting across the cardboard corrugations and not along them as this makes a much better cut.

Some careful craftsmen make a rib pattern of metal. Aluminum is a good choice because it is easy to cut. With such a pattern, it's easy to cut right along the edge with a knife or razor blade. However you make your pattern, cut it out carefully. On cardboard, use a sharp knife, linoleum cutter, or even a small hand saw. If necessary, sandpaper the pattern so that it's smooth and right on the line.



Layout of pattern for longest rib.



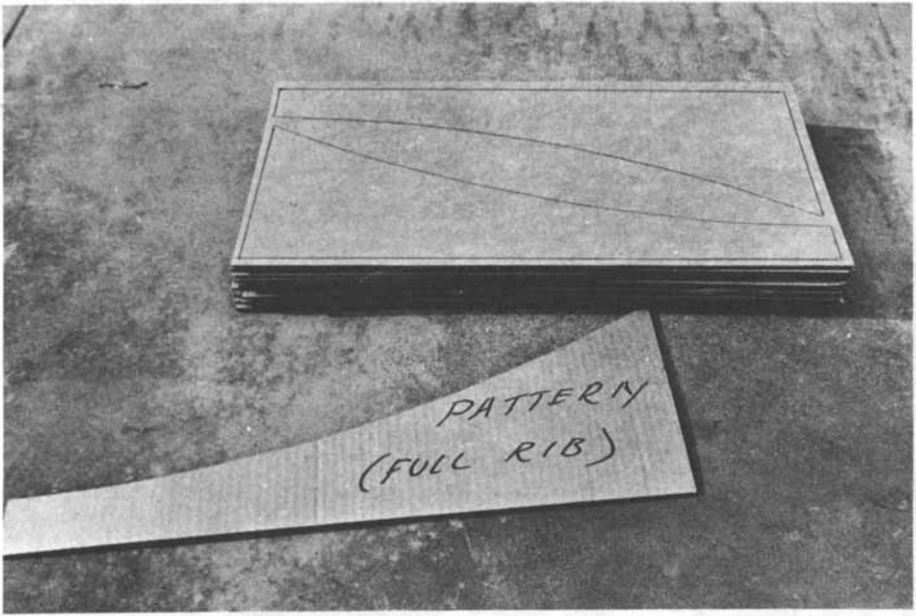
The master rib pattern is being made using a long strip of wood with a pencil inserted in a hole at the proper length.

Since the ribs cannot reach the center of the circle because the pipe flange is in the way, cut off an amount equal to half the diameter of the flange from the 2″ end of the rib pattern. Trim a bit more from the bottom so that the pattern clears the base of the flange. Now place it on the cardboard square, snug against the flange, and mark the end of the longest, or diagonal rib. Make sure you get a vertical line here, and trim the pattern. Mark four ribs on the cardboard sheet, remembering to arrange the cuts across the corrugations as much as possible. Cut out these ribs carefully and set aside.

Now place the long rib pattern on the next shortest line on the base piece, with its small end right up against the flange. Make a vertical pencil line on the pattern to mark the end of the next shortest rib and trim off excess material with a razor blade or sharp knife. Now you have a pattern for another rib. Use it to mark out eight ribs. Cut these as you did the others and set them aside.

Move your pattern to the next shortest rib and mark its end. Trim off the excess and use the new pattern to mark out another eight ribs. After these are cut, move the pattern to the last rib and trim it off. You only need four of these so don't make too many.

You should now have 24 ribs in all. Remember to be accurate. Check the ribs against each other by setting them on a flat surface and holding the small ends even. The curves should match; if they don't the reflective material won't accurately focus the sun's rays on the grill. If necessary, do some more trimming or sanding so that the ribs all have the same curve.

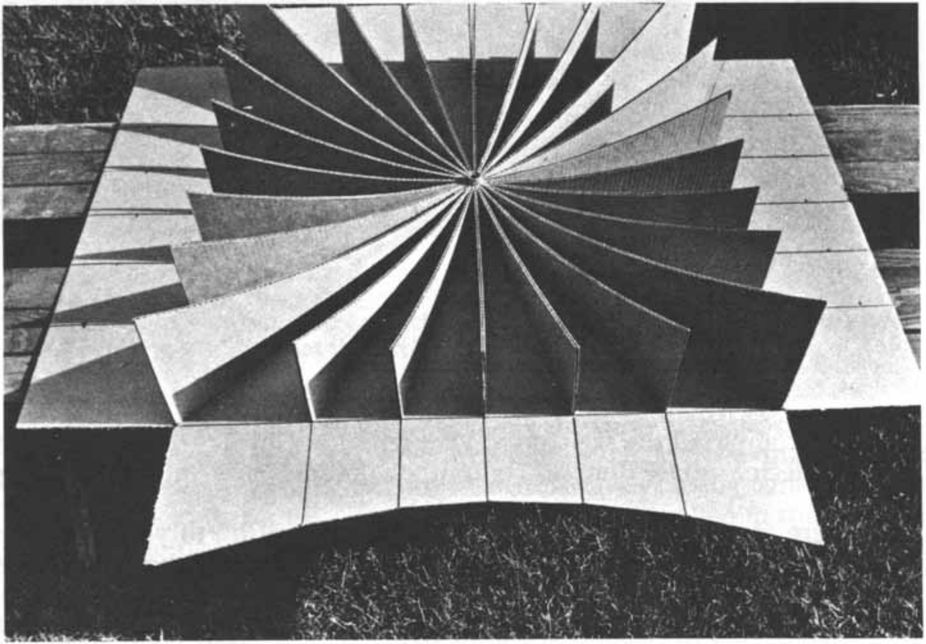


The pattern has been traced on cardboard blanks which are all the same size. The pieces will be glued together so that the curves can be cut all at once.

One way to get very accurate ribs is to cut out two dozen rough blanks of cardboard large enough that you can trace the largest rib pattern on them. Glue all the blanks in a stack, putting glue outside the pattern so that the ribs will come apart later. Now cut the ribs on a bandsaw and all the ribs will have exactly the same curve.

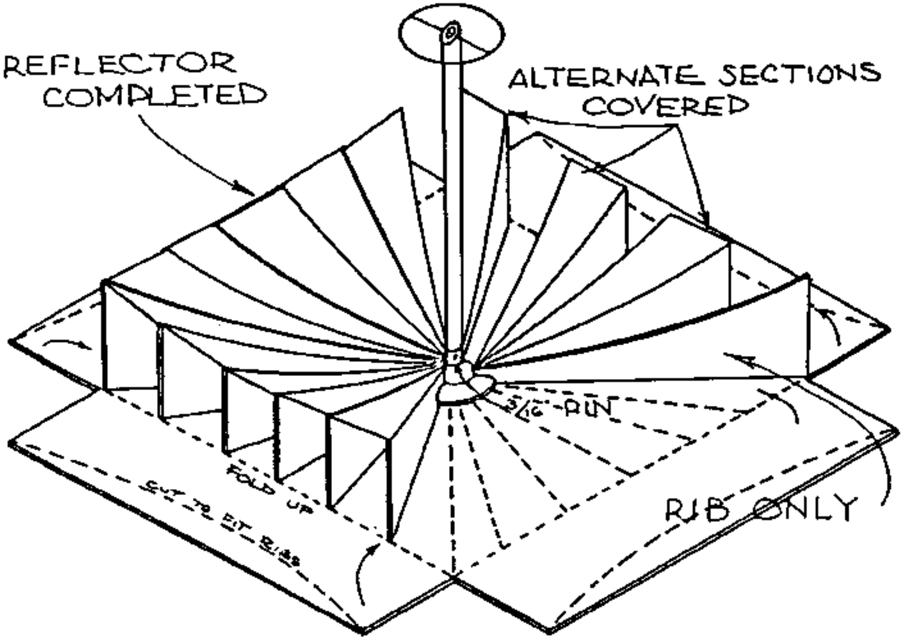
RIB ASSEMBLY

We used model airplane glue (any quick-drying cement will do) so that we didn't have to hold the ribs in place very long. Make sure that the base piece is on a flat surface and does not curl up. You may want to weight it with bricks, paint cans, or something else to keep it flat until you get enough ribs in place. Put a glob of glue every 6" or so along the lines on the cardboard base and hold the proper rib in place until the glue has set. When all the ribs are glued in place, let them dry long enough for full strength. Overnight is best, if you have that much patience.



The ribs have been glued to the box and one side is trimmed and ready to be glued in place.

Now it's time to bend up the sides of the box and mark the top edges of the ribs so you can trim the sides in the gentle curve shown on the drawing and photos. This can be done by laying a strip of thin wood so that it touches all the points you have marked. Carefully trim off the excess with a knife or saw and prop up one side at a time for gluing. Use two or three big drops of glue on each side of each rib. When all four box sides are glued in place, prop the box almost vertical against a wall and add more glue, especially at the box corners and at center where the ribs touch the flange. Let the glue dry. This will make the reflector sturdy enough to survive an occasional hard knock.

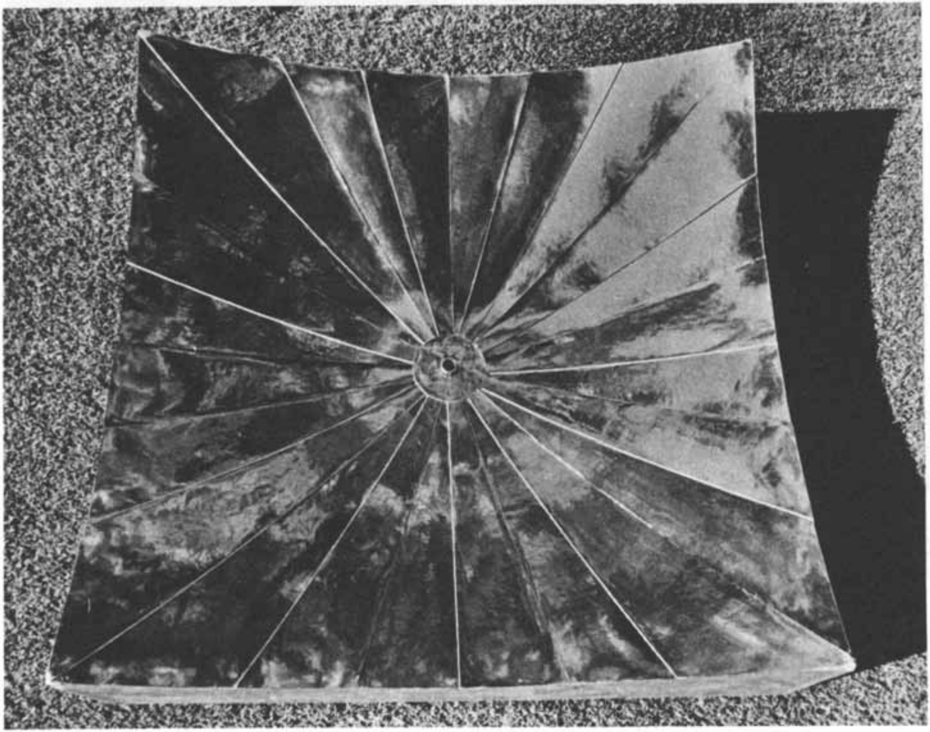


THE MIRROR FINISH

You have completed the skeleton of your reflector. Now it's time to add the curved reflector surface that will concentrate the sun's rays onto the cooking grill.

There are several ways to add this "mirror finish" to your reflector stove. Double-strength aluminum foil can be glued to poster board to make a durable, easily worked reflector material. Or you can use sheets of aluminized Mylar, or the aluminum-finish "Monokote" iron-on covering used for model airplanes. The Monokote makes the smoothest job, as our son-in-law in El Paso showed us. If you do use aluminum, coat the poster board with rubber cement and apply the foil very carefully to keep it smooth.

Make a pattern from poster board of the longest triangle needed. It should slightly overlap the two ribs it will cover. Use this pattern to mark three more poster board triangles. Then turn one of them over and mark four "opposite hand" triangles. This takes care of 8 of the 24 triangles needed. Now make patterns for the two other sizes of ribs—again making four right-hand and four left-hand so you can apply the reflective material to the same side of the poster board.



The complete reflector box has a circle of foil glued to the box where the narrow triangle ends meet. Note that the circle fits around the flange.

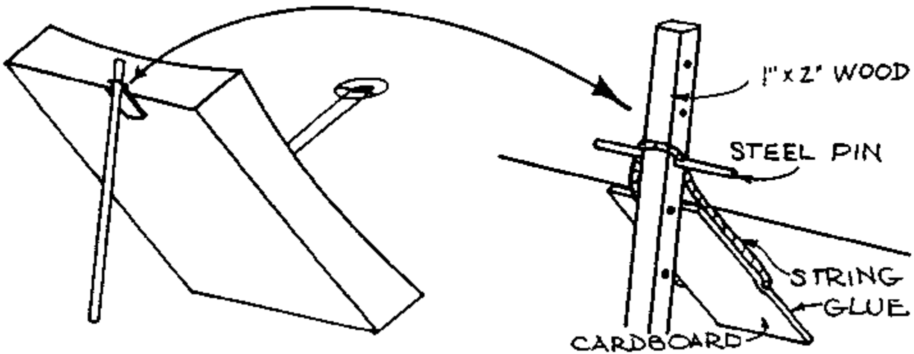
We found that the easiest way to apply the shiny triangles to the skeleton of the reflector is to first cover every other section, leaving openings between. Then apply the remaining triangles—always being sure you have the right one in each case. Use quick-drying cement applied to the edges of the back side of each reflector piece. Set the triangle in place and hold it down by hand or with weights until the glue sets. Carefully wipe off any excess glue before it dries.

You don't have to be too fussy in fitting the narrow ends of the triangles against the flange in the center. When all the triangles are securely glued in place, cut a 4" circle of poster board with aluminum material glued to it, cut a center hole, apply glue, and slip it down over the flange as shown in the photo.

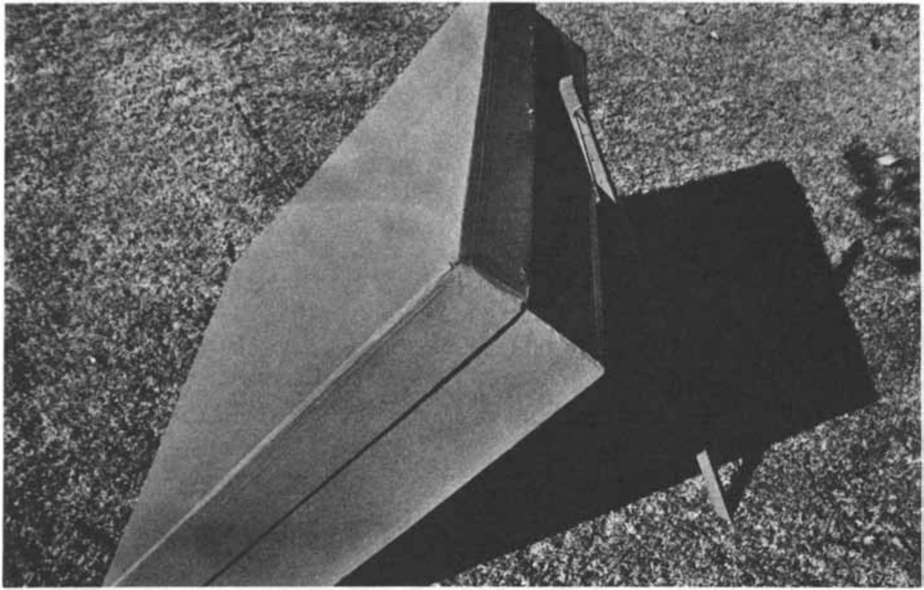
When the glue has dried thoroughly, turn the reflector box over and apply masking tape to the outside joints. Except for a coat or two of whatever color paint you decide on, the reflector itself is complete unless you want to make a cardboard cover for it as shown in the photo. Be sure to make it big enough to fit over the reflector.

REFLECTOR SUPPORT

The 1" x 2" x 35" piece of wood is used to support the reflector at different angles to face the sun. Mark 12 holes on the 1" side of this support, as shown in the drawing. Start 1-1/2" from the top end and make the holes 1-1/2" apart. Drill them through the wood, using a drill that will just let the short length of 1/8" steel pin slide through. By positioning this pin in different holes, you can support the reflector at any desired angle



Construction of reflector support.

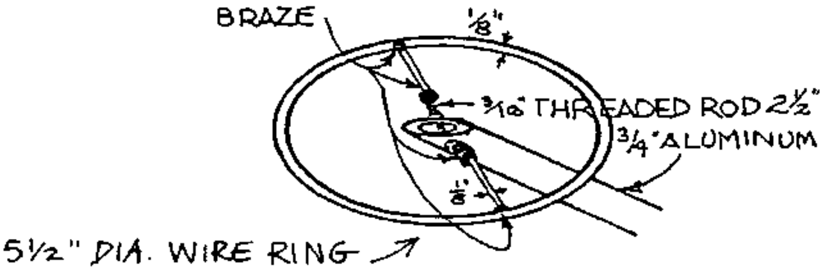


The completed cover fits snugly over the reflector box. Note how the reflector support holds up the box.

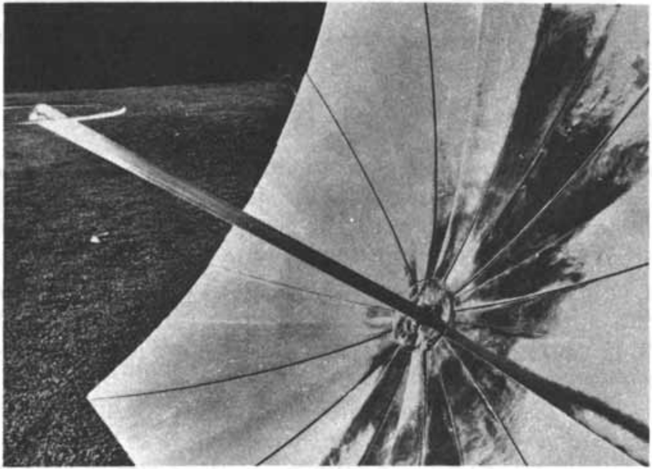
THE HOT PLATE GRILL

Slip one end of the 1/2" aluminum tubing into the flange in the center of the reflector. If it's loose, wrap masking tape around the tubing until it's a snug fit. Because of the 40" radius curve of the ribs, the focal length of your reflector should be about 20". On ours we checked to make sure. To do this, insert the aluminum tubing in the flange and set up the reflector cooker so there is no shadow on it from the tubing. This means the reflector is pointing directly at the sun.

Now take a piece of wrapping paper about a foot square and cut a hole in its center large enough to slide easily over the aluminum tubing. Holding the paper at the edges, slide it down the tubing and watch for the bright spot that should be formed by your reflector. Move the paper back and forth until that spot is the smallest you can make it: this will be the focal point of your particular reflector cooker. Mark the point on the aluminum tubing, being careful not to burn yourself on the hot metal. Move the reflector out of the sun and when it cools cut the tubing to that length, which should be about 20". Now you're ready to install the cooking grill on the tubing.



Construction of hot plate grill.



The aluminum tube, with the grill mounted on one end, has been fitted into the pipe flange.

We bought a 5-1/2" diameter iron ring at the hobby shop. Normally used for making lamp shades, it's just right for our hot plate grill. Drill a 3/16" hole at the end of the 1/2" aluminum tubing as shown in the drawing, and insert the length of 3/16" threaded rod. Twist a 3/16" nut onto each side, and cut the two short pieces of plain 1/8" rod as shown on the drawing.

If you're not an experienced metal worker, have the brazing done at the local sheet metal shop. (We had ours done that way.) Take along the drawing so they will know what you need. Just be sure only one nut is brazed to the threaded rod. The other is left free so that it can be used to tighten the grill in a horizontal position no matter what angle your reflector cooker is tipped to face the sun.

You'll notice that the end of the aluminum tubing sticks up slightly above the surface of the grill. Saw or file off this excess metal at an angle, as shown in the drawing, so your pots and pans will sit level on the grill.

Now it's time to attach the lower end of the aluminum tubing to the flange so the grill won't twist and dump your coffee pot or frying pan. There are already screw holes in the flange assembly. Prop the cooker up on its support in a shady place so the sun won't be a problem. Carefully level the grill (use a level if you have one,or your good eyesight if you haven't) and hold it in place.

With an ice pick, reach through the holes in the flange and mark the aluminum tubing. Remove the tubing, make sure you have two marks, and then center punch the middle of the penciled circles. Drill 3/16" holes, one from each side. Then carefully run the drill two through both sides of the tubing at once. Re-insert the aluminum tubing in the flange and see if a 3/16" bolt will go through. If not, you may have to enlarge the holes in the tubing a bit with a slightly larger drill or a small round file. Slide the bolt into place, tighten the nut, and you are about ready to use the grill.

The hot spot is *very* hot and you'll want to keep your hands out of that area. So how are you going to tighten the grill in the level position? What we do is stand in front of the cooker to shade most of it and thus reduce the heat. Another method is to turn the cooker away from the sun, keeping it at the proper tilt, and then tighten the grill. The hot spot is very bright too, so wear dark glasses while working with the solar hot plate.

A length of 2" by 4" board, placed on top of the box, keeps a pot of beans from upsetting the reflector.

TIPS FOR YOUR SOLAR HOT PLATE

We quickly learned that flat black paint makes the best grill, pot, or pan cook even better. Spray paint the *outside* surfaces of your solar cooking utensils and they'll heat faster. Put them on the grill in bright sunshine before using them and the paint will bake on nicely. And you won't get a paint taste in your food. You may want to use some of the elegant black gourmet cookware now available in department stores.

Use pots and pans large enough to accept all the solar energy your stove reflects onto the grill. A big pot is generally better than a small one. For hot cakes, or for searing a steak or hamburger, we've found that a skillet with a thick bottom works well. It stores up extra heat and quickly transfers it to food when you put it in the pan.

For food that requires a lot of cooking, be sure to cover the pot to keep the heat in. Because the solar hot plate is not as sturdy as the kitchen range, we use aluminum utensils in most cases, although a small steel pot or pan isn't too heavy.

A slight accumulation of dust (and even grease, etc.) doesn't greatly reduce the cooking power of the solar hot plate. But clean the reflector once in a while for best results. A "tack cloth" available from a paint store is handy for removing dust quickly. Grease can be removed with warm water and detergent. Aluminized Mylar is very durable because of its tough plastic coating. If you have used aluminum foil on your reflector, use care in cleaning and handling so it will last a long time.

A word of warning: don't let your solar hot plate get wet, especially if you haven't painted it. Water and cardboard don't mix well, so keep the cooker out of rainy or damp weather.

Byg en solovn

Byggevejledning

Povl-Otto Nissen
Systime

Byg en solovn

Oprindelig sat med Times New Roman 11/13 hos tekst & data, Aabenraa

ISBN 87 616 0042 3
1. udgave (identisk med cd-rom-udgaven fra 1995)

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Forlaget Systime A/S
Skt. Pauls Gade 25
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Tlf: 86 18 14 00
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Web: http://www.systime.dk
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Indholdsfortegnelse

Forord - mest til læreren

Inspirationen til dette temahefte om solovnen er kommet mange steder fra, og det er blevet udviklet over en årrække. Gennembruddet kom, da jeg fandt et legetøjseksperimentsæt over emnet med en indholdsrig og god manual (se litt.henv.). Selve sættet var imidlertid noget småt og uholdbart i længden til undervisningsformål.

Den første solovn i stor størrelse, godt en meter i diameter, blev lavet af et HF-hold i en emneuge i 1984. Den var lavet af spånpladeprofiler, masonit, pålimede spejlstumper og var ret tung. Den har siden været på Miljø-89 udstilling og på FDF-lejr.

Nærværende letvægtsmodel af genbrugspap og alufolie blev udviklet gennem en sommerferies hyggeeksperimenter. Papmodellen kan laves på ca. 3 timer - andre modeller tager længere tid.

Aktiviteten og de håndskrevne noter har så siden været brugt flere gange på seminariets natur/teknik kurser og som eksperimentelt forløb på HF.

Måske vil en aktivitet som denne også lige være sagen i det nye teknikfag. Aktiviteten fremtræder som en passende blanding af manuelt arbejde, elementær måleteknik og teori. Afhængigt af skoleform, klassetrin og ambitioner (pensumkrav) kan de nævnte aspekter gives forskellig vægt.

Man kan vælge at vægte det manuelle og det kvantitative og nøjes med at varme ting op.

Man kan bruge den som udgangspunkt for optikken.

Man kan vægte det energimæssige, kalorimetriske målinger og efterbehandlingen.

Desuden er parablen/parabolen jo matematisk set et ganske interessant fænomen. Der er tale om et godt emne til den analytiske geometri, der åbner mulighed for samarbejde mellem fysik og matematik.

Ved anvendelse i læreruddannelsen vil det være naturligt at knytte didaktiske og metodiske overvejelser på, f.eks. hvad angår betydningen af koblingen mellem det manuelle og det teoretiske.

Solovnens plads i emner omkring energiforsyningen og parabolens i emner omkring kommunikationsteknologi har også samfundsfaglige aspekter.

Det må være op til den enkelte lærer at strukturere aktiviteten og lægge vægten efter formålet.

Den langt overvejende del af forløbet foregår i laboratoriet. Målingerne foregår dog udendørs. For overskuelighedens skyld er afsnit, der beskriver egentlige fysiske eksperimenter, markeret med en lysegrå streg på venstre side.

Hermed overlades ideen til alle, som har lyst til at eksperimentere og afprøve nye muligheder.

Povl-Otto Nissen
Ribe Statsseminarium og HF.

Anvendelse af Solens energi

Der er mange gode grunde til at forske i udnyttelse af Solens energi. For det første er Solen den primære kilde for tilførslen af den energi, som vedligeholder de naturlige fysiske, kemiske og biologiske processer på Jorden. Der er naturligvis mange betingelser, som skal være opfyldt. For eksempel skal der være grundstoffer og mineraler tilstede i passende mængde samt et passende balanceret temperaturniveau. Man kan vel sige, at solenergien er "vedligeholder" af livsprocesserne, hvordan de så end er startet.

At forske i den proces - fusionen -, som i Solen frigør energien i form af stråling, er en kæmpeopgave i sig selv. Den vil vi lade ligge i denne omgang. I stedet vil vi koncentrere os om solenergiens virkning og anvendelsesmuligheder, når den med en fart af 300.000 km/s ankommer til Jorden, ca. 150 mill. km fra oprindelsesstedet.

På jordoverfladen har naturen sin egen teknik. Dels sætter solstrålingen gang i de klimatiske processer, og dels fremmer solstrålingen plantevæksten.

Man kan godt opfatte planternes blade som små solfangere, hvor grønkornene - klorofylet - er katalysatorer for en proces, hvor vand (H_2O) og kuldioxid (CO_2) ved hjælp af solenergien bliver til kulhydrat og den for os så nødvendige ilt (oxygen O_2).

$$6\ CO_2 + 6\ H_20 + \text{lysenergi} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Visse planters evne til yderligere at binde kvælstof (nitrogen N_2) giver i det videre forløb proteiner, som også er nødvendige for dyrelivets processer. Disse processer kan mennesket ikke efterligne i større stil. Det er heller ikke nødvendigt. Vi kan imidlertid godt understøtte naturens egen villighed med kunstgødning og kunstvanding. Men vi skal i lige så høj grad passe på, at vi ikke kommer til at ødelægge de naturlige betingelser eller forrykke balancen med vore aktiviteter.

Menneskets energihunger i forbindelse med den "teknologiske udvikling" mod "højere levestandard" har medført afbrænding af en lang række fossile brændstoffer, som kul og olie. Det ville måske ikke engang være så alvorligt, hvis ikke der i forbindelse med den industrielle produktion udledtes en hel del miljøgifte, som hæmmer den naturlige vækst eller ophobes i fødekæden.

I dette hæfte vil vi se på nogle miljøvenlige måder at udnytte Solens energi på. Der er stort set tre typer af solenergiomsættere.

1. Én type er den flade solfanger, som efterhånden ses på mange hustage. Den består i princippet af en sortmalet metalplade i tæt forbindelse med et rørsystem med væske, f.eks. vand. Vandet bliver varmet op, mens det antager samme temperatur som pladen. Det kan så enten tappes direkte som varmt brugsvand eller lagres til husopvarmning. Varmen flytter rundt med vandet, når det strømmer.

   Et anlæg kan være indrettet, så vandet er selvcirkulerende, men ofte er det cirkuleret med en pumpe.

   Princippet er baseret på det naturfænomen, at der opstår varme der, hvor lyset stoppes. Det hvide lys ændrer bølgelængden, så strålingen bliver til mørk (infrarød) varmestråling. Varmemængden svarer præcis til lysets energiindhold, hvis refleksionen kan forhindres.

2. En anden type er solovnen, som fra et større areal koncentrerer sollyset i et centralt punkt, kaldet brændpunktet. I dette punkt anbringes så den genstand eller den væske, der skal opvarmes. I brændpunktet er princippet det samme som ovenfor. Det gælder om, at lyset stoppes og omdannes til varme.

   Men forinden skal lyset reflekteres så godt som muligt i solovnens flade uden at blive omdannet til varme. Ovnen skal have form som en parabol. Det er der en hel del matematik i, som vi vil vende tilbage til.

   Det drejer sig faktisk om en gammelkendt teknologi. Allerede Newton brugte parabolen i sin opfindelse af spejlteleskopet, og rundt omkring på mange huse sidder nu parabolantenner, der ikke er beregnet til at koncentrere lys, men elektromagnetiske felter. Parabolen anvendes jo også i billygter. Blot går lyset i det tilfælde den modsatte vej, så der sker en spredning ud på vejen fra den elektriske lampe, som er anbragt omtrent i parabolens brændpunkt. Matematikken og refleksionen er i alle tre tilfælde den samme.

3. En tredie type er solceller. Udviklingen af halvleder-elektronikken (transistorer, integrerede kredse o. lign.) har også gjort det muligt at fremstille solceller, der er i stand til at omsætte sollyset direkte til elektricitet. Der skal mange celler til, før man har en energimængde svarende til, hvad der er til rådighed i stikkontakten.

   Men fremstillingsteknologien har udviklet sig, således at solceller absolut er konkurrencedygtige som mobile anlæg eller hvor afstandene gør det for dyrt at trække ledninger.

Disse tre typer af solenergi-omsættere kan hver for sig eller i forening gøres til genstand for eksperimenteren og bearbejdning i skolen, f.eks. i længere eksperimentelle forløb i gymnasiet, på HF eller på seminarierne.

I det følgende findes et forslag til eksperimenter med en primitiv solovn, altså type 2. Man bygger den selv af billige materialer.

Selve den manuelle fremstilling og en del af målingerne vil også kunne udføres af elever i folkeskolen, mens den teoretiske bearbejdning kræver noget mere.

Ved at gennemføre målinger af energiomsætningen i solovnen kan man beregne nyttevirkningen ved at sammenligne den modtagne/omsatte effekt baseret på grafisk fremstilling af målingerne med den indstrålede effekt. I sammenhæng med dette lærer man noget om varme, varmekapacitet og kalorimetri. Til måling af den indstrålede effekt anvendes en solcelle.

Som særlig udfordring er der endvidere et afsnit om matematikken bag parabolens anvendelighed til koncentration af lyset i et punkt. Parablen, som er et plant snit på langs gennem top/bundpunktet og brændpunktet af parabolen, kan beskrives ved hjælp af en andengradsligning. Parablen kan også beskrives som "det geometriske sted" for *de punkter, der ligger lige langt fra en ret linie og et fast punkt uden for linien.* Vi kigger på sammenhængen mellem de to beskrivelser. Dette afsnit er ikke en forudsætning for at kunne gøre alt det andet.

Nu til arbejdet! Man kan for eksempel lægge arbejdet til rette på følgende måde:

Arbejdsplan for et eksperimentelt forløb

Projekt SOLOVN

1. Fremstilling af solovnen. Se byggevejledning.
2. Beregn solovnens åbnings areal.
3. Lav et stativ til ophængning af vandpose i brændpunktet.
4. Afmål en bestemt mængde vand, f.eks. 1/4 liter (250 g) i posen.
   Sæt også et termometer i og anbring posen i solovnens brændpunkt.
5. Mål starttemperaturen. Mål temperaturen igen hvert minut i mindst en ½ time.
6. Tegn en graf over temperaturudviklingen.
7. Bestem den opsamlede energi i joule.
   Se beregningsmetoden i afsnittet “Måling med solovnen”.
   Udregn effekten i watt. Nøjagtigst ved hældningsbestemmelse på grafen.
8. Den indstrålede effekt måles fotoelektrisk med et såkaldt pyranometer og beregnes i forhold til solovnens åbningsareal.
9. Beregn solovnens nyttevirkning som forholdet mellem den opsamlede effekt og den indstrålede effekt.
10. Når vi på den måde har lært solovnen at kende, kan vi bestemme, hvad vi vil bruge den til: Bestemte opvarmningsformål, yderligere udforskning og måling, nye udformninger, og udbygning med tekniske raffinementer.
11. Man kan yderligere bruge de konkrete fysiske eksperimenter som udgangspunkt for en teoretisk matematisk bearbejdning af parablen.

Materialer og værktøj:

- Pap fra gamle papkasser.
- Alu-folie med papirbagside. Det kan købes i ruller som “dampspærre” i byggemarkedet eller som “frokostfolie” i supermarkedet.
- Blyant, lineal, saks, hobbykniv og hvid hobbylim.
- Lommeregner.
- Evt. skæreunderlag.

Byggevejledning

Fremstilling af en parabol

1. Man laver en skabelon ved først at plotte en parabel på tegnepapir eller direkte på pappet. Der er to anvendelige metoder:

   Metode I: Koordinatsystem og kvadratrodsformel.
   Metode II: Det geometriske steds metode.
   Se de følgende sider.

2. Når parablen er plottet og tegnet op med let hånd klippes den ud og overføres til det nødvendige antal papstykker. Det er hensigtsmæssigt med 8 sektioner 360 grader rundt. De laves således:

3. Parabelprofilerne udskæres med enhobbykniv. To som helprofiler, resten som halvprofiler. Se fotografierne de følgende sider.

4. De to helprofiler slidses halvt igenem på midten. Den ene fra oven - den buede kant, og den anden fra neden - den lige kant. De falses ind i hinanden, så de danner et kors.

5. Profilkorset limes på bagpladen. Man kan godt lime med hvid hobbylim på kanten af pappet. De fire halvprofiler limes op i hjørnerne på korset. Lad limen tørre lidt. Læg eventuelt en skoletaske op i parabolskålen, så profilerne presses mod bagpladen under tørringen.

Fremstilling af skabelon med parabelprofil

Metode I, funktionsmetoden

Det kan gøres ved hjælp af en regneforskrift, en lommeregner og et koordinatsystem. En velegnet forskrift er

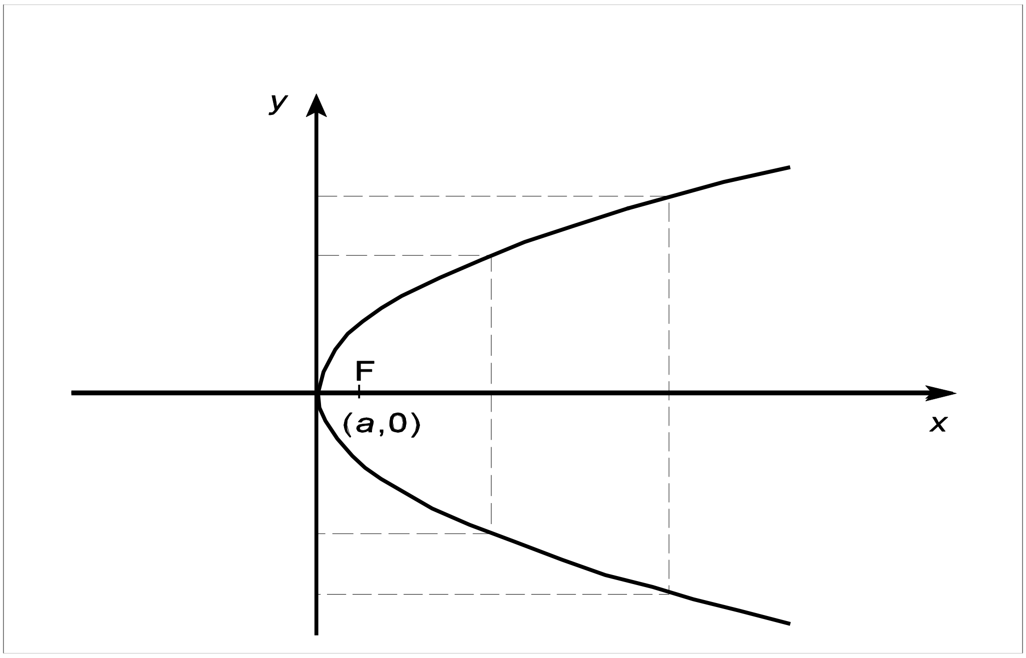
$$y^2 = 4 \cdot a \cdot x \text{ eller } y = \pm\sqrt{4 \cdot a \cdot x}$$

hvor a er den valgte *brændvidde.* Brændvidden er afstanden fra bunden af parabelskålen op til brændpunktet, hvor Solens stråler samles. Vælges f.eks. brændvidden til 9 cm fås

$$y = \pm\sqrt{4 \cdot 9 \cdot x}, \text{ dvs. } y = \pm\sqrt{36x} = \pm 6 \cdot \sqrt{x}$$

Man kan så indsætte forskellige værdier af x og udregne y. Det kan nemt gøres på en almindelig lommeregner, men man kan jo også bruge et regneark.

Værdierne plottes i et koordinatsystem, og man tegner med "let hånd" gennem punkterne. Husk at både den positive og den negative y-værdi skal plottes. Hvis man kun plotter den ene, kan man naturligvis få den anden ved at spejle i x-aksen.



Figur 1: De punkterede linier forbinder punkter med samme værdi af y.

Parablen bliver mere "åben" ved valg af større brændvidde *a*. Anbefalet værdi for *a* er fra 9 til 20 cm.

Advarsel: Brændvidden bør nok ikke vælges så stor, at man af bar nysgerrighed kan få hoved og øjne ind i brændpunktet.

Metode II, det geometriske steds metode

Den bygger på, at punkter på parabellinien har lige stor afstand til et punkt og en linie.

1. Man starter med at tegne en linie (ledelinien) og et punkt F ved siden af linien. Bogstavet F bruges som betegnelse for brændpunktet, Focus. Afstanden mellem punktet og linien skal være dobbelt så stor som den ønskede brændvidde.
   Det kan være en fordel også her at bruge et koordinatsystem, men det er ikke nødvendigt.
   I givet fald kan ledelinien tegnes parallelt med y-aksen gennem (-*a*,0) og brændpunktet F i (*a*,0), hvor *a* er den ønskede brændvidde.

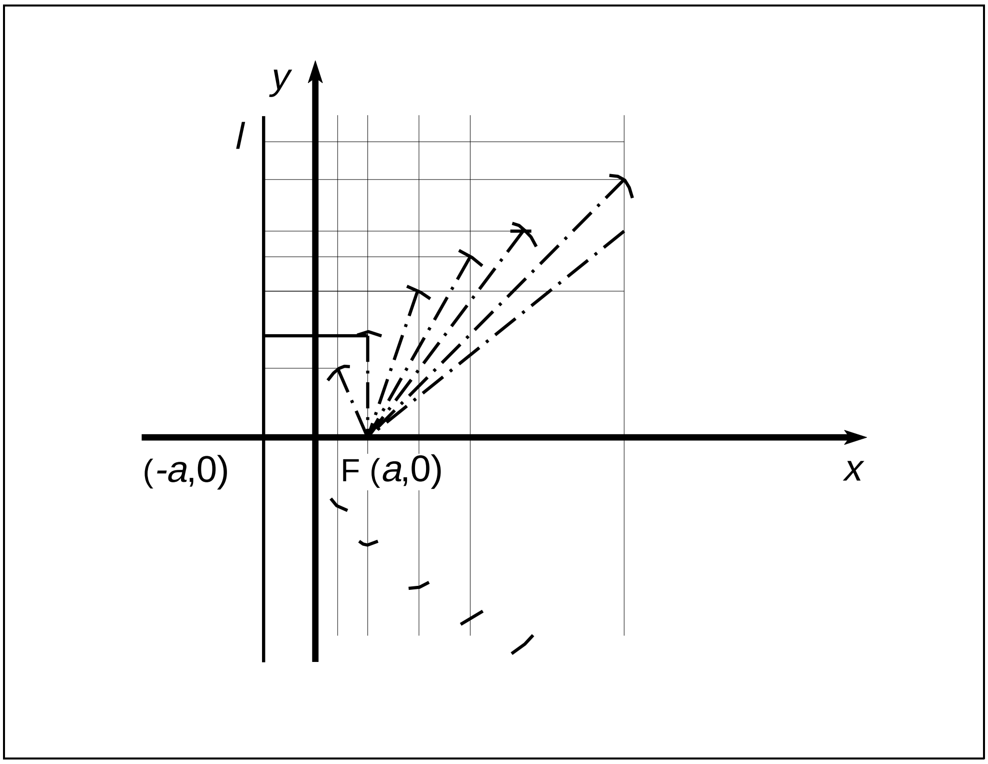
2. Man tegner en række hjælpelinier parallelt med ledelinien.

3. Disse hjælpeliniers afstand (vinkelret) til ledelinien bruges som radier for cirkelbuer med centrum i F. Som passer bruges en blyant i snor.
   Husk, at der er to skæringspunkter på hver linie i tilfælde, hvor radius (afstanden) er større end *a*. Hvis den er lig med *a*, er der kun ét fælles punkt, og linien må være *y*-aksen, dvs. tangent til parablens top/bundpunkt. Er radius mindre end *a*, er tilfældet uinteressant.

4. Hvor cirkelbuerne skærer de respektive hjælpelinier findes en række punkter, som får samme afstand til ledelinien og til punktet F. Ved tegning med let hånd hen gennem disse skæringspunkter fås en parabel.

   En matematisk begrundelse for, at det forholder sig sådan, findes i et særskilt afsnit.

5. Parablen klippes ud, så den kan bruges som skabelon til fremstilling af det nødvendige antal papprofiler. Se på de følgende tegninger. Man skal ikke klippe i ledelinien, men sørge for god plads langs med ledelinien modsat brændpunktet.



Figur 4: Sådan finder man de punkter, der ligger lige langt fra l og F.

Solovnen samles

Ved at følge de anskuelige fotografier trin for trin skulle det være muligt at samle skelettet til solovnen.

Figur 3: Fotografierne viser, hvorledes solovnen samles gradvist.

Beklædning af solovnen

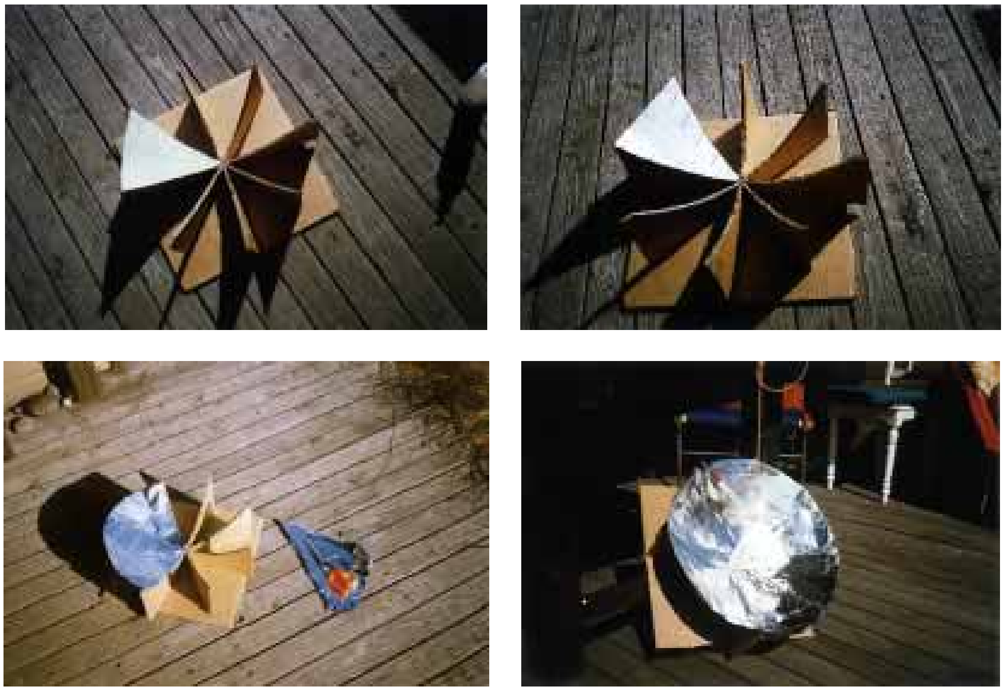
1. Beklædningen med aluminiumsfolien sker bedst sektionsvist. Vinklen i sektionsspidsen mod parabolens bund afhænger af antal sektioner. 8 sektioner giver 360 grader : 8 = 45 grader.

   Det nemmeste er at tegne en cirkel på bagsiden af alu-folien, så arealet lidt rigeligt svarer til parabolskålens krumme flade.

   Inddel cirklen - de 360 grader - i det valgte antal sektioner, og skær dem ud, så vinkel og antal passer sammen.

2. Pålimningen foregår med “let hånd". Man “føler” sig frem til den rigtige runding. Beklædningen skal ikke være stram som en paraply, men skålformet. På grund af krumningen vil alu-sektionerne overlappe yderst på profilerne. Det er kun en fordel, når man skal lime.

   Pas på ikke at få lim på de blanke flader.



Figur 4: Fotografierne viser, hvorledes man foretager beklædning af solovnen.

Afprøvning af solovnen

Advarsel

Aluminiumsfolien er ganske vist så tilpas mat og ujævn, at vi ikke når temperaturer, der kan tænde ild. Men man kan blive blændet. Man bør derfor bære solbriller og helst opholde sig bag solovnen under betjeningen.

Den første afprøvning foregår nemmest ved, at man går ud i klart solskin og anbringer solovnen med åbningen mod Solen. Stikkes hånden ind i brændpunktsområdet, kan man mærke varmen.

Målinger

Mere nøjagtige målinger foregår bedst ved at ophænge en frysepose med en kendt vandmængde og et termometer i solovnens brændpunkt.

Notér temperatur og tid med jævne mellemrum.

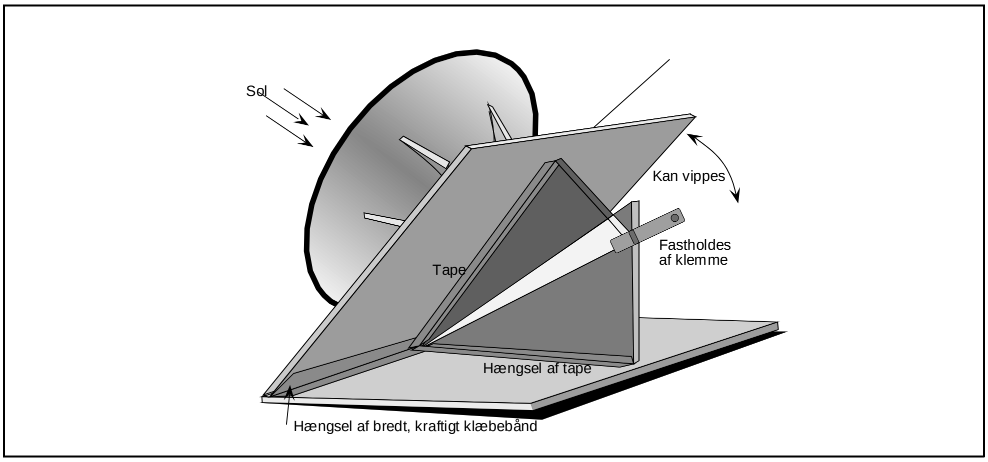
Plot målingerne i et koordinatsystem, så man kan aflæse, hvor lang tid det varer at opvarme en bestemt vandmængde til en bestemt temperatur.

Hvis man vil udregne effekten og nyttevirkningen, må man huske, at varmetabet er størst ved de højeste temperaturer. Mere om det senere.

Indstilling efter solhøjde

Solovnens bund hængsles langs den ene kant på en bundplade af tilsvarende størrelse med kraftigt selvklæbende tape.

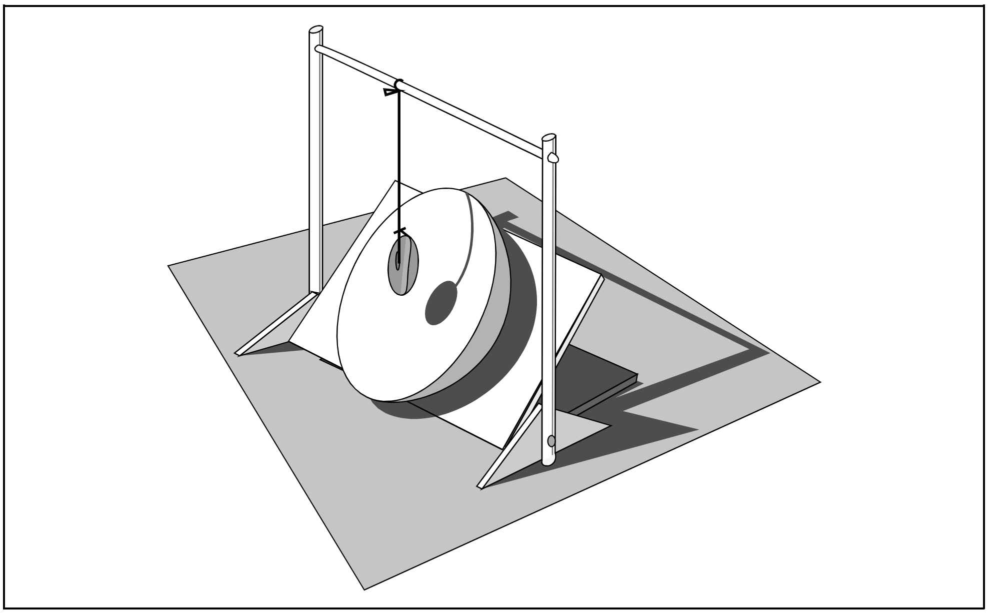
Til at holde solovnen i en bestemt vinkel bruges to trekantede papstykker, som hængsles med tape på henholdsvis den vandrette bundplade og solovnens bund, der nu kan stilles skråt. De to trekanters spidse vinkel skal have en størrelse, så de i forening dækker vinklen mellem største og mindste solhøjde. En bestemt indstilling kan fastholdes med en tøjklemme.



Figur 5: Hængsling og højderegulering af solovnen.

Der er også brug for at opfinde et stativ til ophæng for det (vand?), man ønsker opvarmet. Man kan ikke sidde og holde posen under opvarmningen. Det varer typisk 2-3 kvarter.

Stativet kan naturligvis laves af fysiklokalets stativer og muffer, men det kan jo også laves af sammenbundne bambuspinde.



Figur 6: Stativ og ophæng.

Målinger med solovnen

Forberedelse

Når solovnen er færdig og stillet ud med åbningen mod Solen, kan man allerede med hånden anbragt i området ved brændpunktet mærke, at der dannes varme. Hvis man skal arbejde med solovnen i længere tid, er det en god idé at tage solbriller på og helst opholde sig bag den. I det tidsrum, hvor lyset ikke stoppes i brændpunktsområdet, fortsætter det ud igen, og så er det - til en vis grad - som at kigge ind i Solen.

For at finde ud af, hvor meget energi, der modtages i et bestemt tidsrum, skal vi bruge en afmålt stofmængde og et termometer samt et ur. Desuden foretages en fotoelektrisk måling af solindstrålingen med en lysmåler, f.eks. et *pyranometer,* der er en solcelle, der omsætter en del af lysets energi direkte til elektricitet.

Stofmængden kan for eksempel være en kvart liter vand, 250 gram, i en plastpose. Termometeret sættes i vandet, og det hele hænges op i det fremstillede stativ, så pose med indhold placeres i brændpunktsområdet.

Målingerne kan godt udføres i en gennemsigtig plastpose, men der kan være en vis idé i at bruge en sort eller uigennemsigtig pose. Overvej selv hvorfor.

Det kan også være en god idé til sammenligning at have en tilsvarende pose med vand og termometer liggende i Solen ved siden af solovnen og måske yderligere een et sted i skyggen.

Udførelse

Vi måler begyndelsestemperaturen og fortsætter med at aflæse temperaturen hvert minut i et tidsrum på 30-45 minutter.

Ligeledes aflæser vi hvert minut strålingsintensiten på et pyranometer, f.eks. et Silkeborg-pyranometer, som er en solcelle i en strømkreds, der kan tilsluttes et følsomt voltmeter.

Ved hjælp af spændingen og specifikationerne for apparatet kan vi let udregne solstrålingsintensiteten I målt i watt pr. kvadratmeter. (Se videre i afsnittet om efterbehandling af målingerne).

For en solcelle gælder, at den frembragte spænding er en materialeegenskab (for silicium ca. 0,5 volt), mens strømstyrken afhænger af arealet og strålingen. Man kan så i princippet enten måle på kortslutningstrømmen eller på spændingsfaldet over en parallelkoblet målemodstand.

I måletiden flytter Solen sig noget. Hvis man synes, kan man jo rette lidt på opstillingerne, men det betyder næppe ret meget i den relativt korte tid.
Det kunne imidlertid være en sjov opgave for elektronikinteresserede at konstruere et apparat, der kan få solovnen og pyranometeret til automatisk at følge Solens gang.

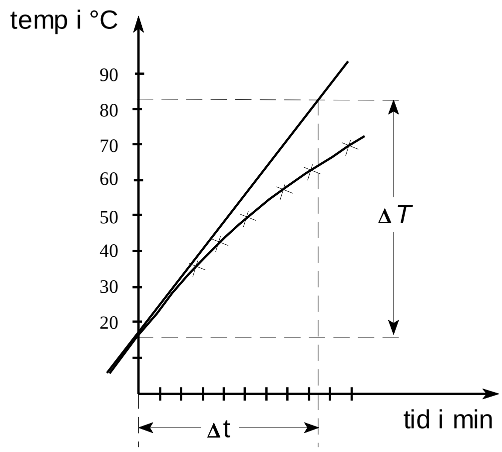
Efterbehandling

Målingerne afbildes i et koordinatsystem med vandret tidsakse. Med temperaturen på 2.-aksen vil grafen formentlig krumme svagt over mod vandret.
I hvert fald vil grafen blive vandret, når vandet koger ved ca. 100 °C. Krumningen skyldes, at der trods jævn energitilførsel opstår øget varmetab til omgivelserne på grund af den tiltagende temperaturforskel til omgivelserne.

Dette gør, at vi må bruge et særligt trick for at bestemme solovnens maximale effekt, bruttoeffekten. Effekten er energiomsætningen pr. tidsrum. Den angiver altså, hvor hurtigt lysenergien bliver omsat til varme. Enheden for effekt er watt = joule pr. sekund.

Vi må først bestemme, hvor meget energi posen med vand modtager fra solovnen.

Trick´et består i at lægge en tangent til den lidt krumme temperatur-graf tæt ved begyndelsestemperatur/tidspunktet. Tangenthældningen angiver den temperaturstigning, der ville have været pr. minut, hvis der ikke havde været varmetab.



Figur 7: Temperaturkurven plottes bedst på mm-papir.

Når vi benytter temperaturstigningen til at beregne varmeenergien, må vi naturligvis tage hensyn til størrelsen af den opvarmede stofmængde og det pågældende stofs evne til at optage varme.

Den specifikke varmekapacitet.
Den angives som den varmemængde, der skal til for at opvarme 1 gram af stoffet 1 grad celsius (eller kelvin). I gamle dage kaldte man den energimængde, der skal til at opvarme 1 g vand 1 grad, for en *kalorie* (1 cal).

I en databog kan man finde forskellige stoffers specifikke varmekapacitet. Man anvender ofte symbolet *c* for specifik varmekapacitet, og måleenheden er J/(g·grad).
For vands vedkommende er *c* = 4,19 J/(gram·grad). Der gælder altså 1 cal = 4,19 J.

Varmekapacitet for stofmængder og sammensatte systemer.
På basis af de specifikke varmekapaciteter er det muligt at beregne *varmekapaciteten* for en given stofmængde ved at multiplicere med massen. Enheden bliver da J/grad, og som symbol anvendes *C*.

Man kan endda udregne den samlede varmekapacitet *C* for et system sammensat af forskellige stoffer og mængder ved at regne ud for de enkelte og lægge sammen.
Vort system, som opvarmes i solovnen, består f.eks. af en vandmængde, en plastpose og et termometer. I princippet skulle disse ting vejes hver for sig, masserne multipliceres med de respektive varmekapaciteter og det hele lægges sammen til C for systemet.

Overvej selv størrelsen af bidrag fra posen og temometeret, når de respektive masser og varmekapaciteter tages i betragtning.

Varmeenergien
Beregning af varmeenergien sker ved hjælp af kalorimeterligningen

$$\Delta E = m \cdot 4{,}19 \; \frac{\mathrm{J}}{\mathrm{g} \cdot \mathrm{grad}} \cdot \Delta T,$$
$$\text{hvor } \Delta T = T_{\mathrm{slut}} - T_{\mathrm{begynd}}$$

m er massen af vandet. ΔT står for temperaturstigningen, som kan aflæses på y-aksen.

Effekten
Effekten P beregnes som energitilvæksten divideret med tidsrummet Δt , altså

$$P = \frac{\Delta E}{\Delta t}, \text{ hvor } \Delta t = t_{\mathrm{slut}} - t_{\mathrm{begynd}}$$

Δt er tidsrummet for energiomsætningen, som kan aflæses på x-aksen. Vi kan nu sammenligne denne opsamlede effekt med den indstrålede effekt, som solovnen faktisk modtager på solovnsåbningens areal. Den fås ved at multiplicere arealet med den på pyranometreret målte strålingsintensitet I, som er den indstrålede effekt pr. kvadratmeter.

Solarkonstanten er 1353 watt pr. kvadratmeter. Det er den effekt, der modtages på en kvadratmeter uden for Jordens atmosfære. Ved jordoverfladen skal man imidlertid ikke regne med mere end ca. 900 watt pr. kvadratmeter i klart solskin. Det skyldes, at atmosfæren absorberer en del af lysenergien.

Den indstrålede effekt
Den tekniske specifikation er individuel for hver enkelt pyranometercelle. Der kan f.eks. være oplyst, at det tilsluttede voltmeter viser 137 millivolt, hvis indstrålingen er 1000 W pr. kvadratmeter. Vi kan så bestemme den indstrålede effekt, når vi har beregnet arealet af solovnens åbning.

Et eksempel: Det nævnte pyranometer viser i hele måleperioden 108 millivolt. Strålingsintensiteten er derfor i dette tilfælde

$$I_{\mathrm{ind}} = 1000 \frac{\mathrm{W}}{\mathrm{m}^2} \cdot \frac{108}{137} = 788{,}3 \frac{\mathrm{W}}{\mathrm{m}^2}$$

Vi kan så bestemme den indstrålede effekt, når vi multiplicerer intensiteten med arealet af solovnens åbning.

$$P_{\mathrm{ind}} = A \cdot I = \pi \cdot r^2 \cdot I$$

Nyttevirkningen
Nyttevirkningen η angiver forholdet mellem den målte effekt, som vandet rent faktisk optager, og den effekt, som solovnen modtager på sit areal.

$$\boxed{\eta = \frac{P_{\mathrm{målt}}}{P_{\mathrm{ind}}}}$$

Beregninger i regneark
Man kan på basis af ovenstående formler indrette et regneark, som vil øge overskueligheden og som vil lette gentagne beregninger.

	A	B	C	D	E	F
1	Masse	Specifik varmekap.	Begynd. temperatur	Sluttemperatur	Temp.stigning	Energitilvækst
2	m i g	c i J/(g·grad)	T_{begynd} i °C	T_{slut} i °C	ΔT i °C	ΔE i J
3	(250)	4,19	(17)	(72)	=D3-C3	=A3·B3·E3
4						
5			Starttid	Sluttid	Tidsrum	Effekt
6			t i s	t i s	Δt i s	P i W
7			(30)	(510)	=D7-C7	=F3/E7
8						
9	**Pyrano-meter**	Apparatspecifikation		Aflæsning	Strålings-intensitet	
10		I i $\frac{W}{m^2}$	mV	mV	I i $\frac{W}{m^2}$	
11		1000	137	(108)	=-B11·D11/C11	
12						
13	**Solovn**	Diameter	Radius	Areal	Indstr. effekt	Nyttevirkn.
14	π	m	m	m^2	W	
15	3,14	(1,20)	=B15/2	=A15·C15^2	=E11·D15	=F7/E15

Hvis dette én gang for alle er sat op i et regneark, kan man i løbet af et øjeblik se det nye resultat med andre målinger. Tallene i parentes er forskellige fra gang til gang.

Diskussion af resultaterne

Foruden af solovnens areal, afhænger nyttevirkningen stærkt af, hvor pæn og glat, man har lavet solovnens spejlende flade. Det kan godt betale sig at være omhyggelig med runding af folien og ikke klatte den fuld af lim.

Det bemærkes, at nyttevirkningen også afhænger af den øjeblikkelige arbejdstemperatur på grund af tabet ved højere temperaturer. I figur 7 er vist, hvordan man kan beregne den tæt ved starttemperaturen, men der er selvfølgelig intet i vejen for, at man kan bestemme den ved en anden temperatur på basis af den tilsvarende tangenthældning.

Det er klart, at ovnen ikke kan blive supergod med alufolie, som i bedste fald stadig er ujævn og bulet. Den energi, som den leverer, er af relativ "lav kvalitet", men det er med vilje. I denne udgave kan den ikke tænde ild eller blænde for voldsomt.

Solovnsprincippet er imidlertid godt nok til at kunne levere energi af meget høj kvalitet, dvs store mængder i koncentreret form. Det er et spørgsmål om, hvor meget man vil ofre på den spejlende flade og hvor stor man vil gøre den. Men en parabol af astronomisk kvalitet vil nok være en for voldsom økonomisk investering.

Forslag til alternative byggemetoder

1. Parabelprofilerne kan saves ud i krydsfiner eller spånplade efter samme princip som papmodellen. I stedet for alufolie kan sektionerne dækkes med masonitplader, som limes og sømmes på profilkanterne. Pladerne belægges med en mosaik af brudstykker af rigtigt spejlglas, som limes på. Stumperne kan sikkert fås billigt som affald hos en glarmester.

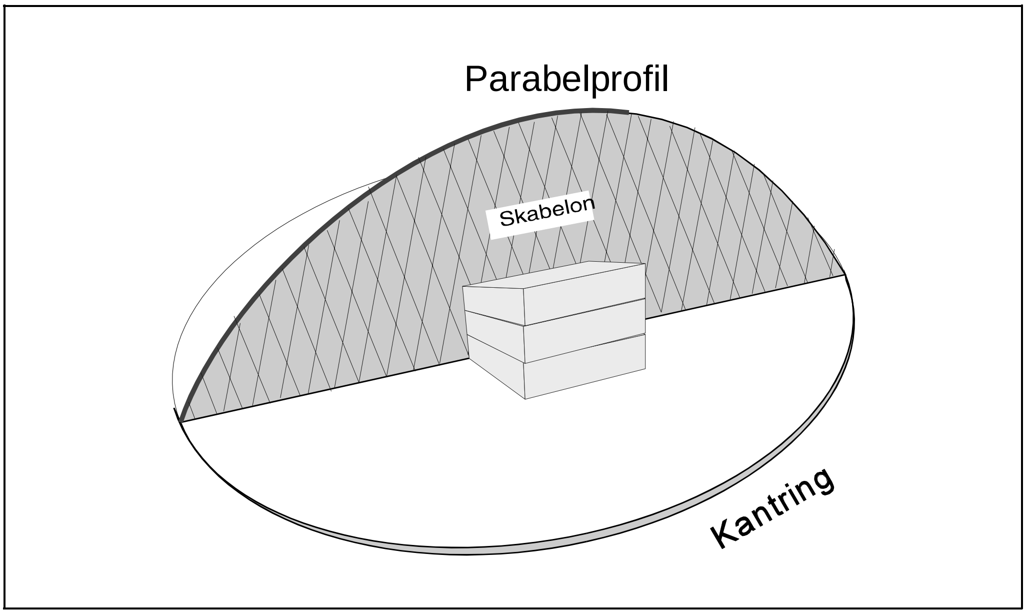
2. Solovn af hønsenet og gamle aviser.
Det bedste er at bruge ikke for brede baner af fintmasket hønsenet, kaldet kyllingenet, endvidere en stak gamle aviser, tapetklister og alufolie.

a. Man starter med at vælge et åbningsareal. Her ud fra bestemmes åbningens radius ved hjælp af arealformlen. Derefter udregnes omkredsen af den kantring, som kyllingenettet skal fæstnes på. Denne ring kan laves af kraftigt tov eller galvaniseret hegnstråd. Udmål længden plus 20 cm til overlap og snøring.

b. Derefter vælger man brændvidde *a*, og der fremstilles en en skabelon med parabelprofil af stift pap eller hård masonit. Anvend én af forannævnte metoder.

c. Når skabelonen er fremstillet, kan man i praksis let finde længden af den krumme kant (det kunne også være en matematisk udfordring at regne den ud). Dette er samtidigt længden af kyllingenetbanerne, men afmål dem ca. 15 cm længere til fastgørelse ved ombukning. Antallet af baner må afhænge af bredden, men brug mindst 6 baner. Se nedenfor.

d. Anbring parabelprofilen på kant med den krumme side opad - evt. støttet af skruetvinger eller et par stabler gamle bøger. Kantringen lægges på gulvet uden om. Tegn evt. kantcirklen med kridt på gulvet, så faconen kan holdes.



Figur 8: Sådan placeres skabelonen.

e. Første kyllingenetbane lægges over parabelprofilen, føres under kantringen i enderne og bukkes om. Vær omhyggelig med at forme netenderne, så kantringens cirkelform holdes. Kyllingenetbanernes langsgående kanter forkortes ved at man "krøller" dem, og man kan derved tilnærme en parabelform "på tværs".

f. Parabelprofilen vendes nu på tværs af første bane, og bane nr. 2 lægges på, fæstnes og formes. Yderligere to baner lægges over "på kryds". Det er vigtigt, at man omhyggeligt former netbanerne ved hjælp af bidetang og ombukning, så vi ender med en parabolsk form i en cirkelring. Afhængigt af banebredden lægges om nødvendigt flere baner på. Det er vigtigt at parabolnettet har en vis stivhed før belægningen.

g. Belægningen foregår som ved tapetsering - blot med aviser. Ugeavis-formatet er velegnet, og ugeaviser har ofte den umiddelbare fordel ikke at være heftede. Limen smøres på med en bred pensel. Eventuelt kan avisarket limes dobbelt før det limes på parabolnettet. Der er erfaring for, at det kan være en fordel først at tapetsere den konvekse bagside først og lade det tørre. Det øger stivheden før belægningen af den interessante inderside af parabolen.

   Det er vigtigt omhyggeligt at sørge for en glat overflade og undgå folder. Der kan ske ved, at man under pålimningen river folderne op, så krumningen skabes ved at papiret kommer til at overlappe sig selv i passende grad.

h. Det yderste lag indvendigt skal naturligvis være så glat og blankt som muligt. Ujævnheder må eventuelt fyldes ud med papirmasse eller slibes af før belægningen med alufolie. Derefter er man klar til afprøvningen.

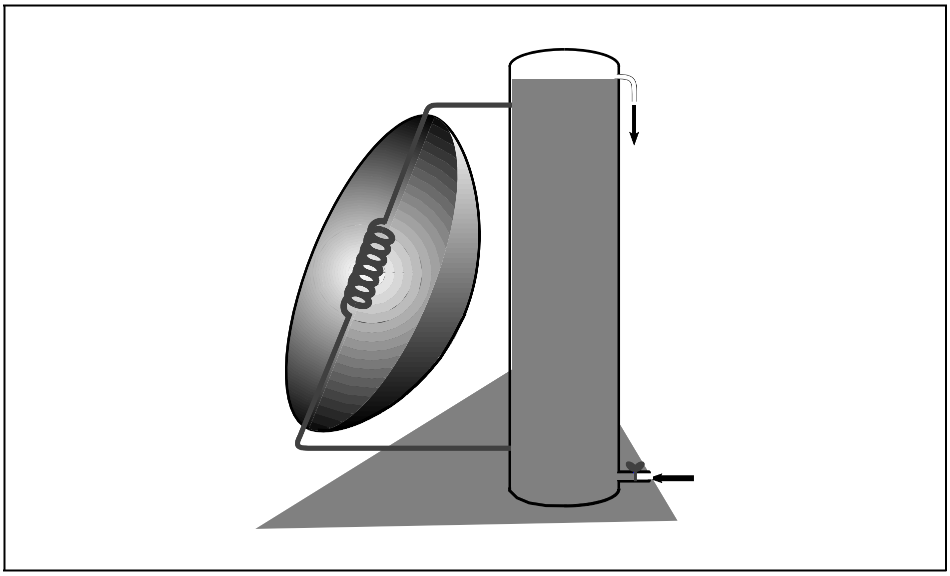
3. Som en mulig belægningsform kan vælges glasfiber i stedet for gamle aviser. Det er noget dyrere, men kyllingenettet kan også i dette tilfælde bruges som skelet - eller avismodellen kan måske ligefrem bruges som støbeform. Pålægningen af glasfiber skal foregå efter de forskrifter, som gælder for den slags med god ventilation, handsker og åndedrætsværn.

   Pudse- og polerearbejde er i dette tilfælde mere omfattende, men også her er alufolien nok den billigste som spejlende flade.

4. Der findes solovne af "tagrendemodellen", altså parabelbøjede plader, hvorfra strålerne focuseres i en "brændlinie". Her kan man så anbringe et rør med vand, og ved indpasning i et system med en svag hældning på røret vil vandet ved opvarmning kunne gøres selvcirkulerende. Se også nedenfor.

Forslag til aktiviteter

1. Opvarmning af brugsvand med solovnen.



Figur 9: Opstilling til opvarmning af vand med solovn.

I brændpunktsområdet anbringes en spiral af kobberrør, som foroven tilsluttes øverst i en vandbeholder. Spiralrøret er forneden tilsluttet den nederste del af vandbeholderen, som vist på skitsen.

Når beholder og kobberrør er fyldt med vand, er systemet selvcirkulerende. Studér de fysiske lovmæssigheder, der ligger til grund for dette.

Det varme vand fås ud som overløb, når der tilføres nyt koldt vand gennem hanen forneden.

Beholderen befinder sig et stykke over tilførslen, men under spiralrørets nederste tilslutning, forsynet med en gennemboret adskillelse for at nedsætte den ekstra strømning, der opstår under tilførslen af koldt vand. Spiralen kan på ydersiden eventuelt isoleres mod luftkøling.

Kobberrør og haner, såvel som materiale til beholderen, kan sikkert findes i byggemarkedet. Det skulle også være muligt at finde en egnet lim til at tætne beholder og tilslutninger med.

2. **Kan det lade sig gøre at grille en kylling med solovnen?**
Det anslås, at en effekt på 3 kW skulle være nok.
Hvor stor skal solovnen så være ?

Ved jordoverfladen skal man som før nævnt ikke regne med mere end ca. 900 W pr. kvadratmeter i klart solskin. Beregn det nødvendige åbningsareal og find den dertil hørende radius.

Næste spørgsmål er valg af brændvidden a.

Advarsel. Her må igen advares mod, at man laver brændvidden så stor, at nogen uforvarende kan få hoved og øjne ind i brændpunktsområdet. Etabler eventuelt en sikkerhedsafstand og bær solbriller.

Et andet spørgsmål er naturligvis den spejlende flades effektivitet og evne til at fokusere, dvs. om den er blank nok og uden ujævne buler.

Her ved vi fra målinger af nyttevirkningen, at alufolien har sine begrænsninger, men det skulle være muligt at kompensere for dette ved at øge arealet. Det er hermed overladt til læseren at finde en eksperimentel løsning.

3. Bestemmelse af smeltepunktet for f.eks. stearin.

Det skulle også - i princippet - være muligt at bestemme smeltevarmen, hvis man holder øje med, hvor lang tid det tager at smelte en bestemt masse stearin og iøvrigt ved hvor stor effekten er den dag.

4. Automatisk drejning af solovnen.

Det kunne være en sjov opgave at få solovnen til at følge med Solen mens tiden går. Det kan måske løses ved hjælp af et vækkeur af ældre dato. Søg på loppemarkedet.

Det kunne sikkert også løses med tandhjul, lodder og et pendul.

En elektronisk løsningsmulighed ved hjælp af fotosensorer og Wheatstones bro er foreslået i “Bogen om Solenergi”, side 52, (Clausen Bøger 1978).

Matematisk baggrund for parabolen

Vi vil i dette afsnit se på den matematiske baggrund for parabolens egnethed til at reflektere lyset, så den kan bruges som solovn. Skabelonerne til solovnens parabelprofiler kan udskæres efter at være plottede på én ud af to forskellige måder.

Først et lille detaljeret resumé af de to fremstillingsmetoder:

Metode I

Den ene er, at man i et koordinatsystem plotter en graf med ligningen

$$y^2 = 4 \cdot a \cdot x \text{ eller } y = \pm\sqrt{4 \cdot a \cdot x},\ a > 0 \text{ og } x > 0$$

simpelthen ved først at vælge en række *x*-værdier og udregne de tilsvarende *y*-værdier.

Det er en parabel, der "ligger ned" med åbningen i *x*-aksens retning og top/bundpunkt i (0,0). Man skal plotte både den positive og negative y-værdi for forskellige *x*-værdier.

Parabolen fremkommer ideelt set, når parablen roteres 180 grader med *x*-aksen som omdrejningsakse. I vort tilfælde har vi bygget den op af 8 sektioner.

Værdien *a* vælges konstant for den enkelte parabel, og dens størrelse bestemmer faktisk brændvidden, som er afstanden fra parabolskålens bund op til det punkt F, hvor stråler parallelle med *x*-aksen samles. Det kaldes brændpunktet og har således koordinaten (*a*,0). Man kan netop ved fastsættelse af denne værdi bestemme dimensionerne på sin solovn.

Metode II

Den anden metode er kaldt "det geometriske steds metode". Den bygger på, at parablen er en punktmængde, hvor punkterne opfylder den betingelse at ligge lige langt fra en ret linie og fra et fast punkt uden for linien.

Når man skal tegne den, er det nemmest først at tegne et koordinatsystem. Man vælger så en brændvidde *a* og afsætter et fast punkt F på *x*-aksen med koordinaten (*a*,0). Parallel med *y*-aksen tegnes nu en ret linie *l* gennem (-*a*,0). Den kaldes *ledelinien*.

Parallelt med ledelinien (og *y*-aksen) tegnes i vilkårlige afstande for positive værdier af *x* nogle hjælpelinier. En given hjælpelinies afstand til ledelinien tages som radius i en passer eller en blyant i snor. Husk at afstanden skal måles vinkelret på linierne

Med denne radius og med F som centrum tegnes nu en cirkelbue. Hvor denne cirkelbue skærer den valgte hjælpelinie, findes punkter, der tilhører parablens punktmængde. Husk at der er to på hver linie, hvis det ikke ligefrem er *y*-aksen. Den ligger jo i forvejen midt mellem ledelinien og F.

Ved på denne måde et antal gange at finde skæringspunkter, vil man hurtigt få nok til med fri hånd at kunne tegne parabelprofilen.

Bevisførelse

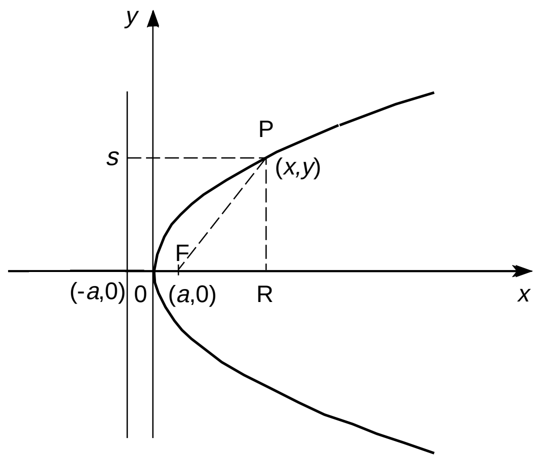
Vi vil nu bevise,

1. At punkter med lige stor afstand til en linie og et fast punkt udgør en parabel.
2. At punkter på en parabel ligger lige langt fra et fast punkt og en linie.

1. Vi vil først se på følgende påstand:

> Vilkårlige punkter, der har lige stor afstand til en linie *l* og et fast punkt F uden for linien, ligger på en parabel.

Vi tegner en figur med et vilkårligt punkt P, der har lige stor afstand til linien *l* og punktet F:



Figur 10: Punktet P ligger lige langt fra F og S. Vi viser, at P ligger på en parabel.

Husk, at afstanden fra et punkt til en linie altid er den korteste strækning, altså vinkelret ind på linien. P er valgt således, at længden af PS er lig længden af PF. Denne længde er $x+a$.

Vi kan nu opstille en ligning ved at bruge den pythagoræiske læresætning på den retvinklede trekant PRF, hvor *PF* er hypotenusen og *FR* og *RP* er kateterne.

$$FR^2 + RP^2 = FP^2$$

Vi indfører de tilsvarende størrelser og variable, som de kan læses på figuren:

$$(x-a)^2+y^2=(x+a)^2$$
$$x^2-2\cdot a\cdot x+a^2+y^2=x^2+2\cdot a\cdot x+a^2$$
$$y^2=4\cdot a\cdot x$$

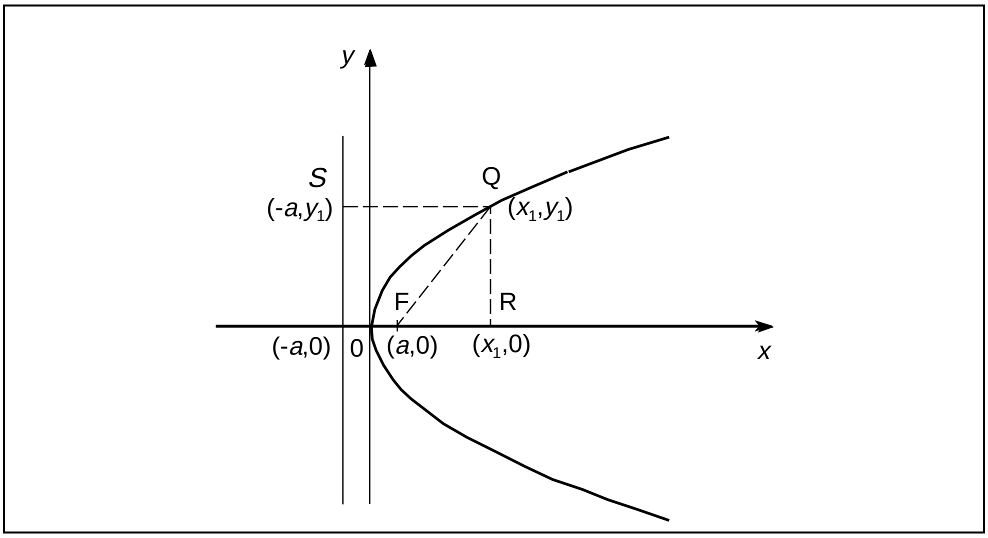
Vi kan nu se, at vi ved reduktion af udtrykket netop får et andengradspolynomium i *x* og *y*. Polynomiets graf er en parabel, og vi fik altså ved at tage udgangspunkt i metode II netop den forskrift, som vi brugte i metode I.

$4\cdot a = p$ kaldes sommetider parablens *parameter*. Brændvidden *a* er altså en fjerdedel af parameteren. Parameteren har også den betydning, at det er afstanden mellem de to *y*-værdier på parablen, der hører til $x = a$. Det er således afstanden (tværmålet) mellem skæringspunkterne, når man lægger et snit gennem brændpunktet parallelt med *y*-aksen.

Vi vil nu se, om vi også kan bevise gyldigheden af metode II ved at tage udgangspunkt i ligningen anvendt i metode I.

2. Vi skal altså omvendt vise, at

Et punkt Q, hvis talpar (x_1,y_1) tilfredsstiller $y^2 = 4ax$, har samme afstand til F og til ledelinien *l*.



Figur 11: Q ligger på en parabel. Vi vil vise, at Q ligger lige langt fra F og S.

Punktet Q´s afstand til ledelinien *l*, længden af liniestykket QS, er x_1+a. Punktet Q´s afstand til F kan ved hjælp af Pythagoras udtrykkes således:

$$QF = \sqrt{y_1^2 + (x_1 - a)^2}$$

Ved hjælp af ligningen $y^2 = 4 \cdot a \cdot x$ fås for $x = x_1$ følgende udtryk for ordinaten y_1:

$$y_1 = \pm\sqrt{4 \cdot a \cdot x_1}$$

som indsat i udtrykket for *QF* giver

$$QF = \sqrt{(\pm\sqrt{4 \cdot a \cdot x_1})^2 + (x_1 - a)^2}$$

$$QF = \sqrt{4 \cdot a \cdot x_1 + x_1^2 - 2 \cdot a \cdot x_1 + a^2} = \sqrt{x_1^2 + 2 \cdot a \cdot x_1 + a^2}$$

$$QF = \sqrt{(x_1 + a)^2} = x_1 + a$$

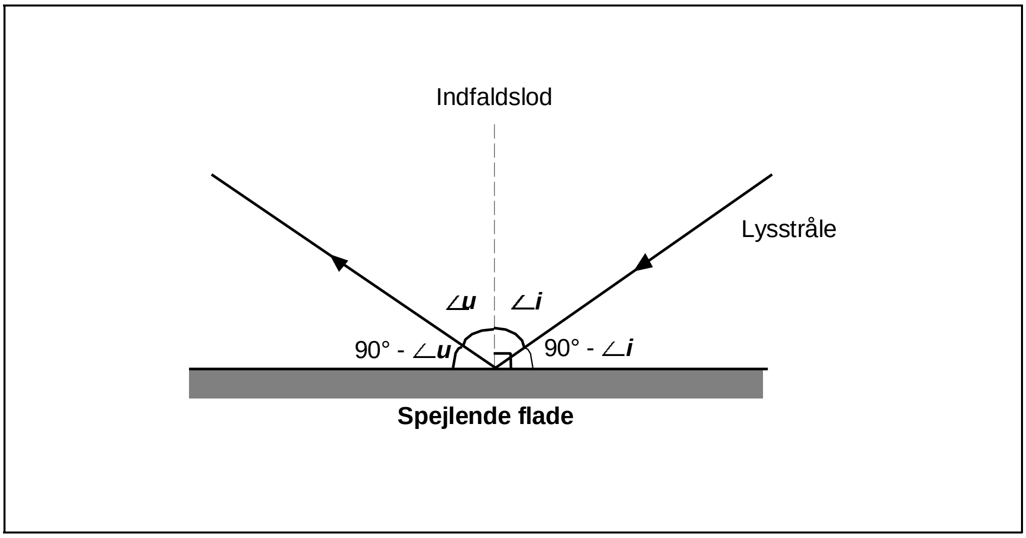
Hermed har vi vist, at *QF* = *QS*.. Vi har altså vist, at et punkt Q, som har vilkårlige koordinater (x_1,y_1) på parablen $y^2 = 4 \cdot a \cdot x$, ligger lige langt fra punktet F = (a,0) og ledelinien *l*, hvis ligning er $x = -a$.

Matematisk behandling af refleksionen

Ved refleksion i et plant spejl gælder lovmæssigheden

Udfaldsvinkel lig med indfaldsvinkel	$\angle u = \angle i$

Det kan man let overbevise sig om ved at eksperimentere med et spejl og en lysstråle.



Figur 12: Refleksionsloven.

Traditionelt mener man med disse betegnelser vinklerne mellem strålen og den tænkte linie "indfaldsloddet", som står vinkelret på den spejlende flade. Når vinklerne er lige store, er det naturligvis klart, at strålernes vinkler med den spejlende flade også er lige store. Det er komplementærvinklerne

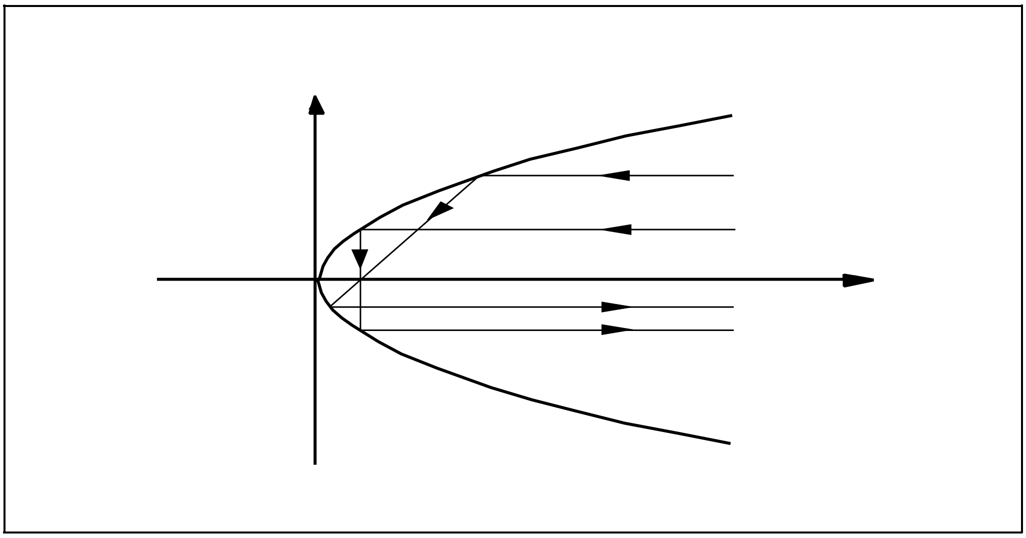
$$90° - \angle u = 90° - \angle i$$

Det vil i praksis sige, at parallelle stråler før refleksionen også er parallelle stråler efter refleksionen i et plant spejl.

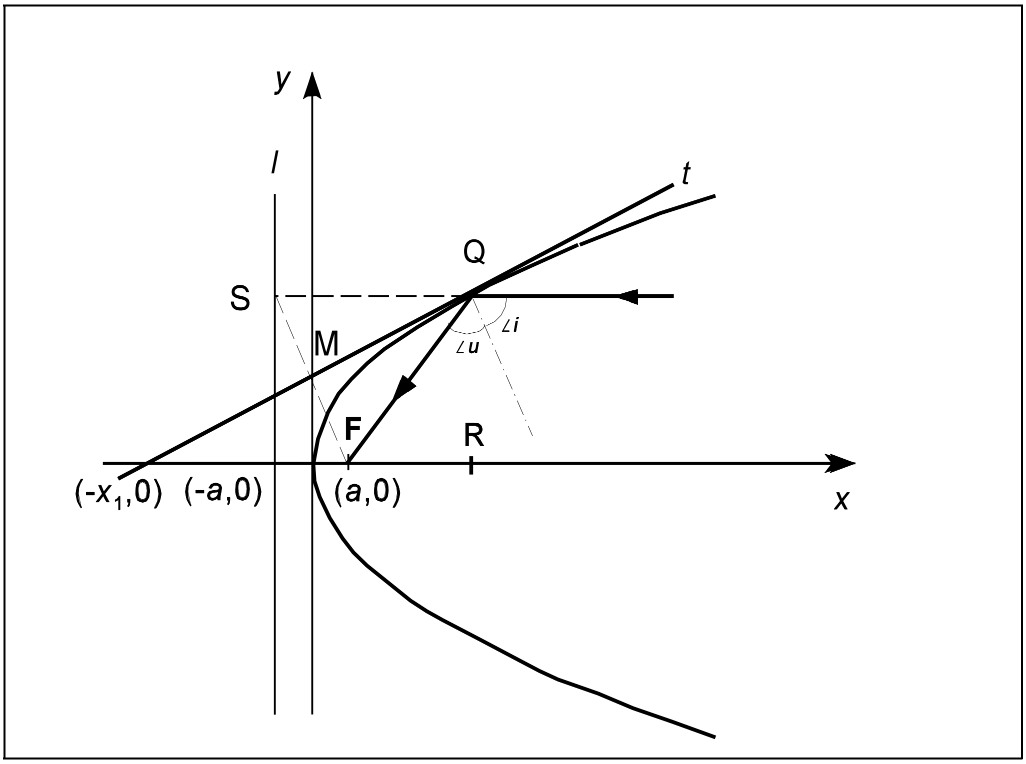
Solovnens spejlende flade derimod er parabolsk, og dette medfører, at indkommende stråler parallelt med aksen reflekteres, så de alle går gennem brændpunktet F. Hvis de ikke stoppes der, bliver de igen reflekteret i parabolen og sendt ud igen parallelt med aksen.

Lyset har en meget lille bølgelængde. For en enkelt stråle kan man derfor vælge at betragte den parabolske flade som et plant spejl med hældning som tangentplanet i refleksionspunktet. Lad os se nærmere på det:

Vi lægger et plant snit langs parabolens akse. Snitkurven bliver en parabel. Vi lægger et koordinatsystem, så y-aksen er tangent til parablens top/bundpunkt i (0,0). x-aksen peger ud ad parablens åbning. En linie l parallel med y-aksen tegnes, så den skærer x-aksen i $(-a,0)$. Den kaldes *ledelinien.*



Figur 13: Stråler, der rammer parabolen parallelt med aksen, vil alle gå igennem brændpunktet.



Figur 14: Refleksion af en stråle parallelt med aksen i et vilkårligt punkt Q på parabolfladen.

En lysstråle kommer ind parallelt med *x*-aksen og rammer parablen i et vilkårligt punkt $Q = (x_1, y_1)$. Det er nu muligt at vise, at strålen ved at overholde refleksionsloven $\angle i = \angle u$ vil blive sendt mod et bestemt punkt F med koordinaten $(a,0)$ på *x*-aksen.

Vi tegner tangenten *t* til parablen i Q = (x_1,y_1). Tangenten skærer *y*-aksen i M og *x*-aksen i T.

Det hele står og falder med, om vi kan vise, at ∠FQM = ∠SQM, idet ∠SQM er topvinkel sammen med strålens vinkel med tangenten, altså 90° - ∠*i*.. ∠FQM er jo, som det ses af figuren, lig med 90° - ∠*u*.

Dette er tilfældet, såfremt tangenten i skæringspunktet M med *y*-aksen står vinkelret på midten af FS, og at dette punkt har koordinatsættet $(0,\frac{y_1}{2})$.

I samme tilfælde er tangentens skæringspunkt med *x*-aksen T = (-x_1,0). I så fald er tangenten højde i den ligebenede trekant SQF med SQ = QF og der gælder, at

$$\angle\ \text{FQM} = \angle\ \text{SQM}$$

For at være sikker på dette er vi nødt til at finde tangentens ligning og bestemme dens skæringspunkter med akserne. Der gør vi med lidt differentialregning. Udledningen kan ses i et efterfølgende afsnit.

Vi vælger at se på funktionen $f(x) = \sqrt{x}$, hvilket svarer til, at vi i vor anvendte ligning $y = \sqrt{4 \cdot a \cdot x}$ for nemheds skyld har valgt *a* = 0,25. Ved hjælp af differentiation finder vi tangentligningen

$$y = \frac{x}{2\sqrt{x_1}} + \frac{y_1}{2},$$

hvor (x_1,y_1) er koordinaten til tangentens røringspunkt.Skæringspunkterne med akserne findes. Det ses netop at

$$x = 0 \Leftrightarrow y = \frac{y_1}{2} \text{ og}$$

$$y = 0 \Leftrightarrow 0 = \frac{x}{2\sqrt{x_1}} + \frac{\sqrt{x_1}}{2}, \text{ idet } y_1 = \sqrt{x_1}$$

Heraf fås

$$x = -\frac{\sqrt{x_1}}{2} \cdot 2 \cdot \sqrt{x_1} = -x_1$$

Vi har hermed fundet, at tangenten til parabelgrenen $y = \sqrt{x}$ skærer *x*-aksen i punktet med koordinatsættet (-x_1,0) og *y*-aksen i punktet med koordinatsættet $(0,\frac{y_1}{2})$, når (x_1 ,y_1) er tangentens røringspunkt.

Dette var netop forudsætningen for, at en indfaldende stråle parallelt med *x*-aksen reflekteres gennem et punkt F = (*a*,0).

Et taleksempel:

Vi vælger at lade tangenten røre i (x_1,y_1) = (9,3), som tilfredsstiller $y = \sqrt{x}$. Talparret indsættes i tangentligningen

$$y = \frac{x}{2\sqrt{x_1}} + \frac{y_1}{2}$$

$$y = \frac{x}{2\sqrt{9}} + \frac{3}{2} \Leftrightarrow y = \frac{1}{6}x + \frac{3}{2}$$

Heraf ses umiddelbart, at skæringen med *y*-aksen sker i $y = 3/2$.

Skæringen med *x*-aksen bestemmes

$$y = 0 \Leftrightarrow \frac{1}{6}x = -\frac{3}{2} \Leftrightarrow x = -9$$

Det ses hermed, at tangenten i (9,3), skærer *x*-aksen i (- 9,0) og *y*-aksen i (0, 3/2)

Udledning af tangentligningen

Vi kigger på den differentiable funktion $f(x) = \sqrt{x}$, hvis graf er parabelgren i 1.kvadrant. Tangenthældningen for $x=x_1$ kan udtrykkes

$$f'(x_1) = \frac{f(x) - f(x_1)}{x - x_1}$$

Vi sætter $f(x) = y$. Tangentens ligning kan herefter udtrykkes

$$y = f'(x_1)(x - x_1) + f(x_1)$$

Idet $f'(x_1) = \frac{1}{2\sqrt{x_1}}$, fås

$$y=\frac{1}{2\sqrt{x_1}}(x-x_1)+\sqrt{x_1}$$

$$y=\frac{x}{2\sqrt{x_1}}-\frac{x_1}{2\sqrt{x_1}}+\sqrt{x_1}$$

$$y=\frac{x}{2\sqrt{x_1}}-\frac{\sqrt{x_1}}{2}+\sqrt{x_1}$$

$$y=\frac{x}{2\sqrt{x_1}}+\frac{\sqrt{x_1}}{2}$$

Da $\sqrt{x_1} = y_1$, får vi

$$y=\frac{1}{2\sqrt{x_1}}x+\frac{y_1}{2}$$

Dette er ligningen for en tangent til parabelgrenen med ligningen $y = \sqrt{x}$, hvor (x_1,y_1) er koordinatsættet for tangentens røringspunkt.

Som man kan se, skærer tangenten *y*-aksen i $(0,\frac{y_1}{2})$. Som vi har påvist foran, skærer den *x*-aksen i $(-x_1,0)$.

Litteraturhenvisninger og referencer

Der findes umådelig meget litteratur om solenergi. I forbindelse med udarbejdelsen af dette temahefte er især anvendt

1. "Sonnenenergie", Avi Sochaczevsky, Tree of Knowledge, Yasur, Israel.
   (Manual til legetøjseksperimentsæt).

2. "Bogen om Solenergi", Esbensen og Lawaetz, Clausen Bøger 1978.

3. "Vedvarende energi", masser af artikler, Organisationen for Vedvarende Energi.

Afsnittet om den matematiske baggrund for parabolen har hentet inspiration fra

4. "Matematik til anvendelse i Fysik og Teknik", Poul Thomsen, Gyldendal 1967.

5. "Differentialregning, Teori og redskab", S.Jensen og K.Sørensen, Chr. Ejler 1982.

Til beregninger og basis for parabelgrafer er anvendt

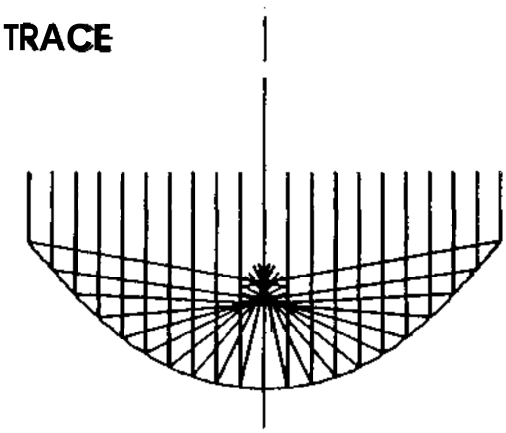
6. EDB-programmet "GrafMat", Jens Ole Bach, Matematiklærerforeningen.

Som måleudstyr er - udover termometer, ur og universalinstrument - anvendt

7. "Pyranometer" fra "Soldata", F.Bason, Linåbakken 13, 8600 Silkeborg.

A Parabolic Collector

One of the problems faced by people who want to build their own parabolic reflector is finding out and producing the correct parabolic shape. This problem was solved very simply when researchers from the University of Western Australia found that by bending a sheet of galvanised iron in a certain way the sheet would naturally take on a parabolic shape making a trough or linear focus concentrator,



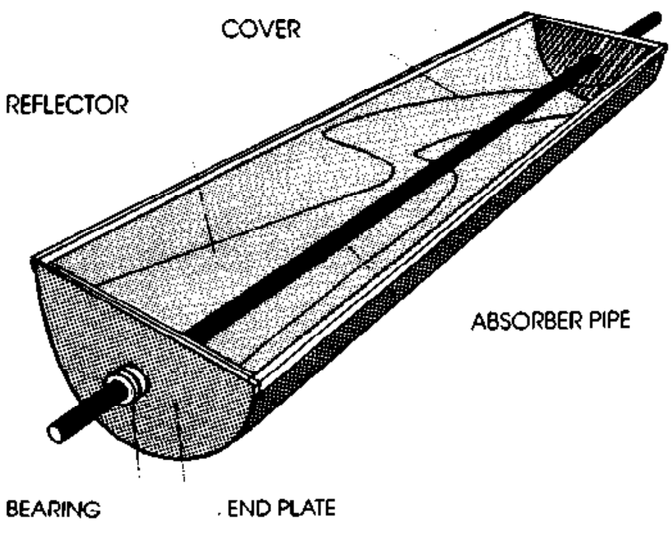
The thing about the design of these concentrators is that they are very easy for the do-it-yourselfer to build, and give you a way of producing quite high temperatures (up to 100°C).

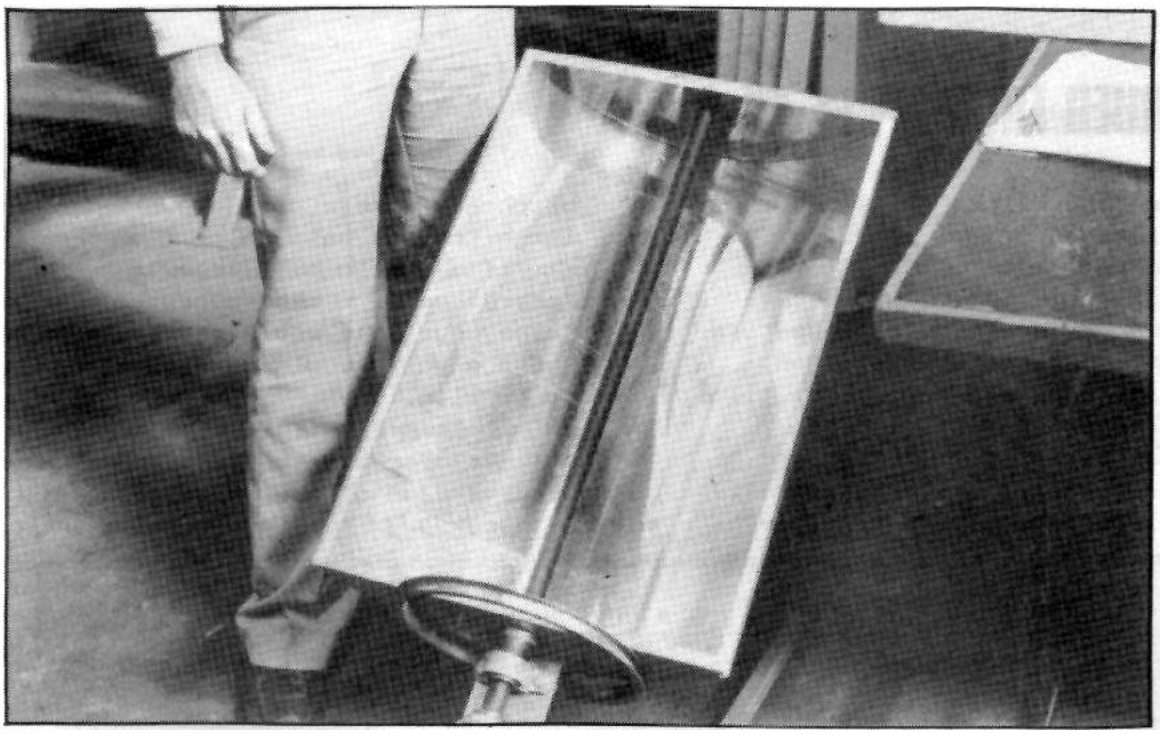
The major component of one of these collectors is a sheet of polished anodised aluminium or galvanized iron sheeting with aluminised polyester or aluminised acrylic laminated or glued to the sheet to give the reflective surface. The only other major component is a sheet of perspex (acrylic), with the edges of the sheet bent over to just past a right angle. The collector is then put together simply by bending the metal sheet and clipping the edges in under the corners of the perspex. This allows the sheet to form and maintain the natural parabolic shape.

Galvanised iron sheeting is cut to fit the open ends with a hole drilled in each of these ends for the bearing. Blackened steel or copper water pipe is passed through the length of the collector and the bearings fixed at either end. All joints are sealed and weather-proofed and you have a completed concentrator.

You now have a collector which will pivot around the central pipe. If you want to use the pipe to aim the collector at the sun then you fix the pipe directly to the ends of the concentrator. Don't forget to insulate the pipe so it does not come in contact with the metal at the collector ends.

If you find it difficult getting polished aluminium sheet or fixing a reflective film to your galvanised iron sheet, you could try lining it with mirror glass. You can buy sheets of roughly 1" square mirrorsfrom glass shops. These mirrors need to be removed from the backing material and then washed. This is because the backing material is water soluble and if you attach the mirror with this material





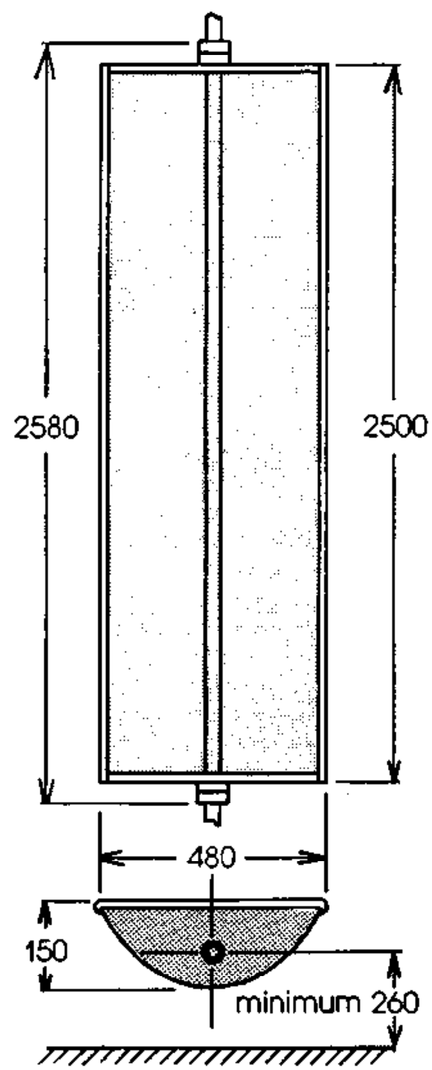
intact a bit of moisture will cause your mirrors to moult. Fix the washed mirrors with contact cement. If you are going to use a reflective film, the best way would probably be to use "Mylar" film fixed in place with a spray adhesive.

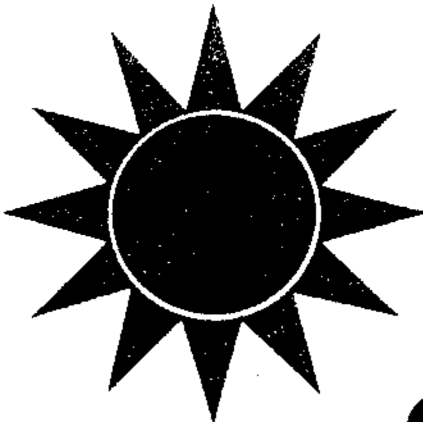
If you built a number of these collectors you can make them track the sun by fixing one corner of all the collectors to a common metal rod or strap. This is fixed to a tracking mechanism. As a result all the collectors track simultaneously and simply.

In Western Australia, these collectors have been used in a number of industrial applications. These include for an air conditioning plant and for heating propagating beds in a large nursery. They could also be used in food and beverage manufacture, mineral processing, textile manufacturing and laundering, chemical manufacturing and the accommodation industry.

For the do-it-yourselfer, the uses for these collectors are limited only by your imagination.

Harry Michaels.





Hot Dog Cooker

The hot dog cooker is a project that is not difficult for anyone to build. It can be used to produce very good results, providing you have bright sunny weather. Bear in mind that any concentrating collector of this type will not work effectively with diffuse sunlight.

Three hot dogs or sausages can be cooked in about 3 or 4 minutes under ideal conditions. When weather conditions are less than ideal, wrapping the hot dogs with blackened foil or smoking them will cook them faster. Shish kebab or pieces of chicken can also be cooked. The dark color of the beef helps light absorption, and barbecue sauce on chicken will produce a mouth-watering treat!

This is a great project for a child-parent team to construct and helps quite dramatically to illustrate the real potential of sun power.

To draw a parabola

1 piece of rigid cardboard from a large appliance carton

3 foot length of 1-by-6-inch softwood

To construct the cooker

1 4-by-8-foot sheet of ¾-inch plywood

1 13⅝-by-51¼-inch piece of ⅛-inch hardboard

5 1-foot-square mirror tiles

1 small tube of clear silicone sealant

3 1½-inch tight-pinned butt hinges with screws

½ pound of 1¼-inch ring nails

waterproof glue

paint

glass cutter

Parabolic Reflectors

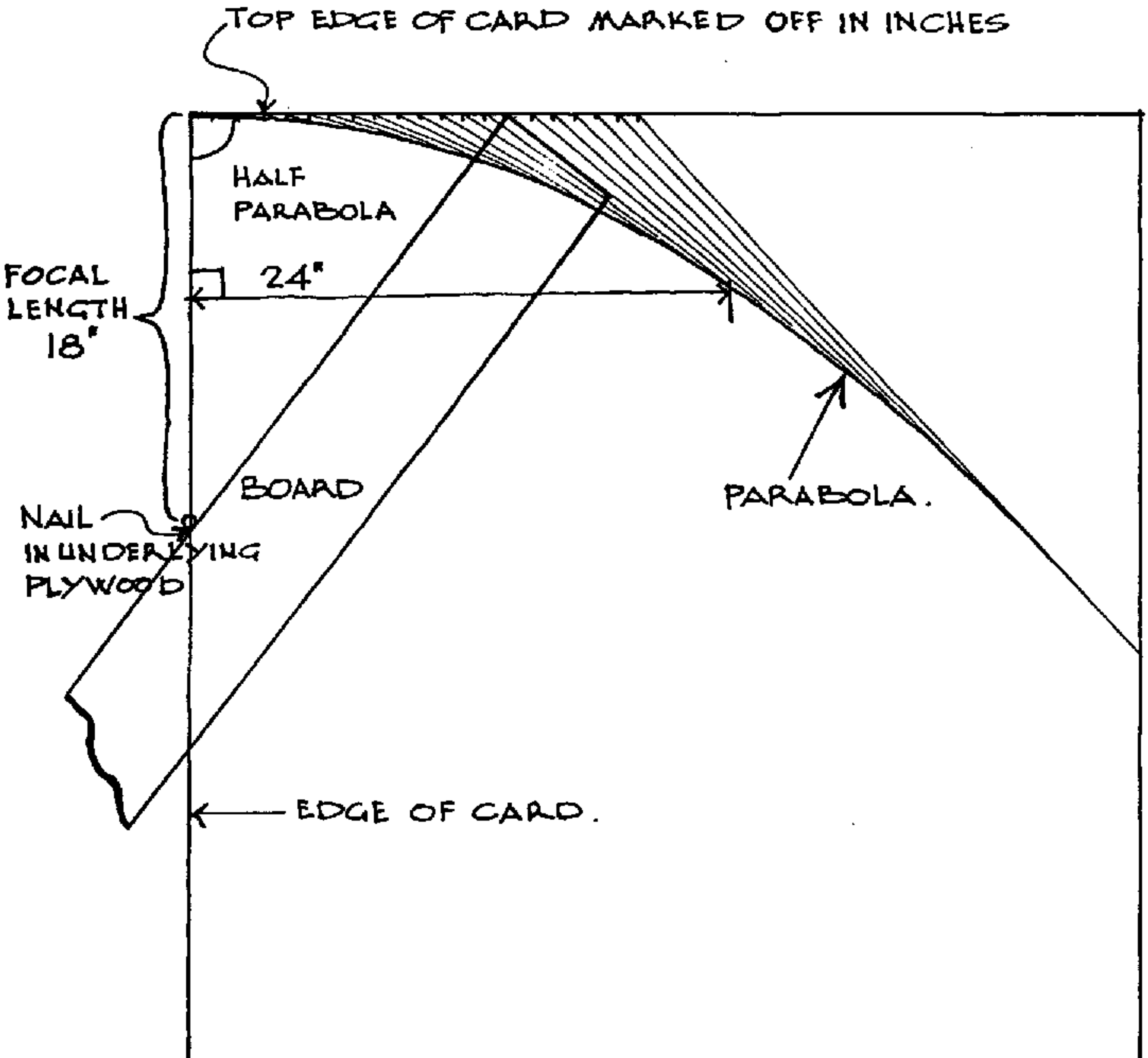
The reflecting surface of concentrating-type collectors such as this hot dog cooker is normally parabolic in shape. This shape produces a sharp focus of 1 inch or so.

Parabolic shapes are quite easily drawn. The specific method described can be adapted for any parabola you may wish to draw. Two things have to be decided: (a) how far away from the reflecting surface you wish the food to be placed, i.e. the focal point (in this case 18 inches), and (b) how long you want your parabola to be (in this case 4 feet).

Drawing a Parabola

1. Cut a sheet of rigid cardboard to produce a rectangle 30 by 30 inches (each corner must be absolutely square).
2. Using thumbtacks, firmly attach the card to an underlying sheet of plywood that is larger than the piece of cardboard.
3. Make a mark on one edge of the cardboard 18 inches from one corner. Also mark off one side of the cardboard in inches (see illustration).
4. Hammer a thin nail into the plywood next to the 18-inch mark on the cardboard.
5. Take a 3-foot-long board of 1-by-6-inch material that has absolutely square ends. Place this board with one long edge up against the nail.
6. Rotate the board to the right inch by inch and use a pencil to mark straight lines along the end of the wood as you rotate it. Ensure that the left-hand side of the board is kept in contact with the nail at all times and that the top left-hand corner of the end of the board is always level with the top edge of the cardboard.
7. Eventually the multiple lines drawn, when extended, will link and the resulting shape will constitute a half-parabola.
8. A 2-foot piece of the half-parabola drawn is cut out carefully and is used as an accurate guide for drawing a full parabola later.

HOW TO DRAW A PARABOLA



Cutting the Parabolic Frame

Take a sheet of ¾-inch plywood and rip two pieces 48 by 8¼ inches. Mark the middle point of the boards; i.e. 24 inches. Place the half-parabolic shape on the middle line of a board and trace the half-parabola shape. Complete the total parabola by flipping over the half-parabola and tracing the outline. Using the same method, trace out the other parabola. A jigsaw or bandsaw can then be used to cut out the parabolic shapes.

If you put both parabolic shapes side by side you can see how accurate your work was. Accurate or not, the two shapes can be clamped together and sanded so that they are identical.

Reflector Backing

Next rip a strip of hardboard ⅛ inch thick and 13⅝ inches wide. Cut the hardboard to a length of 51¼ inches. Put beads of glue on the parabolic shapes and, using plasterboard nails, carefully fix the hardboard (smooth side out) onto the curved edges of the parabolic shapes placed 12⅛ inches apart. The hard stage of the project is completed; don't give up!

Cut five plywood ribs out of ¾-inch plywood, 13⅝ inches long by 1½ inches wide. These are then glued and nailed onto the back of the hardboard to help support and strengthen it. Place one rib at either end of the parabolas and one at the middle. The remaining two should be placed at equal intervals between the ribs already attached.

Rotisserie Support

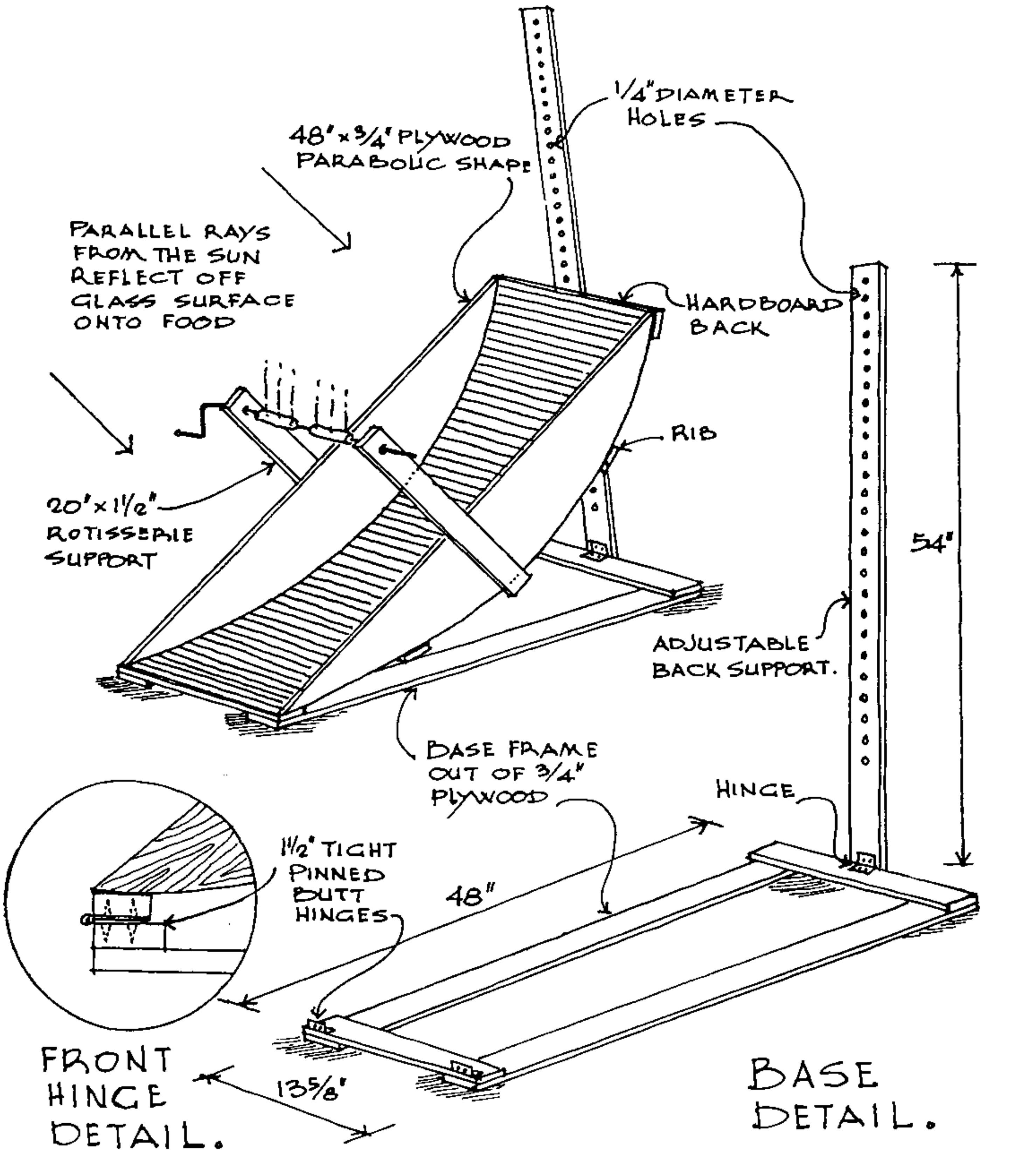
The two rotisserie supports are made from 20-by-1½-by-¾-inch plywood pieces. Drill an ⅛-inch hole in each of the 1½-inch-wide sides of each piece of plywood, 2 inches from the ends of the supports. Use a jigsaw to cut a slot from one edge of one support to one of the holes drilled. Nail and glue the rotisserie supports onto one side of each parabola, making sure they are precisely in the middle of the parabolas. Ensure that the slot faces upwards, and both the hole and slot are 18 inches from the inner surface of the hardboard.

Base and Rear Support Struts

Now for the base and rear support strut strips, which are fabricated from ¾-inch plywood. Cut to length two pieces 4 feet long, two pieces 13⅝ inches long, and one piece 4 feet 6 inches long, each piece 2 inches wide. Place the two 4-foot lengths on a bench parallel to each other and 9⅝ inches apart. Nail and glue the short pieces of plywood to join the ends of the two parallel pieces. Drill ¼-inch-diameter holes in all but the last foot of the 4-foot-6-inch rear support strut at 1-inch intervals.

Attach three 1½-inch tight-pinned butt hinges, two to the front of the stand and one to the middle of the rear of the stand, as shown in the illustrations. Place a nail in the middle of the top rib

Hot Dog Cooker



of the parabola. The parabolic shell may now be attached to the base by screwing the two hinges to the shell.

Cutting Mirrors for the Reflector

Now the fun of cutting mirrors! One-foot-square mirror tiles are ideal as a source of mirrors for the cooker and may be obtained from almost any hardware store. Prices vary greatly, so shop around.

Using a felt-tipped pen, mark 1-inch intervals along one side of each of five tiles.

Obtain a good-quality glass cutter (e.g. Diamantor). The mirrors should be placed on a newspaper and the glass cutter's cutting tip dipped in oil prior to cutting. Place one mirror on top of another, leaving a 1-inch strip showing on the lower mirror. Holding the upper mirror firmly and squarely in place, scribe a *continuous* mark with the glass cutter held *vertically*. The cut should be started about ⅛ inch from the edge of the mirror to avoid damaging the cutting edge. The newspaper will protect the cutter as it comes off the tile. Place a small nail underneath the end of the completed scribe and push down quickly and evenly on either side of the mark. Mirror number one, we hope! Proceed until you have cut at least fifty mirrors.

Mounting the Mirror Strips

Take a square and mark off a series of lines, about 2 inches apart, on the inside of the cooker. These lines will guide you in the placement of the mirrors and will help to keep them square to the edges of the cooker.

Run three beads of clear silicone down the inner hardboard shell; one bead down the middle, the other two an inch from either side. Gently press each of the one-inch strip mirrors into place, taking care to keep them square.

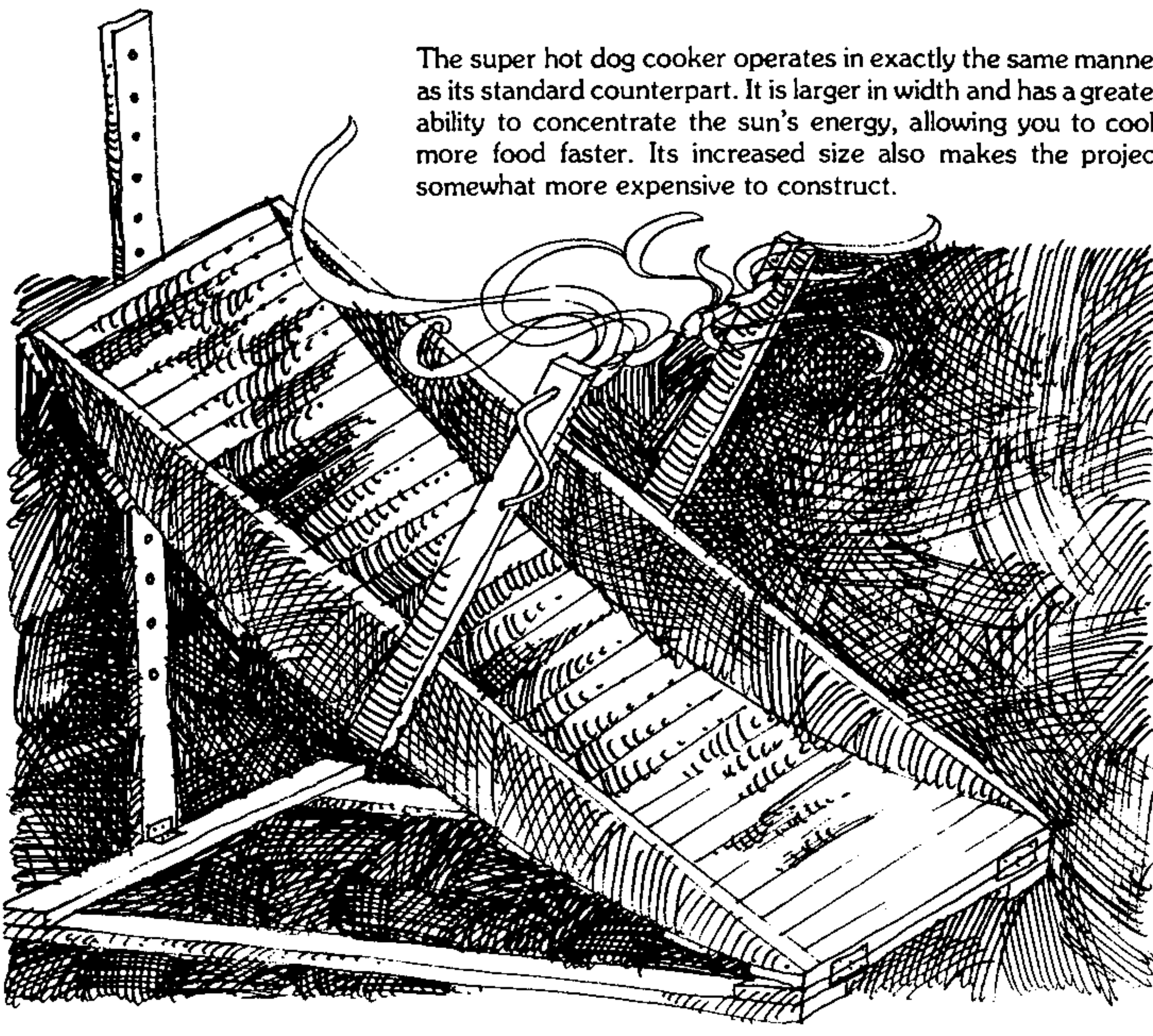
Installing the Spit

Place a thin 15-inch-long stainless steel rod or a straightened coat hanger into the hole and slot of the rotisserie supports, and *voilà!* you are ready for *le hot dog*.

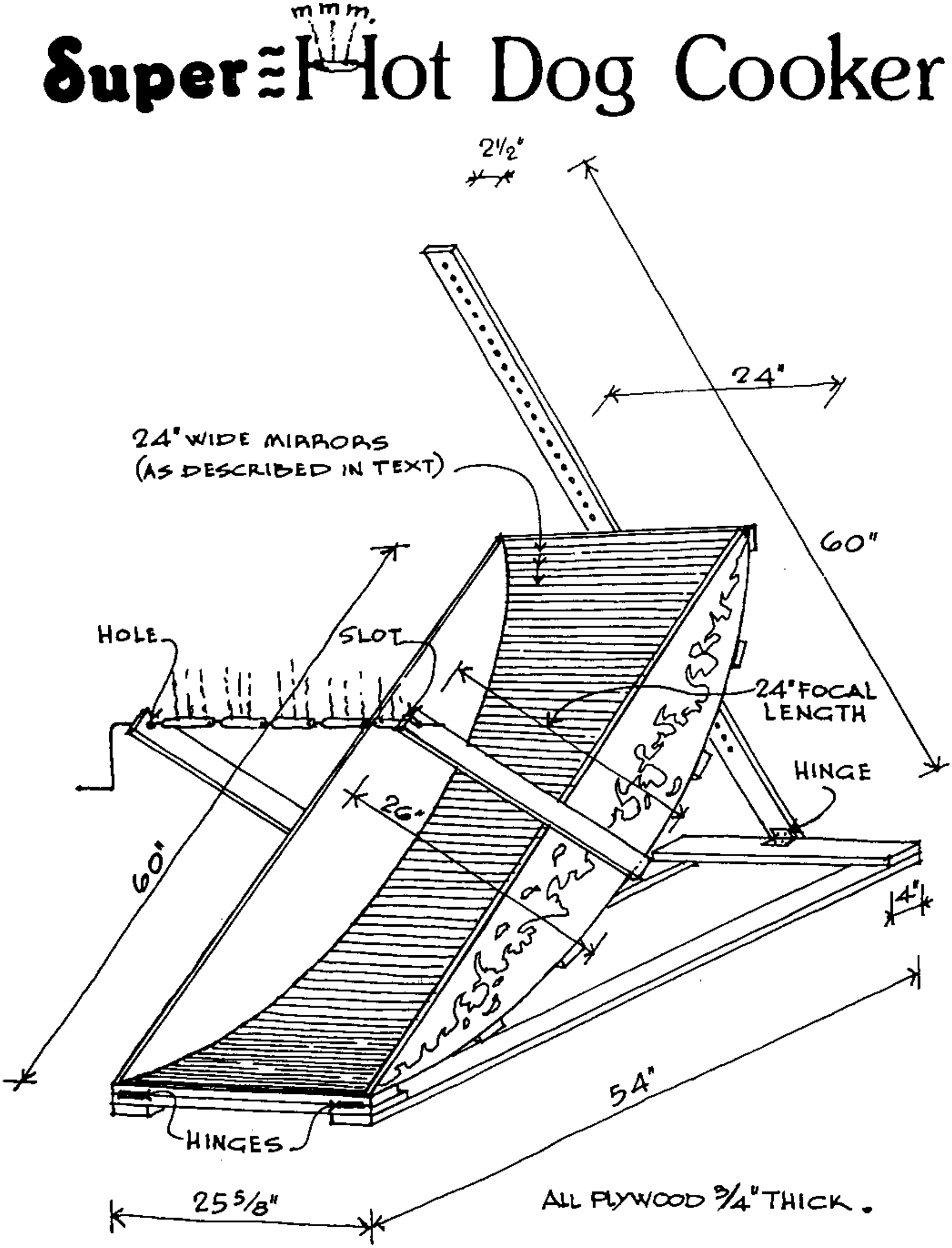
Painting or varnishing completes the project.

Super Hot Dog Cooker

The super hot dog cooker operates in exactly the same manner as its standard counterpart. It is larger in width and has a greater ability to concentrate the sun's energy, allowing you to cook more food faster. Its increased size also makes the project somewhat more expensive to construct.



Super Hot Dog Cooker



CONSTRUCTION DETAIL.

Materials Required

To build this cooker follow the instructions for the standard hot dog cooker with the exception of the modifications outlined below.

Again, ¾-inch plywood is suggested as the basic material for most of the construction. Rip two pieces of the plywood, 5 feet long and 10 inches wide.

1 4-by-8-foot sheet of ¾-inch plywood

1 25⅝-by-72-inch piece of ⅛ inch hardboard or thin plywood wallboard. This is to be trimmed to length later.

65 1-by-24-inch strip mirrors (cut from scrap mirror pieces)

3 2-inch loose-pinned butt hinges with screws

1 30-inch steel welding rod

1 large tube of clear silicone sealant

½ pound of 1¼-inch ring nails

waterproof glue

paint

glass cutter

Reflector Frame

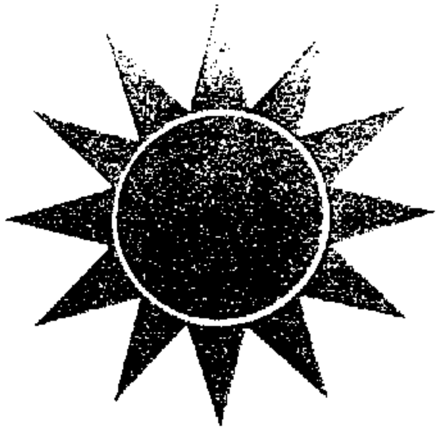
Using the method described previously, mark out a parabola, in this case having a focal point of 24 inches and total parabola length of 60 inches. Using this shape, mark out the two parabolas necessary for your construction and cut them out. Seven equally spaced ribs 25⅝ inches long and 1½ inches wide are used to support a 25⅝-inch-wide band of ⅛-inch hardboard, which is trimmed to length once nailed to the parabolic shapes.

Rotisserie Supports and Base

The rotisserie supports are 2 inches wide and 26 inches long. The back support is 3 inches wide and 5 feet in length. The base is made from two pieces of ¾-inch plywood 54 inches long by 4 inches wide. The crosspieces on the base are 25⅝ inches wide.

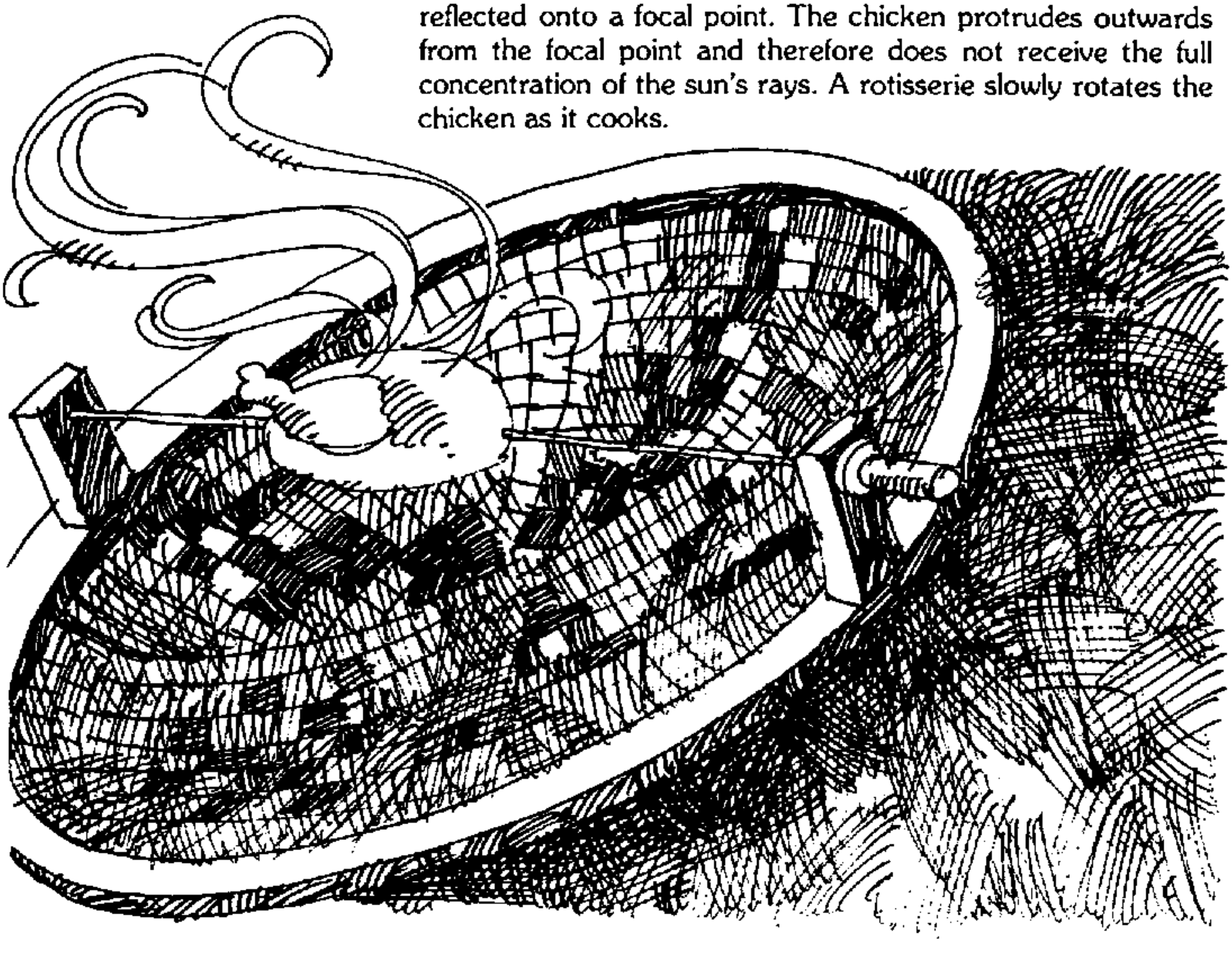
Reflective Surface

The super hot dog cooker we made had 24-by-1-inch mirrors mounted in it. The mirrors were cut from scrap pieces obtained from cooperative glass shops. Reflective self-adhesive aluminized Mylar obtained from Edmund Scientific or a graphic arts supply shop may be substituted for the mirrors; but it is expensive. Aluminized paper, used commonly as a reflective vapor barrier, can also be used but is not really as satisfactory as it tends to wrinkle and tarnish, particularly when fat splatters on it during cooking. Mirrors are preferred as they are easy to clean and are very long-lasting.



Chicken Cooker

This solar chicken cooker is capable of cooking a 3-pound chicken in about an hour and a half under ideal conditions. Light falling on the internal surface of the parabolic mirrored surface is reflected onto a focal point. The chicken protrudes outwards from the focal point and therefore does not receive the full concentration of the sun's rays. A rotisserie slowly rotates the chicken as it cooks.



The sun's rays can be focused by adjusting the position of the parabolic shape by first rotating the support stand and then moving the parabola up and down using the chain adjustment.

Materials Required

2 4-by-8-foot sheets of ½-inch plywood

1 4-by-8-foot sheet of ¾-inch plywood

1 4-by-8-foot sheet of ⅛-inch hardboard

25 pounds of plaster of paris for parabolic shell (or fiberglass resin, matt and catalyst)

25 pounds of plasterboard filler for dome mold construction

450 2-by-2-inch mirrors cut from scrap mirror pieces

15 square feet of ½-inch welded steel mesh

1 vehicle brake-drum assembly

3 feet of 2-by-4-inch softwood

1 ⅜-inch-diameter steel rod 52 inches long

1 5-foot heavy-duty metal chain

1 ½-inch-diameter 5-inch bolt

1 rotisserie motor; battery or 110v

1 caulking tube of clear silicone sealant

4 heavy-duty castors

1 1-by-1-inch galvanized plate

1 pound of 1¼-inch galvanized finishing nails

waterproof resin glue

½-inch staples

petroleum jelly

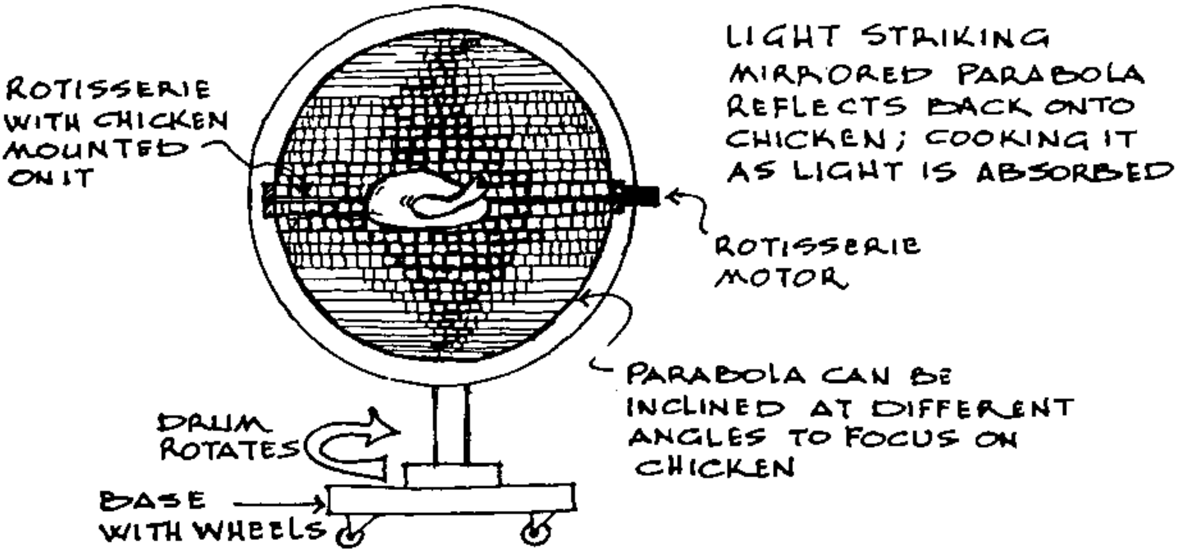
paint

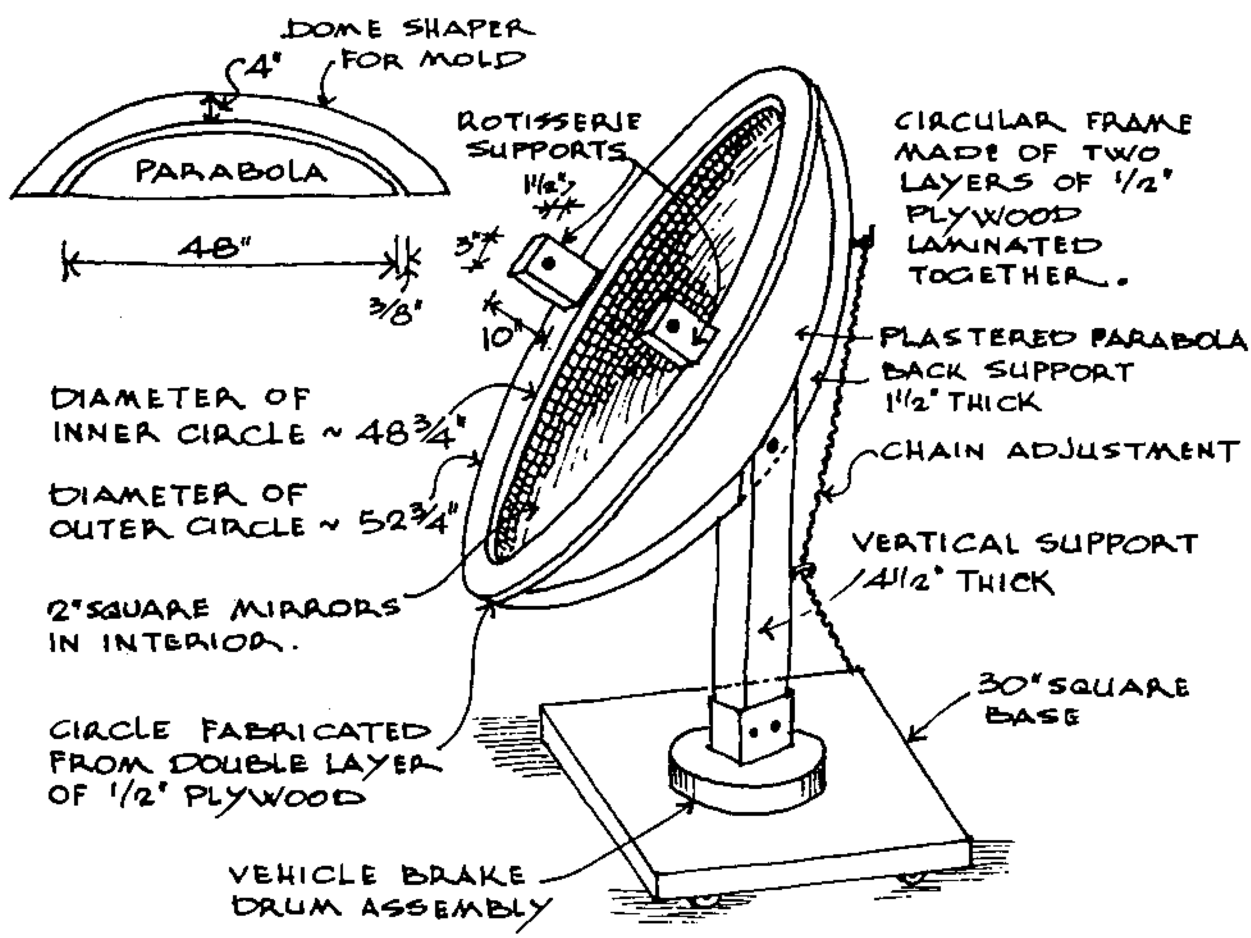
Parabolic Reflector

First a mold must be made so that a reflector shell may be accurately formed. Mark and cut out fifteen half-parabolas, of ½-inch plywood, each half-parabola being 2 feet across and having a focal length of 18 inches. (Follow the details of parabola layout outlined under the construction of the hot dog cooker.)

Draw a circle on the ground, having a diameter of 4 feet. Symmetrically arrange the fifteen half-parabolas in a circular pattern to produce a dome shape. Use individually cut pieyum.

Chicken Cooker





CONSTRUCTION DETAIL.

shaped sections of ⅛-inch hardboard to cover the shape on the floor.

Cover the dome-shaped mold with several layers of plaster; plasterboard plaster does a good job. Fabricate a piece of wood that will be used to accurately finish the mold. Using your original parabolic shape (focal point 18 inches, width 4 feet), produce this plywood shape from ¾-inch plywood. Its inner parabolic surface should be ⅜ inch away from the outer surface of the original parabola used to produce the dome (see illustration). This "dome-shaper" board is then carefully rotated over a thin layer of wet plaster to obtain an accurate mold. The dome-shaped mold is smoothed off when dry and is then painted with a hard, high-sheen enamel paint.

Front Frame

Next comes the fabrication of the front frame of the cooker. Draw two concentric circles on ½-inch plywood having radii of 24⅜ inches and 28⅜ inches. It will be impossible to cut a whole circle out of one sheet of plywood. The shape has to be made up of six segments of ½-inch plywood. The inner partial circumference of each piece of plywood is 51 inches. Three of these shapes are glued and nailed to three identical shapes underlying them. Make sure the joints on the underlying circular shapes are in between the joints of the top circle.

Back Support

Take the plywood dome-shaper and cut another identical piece of ¾-inch plywood. Laminate the two pieces together with glue and nails, and attach with screws to the circular shape that you have already made. Glue and screw 1½-by-3½-by-4-inch blocks to either side of the back support where it joins the circular shape to hold it rigidly.

Forming and Plastering the Reflector Shell

Staple ½-inch welded iron mesh all over the interior of the shape you have now completed. Check frequently to see that the shell being formed out of the wire will clear the mold when you place the shell over the mold.

When all stapling is completed, place the shell over the mold, which has first had petroleum jelly applied all over its surface. Plaster is then forced through the wire until a thickness of some ½ inch is achieved. Allow to dry thoroughly and then remove carefully. Use solvent to remove any petroleum jelly remaining on the parabolic shell. Replaster and sand to obtain a perfect finish inside and outside the shell. (Fiberglass could be used instead of plaster and would probably give a more permanent finish.)

Installing Mirrors

Cut about 450 mirrors, 2 by 2 inches, from scrap pieces obtainable from glass shops. Use clear silicone to secure these mirrors to the shell. The first line of mirrors should be placed along any straight line passing from one side of the shell, through the center, and on to the opposite side of the shell. Keep putting mirrors into the shell until its surface is totally mirrored. Clean the mirrors with a razor blade twenty-four hours after they are completely set in place. Traces of silicone can be removed by rubbing the mirrors with steel wool followed by a cloth soaked in vinegar.

Rotisserie Support Rotisserie supports are made from 3½-by-1½-by-10-inch wood. Drill ⅜-inch holes through the 3½-inch face of each of these supports. The holes should be centrally located 1 inch from the end of each support. Mount the rotisserie supports as illustrated; secure firmly to the circular frame. Screw a small galvanized plate over the outer end of one of the holes in one rotisserie support to keep the rotisserie rod from coming out of the support. The exact length of the ⅜-inch-diameter rod is measured according to the rotisserie motor you can obtain to rotate it.

Vertical Reflector Support The vertical support is made from multiple layers of ¾-inch plywood which are glued and nailed together. First cut two pieces 24 inches long and 6 inches wide and laminate these pieces together. Cut the end of the plywood, as illustrated, so that one side is 24 inches long and the other 19 inches. Four further pieces of ¾-inch plywood are cut 6 inches wide, 30 inches long on one side, 25 inches on the other. Glue and nail two of these pieces on one side of the support pieces already laminated, and two on the other side. A groove will then be formed to accommodate the back support of the mirrored parabola shell.

Drill a ½-inch hole in the back support 2 inches from the back edge of the support's midpoint. Also drill matching ½-inch holes 1 inch away from the midpoint of the top sloping edge of the support stand. A 5-inch-long ½-inch bolt will later hold the vertical support and back support together.

Base The base is made from two 30-by-30-by-¾-inch plywood pieces glued and nailed together. Four castors are screwed to the base; these should be placed close to the corners.

The brake drum assembly used to allow the stand to rotate will have to be custom-fitted to the base and stand according to the size of the unit available.

A chain is secured to the back support by means of a screw-threaded hook. Another screw-threaded hook is screwed into the support stand. The collector is now fully adjustable.

Paint or stain your chicken cooker as desired. Your cooker is ready for its first cookout. Have fun!

Parabolic Concentrating Cooker

This parabolic concentrating cooker is basically a solar furnace. It can easily be used for cooking or other experimental purposes. The mirrored parabolic surface reflects the light, bringing it to a fairly sharp focus, depending upon the size of the mirrors used and the accuracy of construction. The whole mirrored parabolic shell, mounted on a pipe which pivots on a stand, can be readily adjusted to focus the sun. A rotisserie can be mounted on the furnace if you wish to use it for cooking.

Materials Required

1 4-by-8-foot sheet of ¾-inch plywood

2 4-by-8-foot sheets of ½-inch plywood

1 4-by-8-foot sheet of ⅛-inch hardboard

450 2-by-2-inch mirrors (cut from scrap mirror pieces)

80 feet of 1-by-1-inch softwood

2 feet of 1½-by-1½-inch softwood

1 56-inch-long 1-inch-diameter steel pipe

10 pounds of plasterboard filler

4 6-inch steel brackets

1 pound of 1½-inch galvanized nails

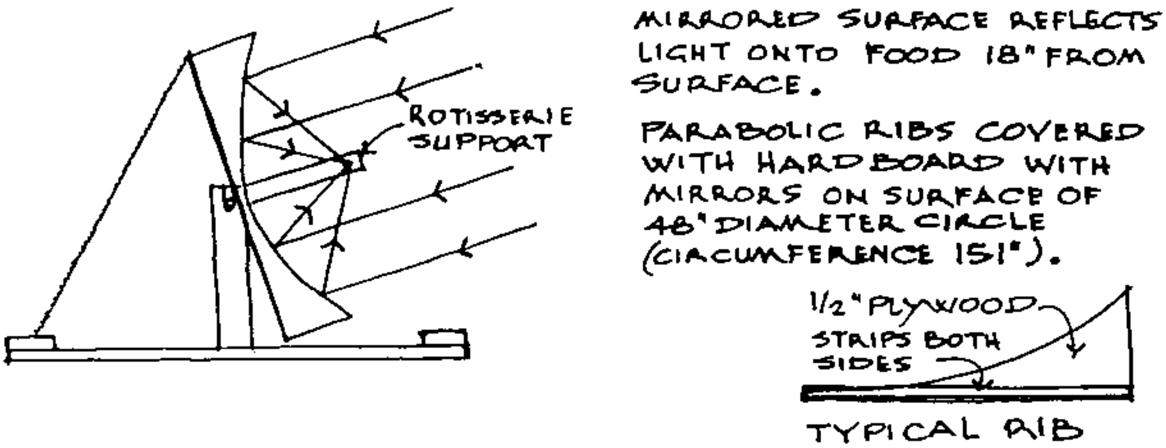
½ pound of 1¼-inch galvanized nails

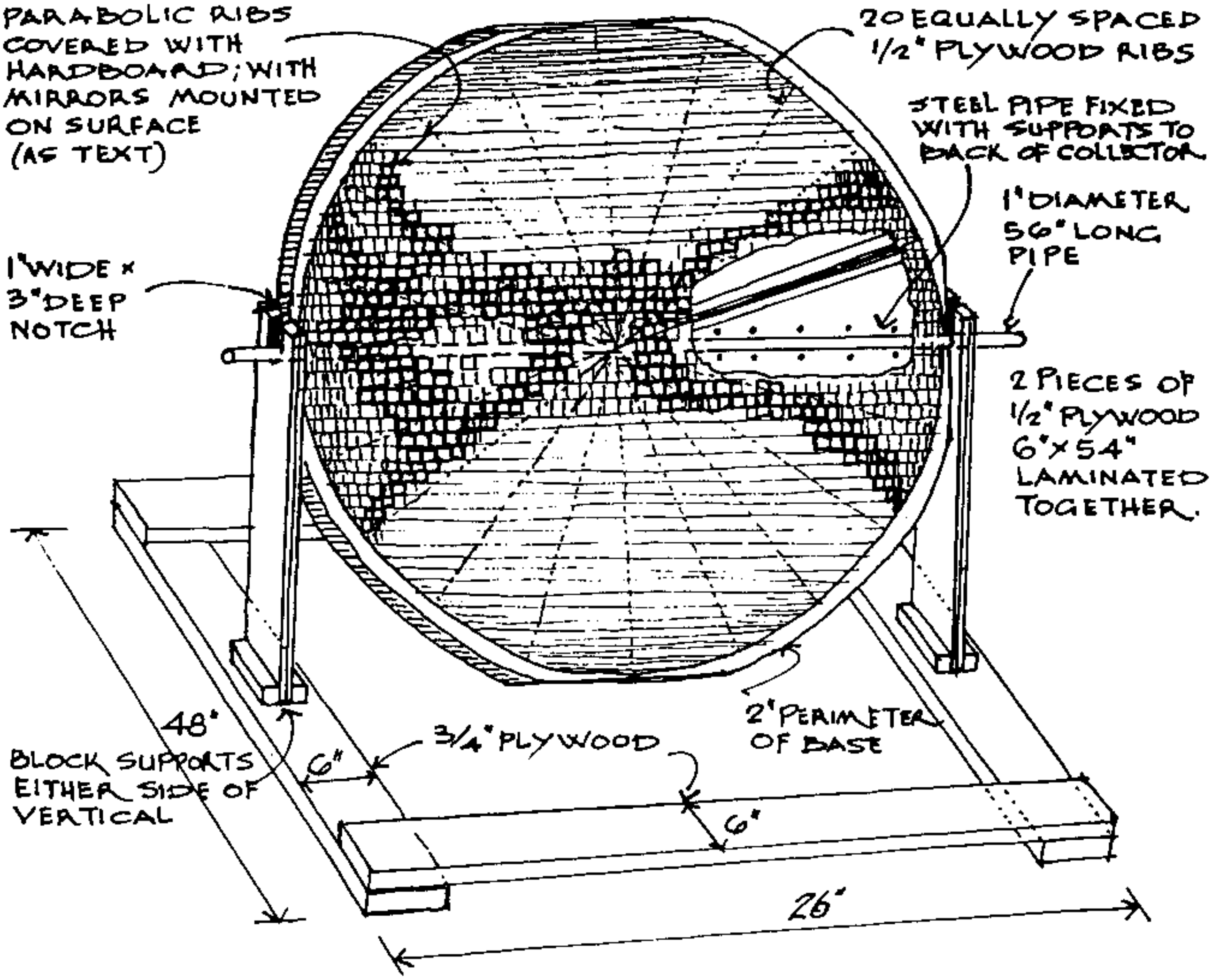
8 1-inch pipe fasteners

1 1-inch threaded hook

1 caulking tube of clear silicone sealant

Parabolic Concentrating Cooker





CONSTRUCTION DETAIL.

waterproof glue

paint

Parabolic Shell Frame

A 4-by-4-foot piece of ¾-inch plywood is cut out to form the base for the parabolic shapes upon which the mirrors will be mounted. Draw a 4-foot-diameter circle on the sheet of plywood.

Rip out 20 pieces of ½-inch plywood, 2 feet long and 10 inches wide. Using a parabolic shape with a focal point of 18 inches (following the instructions for the hot dog cooker), mark out half-parabola-shaped ribs on the 20 pieces of plywood. Glue and nail 1-by-1-inch strips onto each of the parabolic ribs along one side of the long straight edge of each rib. Then glue and nail all these ribs to the base so that each one radiates from the center, 7½ inches on center, around the circumference. Trim the narrow ends of the ribs as necessary to fit them all on the base.

Inner Shell

Hardboard, ⅛ inch thick, is used to cover over the parabolic ribs and form an inner shell. Push the hardboard down onto two ribs at a time and use a pencil to mark the shape of a section of the hardboard by running the pencil line along the outside of the top edge of the two ribs in question. Using a bandsaw or jigsaw, cut the section of hardboard ¼ inch inside the lines marked. Glue and nail the hardboard in place. Repeat the process until all the shell is covered with hardboard. Glue and nail a 10-inch-wide hardboard trim around the vertical perimeter of the cooker shell. Trim any excess plywood from the base so that 2 inches protrudes beyond the vertical trim just completed.

Installing Pivot Shaft and Finishing the Shell

Using pipe fasteners secure a 56-inch-long 1-inch-diameter steel pipe to the base of the collector. Put a thin layer of plaster over the inside of the shell and rotate a complete parabola (4 feet wide, 18 inches focal point) over the plaster surface until it is smooth; sand when dry. Using silicone, mount 450 2-by-2-inch mirrors onto the completed shell of the furnace. Follow the same procedure for mounting and cleaning the mirrors as outlined for the previous project.

If you want to mount a rotisserie, then the holes supporting the rotisserie must be arranged so that they are 18 inches above the center of the reflecting surface of the collector.

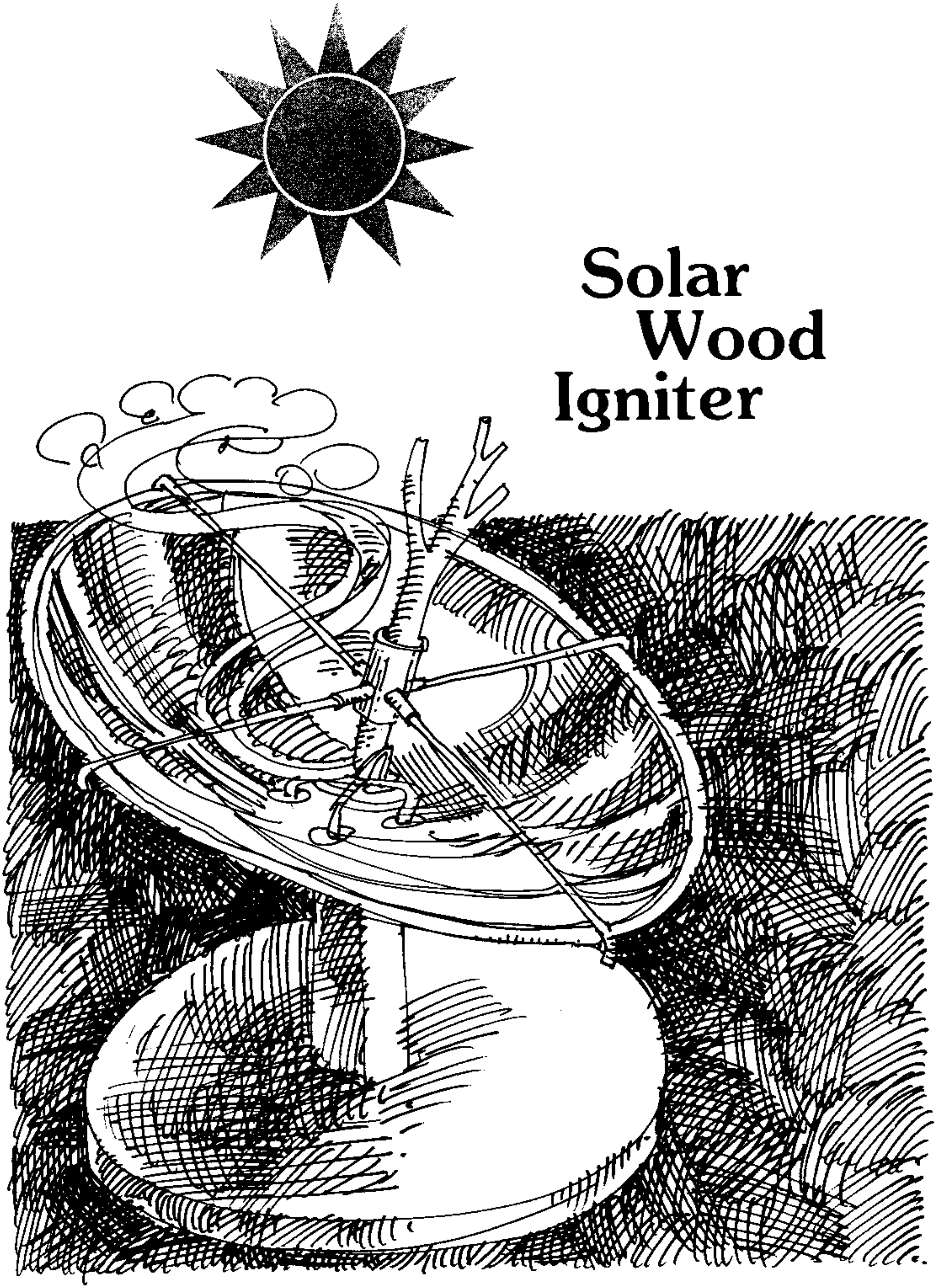
Stand

The stand is constructed from plywood. The following pieces are cut: two base side struts, ¾ by 6 by 48 inches; two base cross supports, ¾ by 6 by 55 inches; and two vertical supports, made from four pieces of ½-inch plywood, 6 inches wide and 26 inches high, having notches 1 inch wide and 3 inches deep cut into their top ends. Assemble the base, gluing and nailing the pieces together as shown in the illustration.

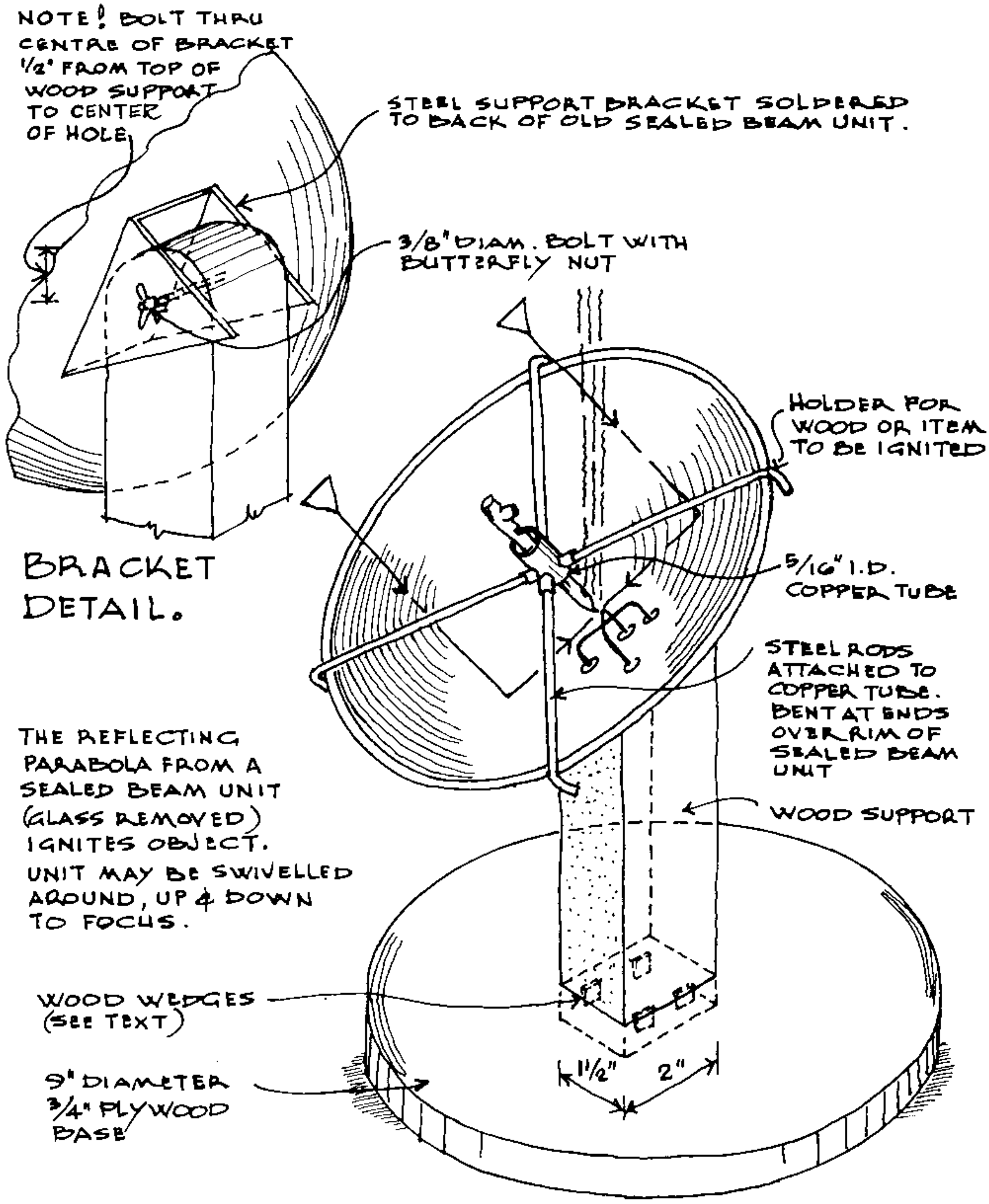
Cut four 6-by-1½-by-1½-inch block supports; glue and screw these on either side of the verticals to give them stability. Steel brackets may also be added to attain further strength and rigidity if desired. Use hooks to attach a chain to the middle of one of the base cross supports, and to the base of the collector structure. Adjustments in the inclination of the collector are then easily made by altering the length of the chain.

Paint the whole cooker-furnace according to your preference and you will then be ready for cooking or experimenting. Try putting a piece of dark colored wood at the focal point; surprising results!

Solar Wood Igniter



Solar Wood Igniter



CONSTRUCTION DETAIL.

The solar wood igniter provides an interesting conversation piece, even if it is not totally practical. It is remarkably effective, capable of lighting a piece of wood within seconds.

The sealed-beam headlamp unit, minus its glass lens, is pointed towards the sun and is swiveled up and down to focus on the ends of the filament supports. The object to be ignited is lowered through a special holder to the focal point and rapid ignition follows.

Materials Required

1 used sealed-beam unit (headlamp)

1 ¾-by-9-by-9-inch piece of plywood for base

1 8-by-2-by-1½-inch piece of softwood

18 inches of ⅛-inch-diameter steel rod

1 1-inch length of 5/16-inch I.D. copper tubing

1 U-shaped steel support 2 by 2 by 2 inches (approximately; see illustration)

1 ⅜-inch-diameter 3-inch bolt with washer and butterfly nut

1 small tube glue

paint

Reflector

When you select a sealed-beam unit, make sure that the rear aluminized finish is not unduly tarnished. Wearing safety glasses, very carefully remove the lens, using a cutting blade to grind off the glass. I would emphasize that extreme care is required; this is not a procedure that should be carried out by an inexperienced person without supervision.

Once the glass has been removed as cleanly as possible, unsolder the connectors on the back of the reflector unit. This may be conveniently achieved by playing a propane torch flame on the solder. Be careful not to heat any glass, as it cracks very easily.

Reflector Support Bracket

Weld or braze together the reflector support bracket as shown in the illustration. Drill ⅜-inch holes on either side of the metal support. Drill further holes in the support to match the soldered joints on the back of the reflector unit. Turn the unit upside down and solder the steel support in place.

Base

Using a jigsaw, cut out a 9-inch-diameter base from ¾-inch plywood. Cut a 2-by-1½-inch hole in the center of the base. Cut a piece of wood 8 by 2 by 1½ inches, rounding off the top end. Drill a ⅜-inch hole close to the top end of the support. Put the wood support inside the metal support bracket to obtain the exact location of this hole. Place this wood support vertically on the middle of the base and scribe around it. Chisel out a hole in the base to accommodate the support.

Before fixing the wood support in place, cut two ¾-inch-deep grooves into the bottom of the support. Glue the support in place and force glued wood wedges into the grooves to produce a tight permanent fix. Trim the ends of the wedges.

Finishing the Unit Sand and paint the whole structure according to your own taste. Push the 2¼-by-⅜-inch bolt into place through the holes in the wood and metal supports; tighten the butterfly nut.

Wood Holder A wood holder may be made to support the material to be ignited. It will have to be custom-made from copper tubing and steel rods, according to the actual size of your sealed-beam reflector. The illustration shows a wood holder fabricated for a reflector having an external diameter of 7 inches.

When your completed lighter is placed on the picnic table at your next barbecue it is guaranteed to be an attention-getter.

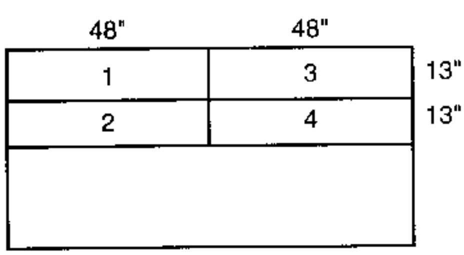
The Yellow Cradle

Jeff Gilbert

The Yellow Cradle is a simple to use solar cooking design that can be made from common material such as plywood, cardboard, aluminum foil and glass.

Steps for Construction

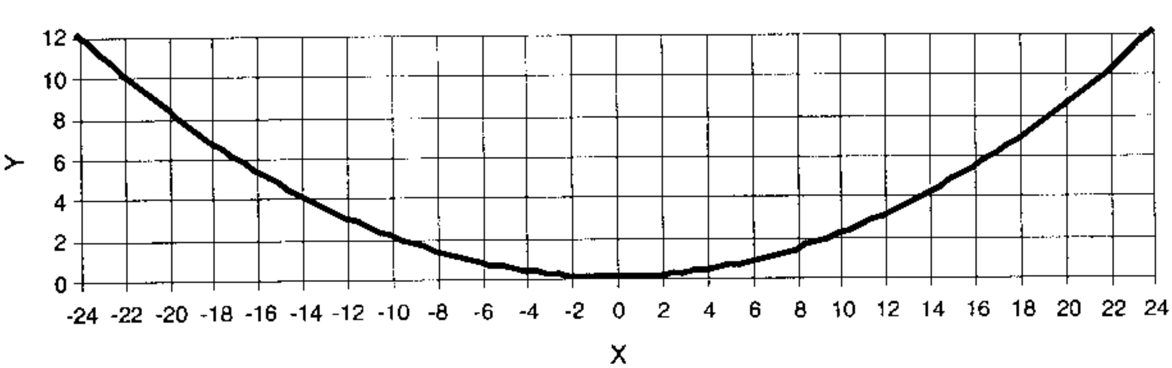
1. Mark a 4 foot x 8 foot piece of 1/4 inch plywood into four 13 inch x 48 inch sections as shown in the diagram below. Cut out these sections.



2. Draw a line across the plywood spaced every 2 inches The 24 inch line (halfway between the ends) will become the center point of the parabola (x = 0).

Example: The coordinates (±2, .08) simply means that 2 inches either side of the center point, you should measure .08 inches from one edge of the plywood and make a mark. Don't worry if you never could grasp plotting graphs in school; this is not complex.

Below:Template for the Parabolic "Yellow Crade"



The parabola used for this cooker has the formula

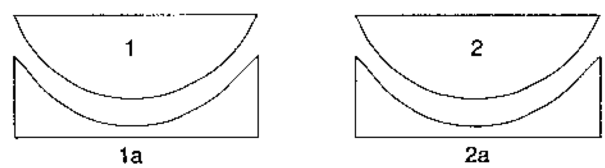
$$X^2 = 4Fy$$

where F is the height of the focus, (i.e., where the light will focus).

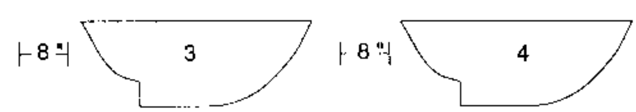
For this design, the F is at = 12 inches

3. Draw a line joining the marks which form the outline for the parabola and cut along this line. Use the first piece as a template for marking the same cut on another of the 13 inch x 48 inch plywood pieces. Cut carefully and accurately. Note: Do not cut out the 8 inch wide pieces yet (see measurements diagram on page 37 to see what is meant by the 8 inch wide piece).

Template



4. Using your template parabola, trace and cut the other two pieces of plywood according to the measurements diagram, including the 8 inch pieces. The parabola template should be positioned 1 inch down from the top edge before you begin tracing.

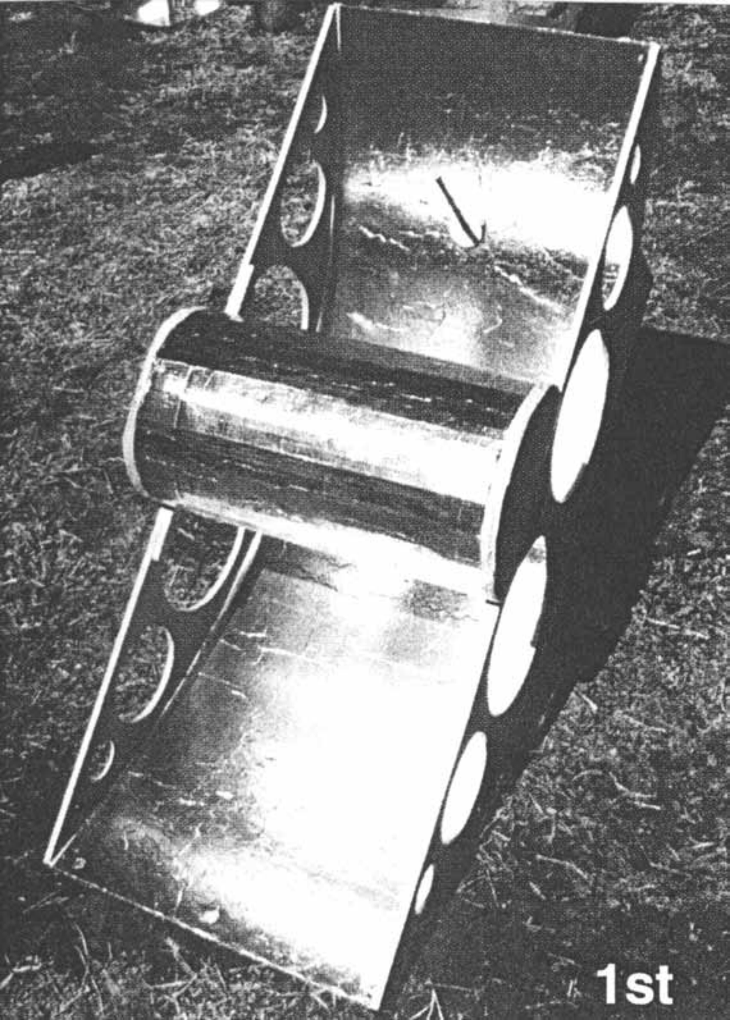


5. Glue piece 1a to piece 3 with the bottom edges flush to each other and the parabolas facing up (see main diagram). Repeat this step with piece 2a and piece 4. Note: Use clamps or weights to hold pieces firmly together while glue is drying.

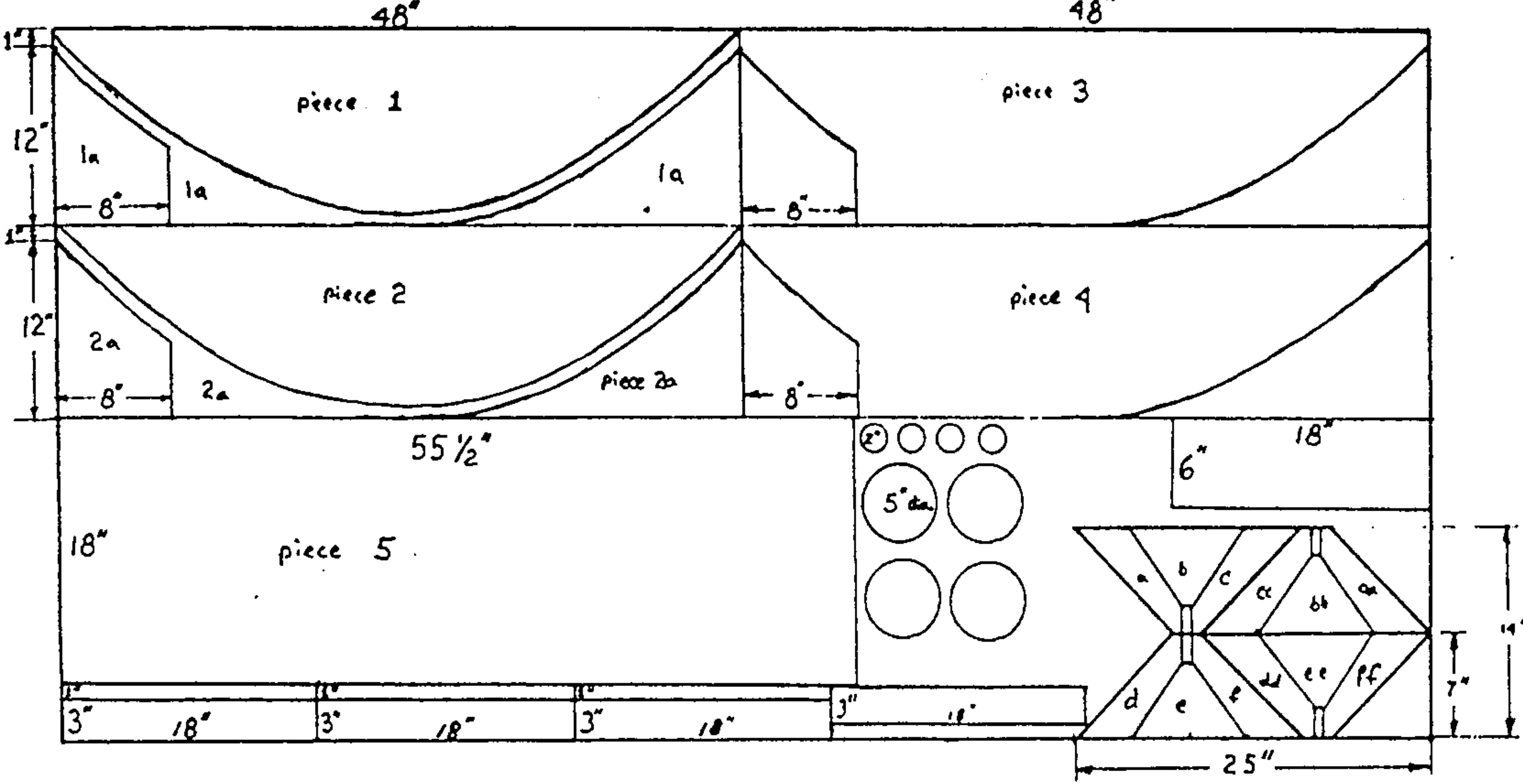
6. Mark and cut out piece 5 from the main stock of plywood. This piece will be used to form the curved surface of the cooker.

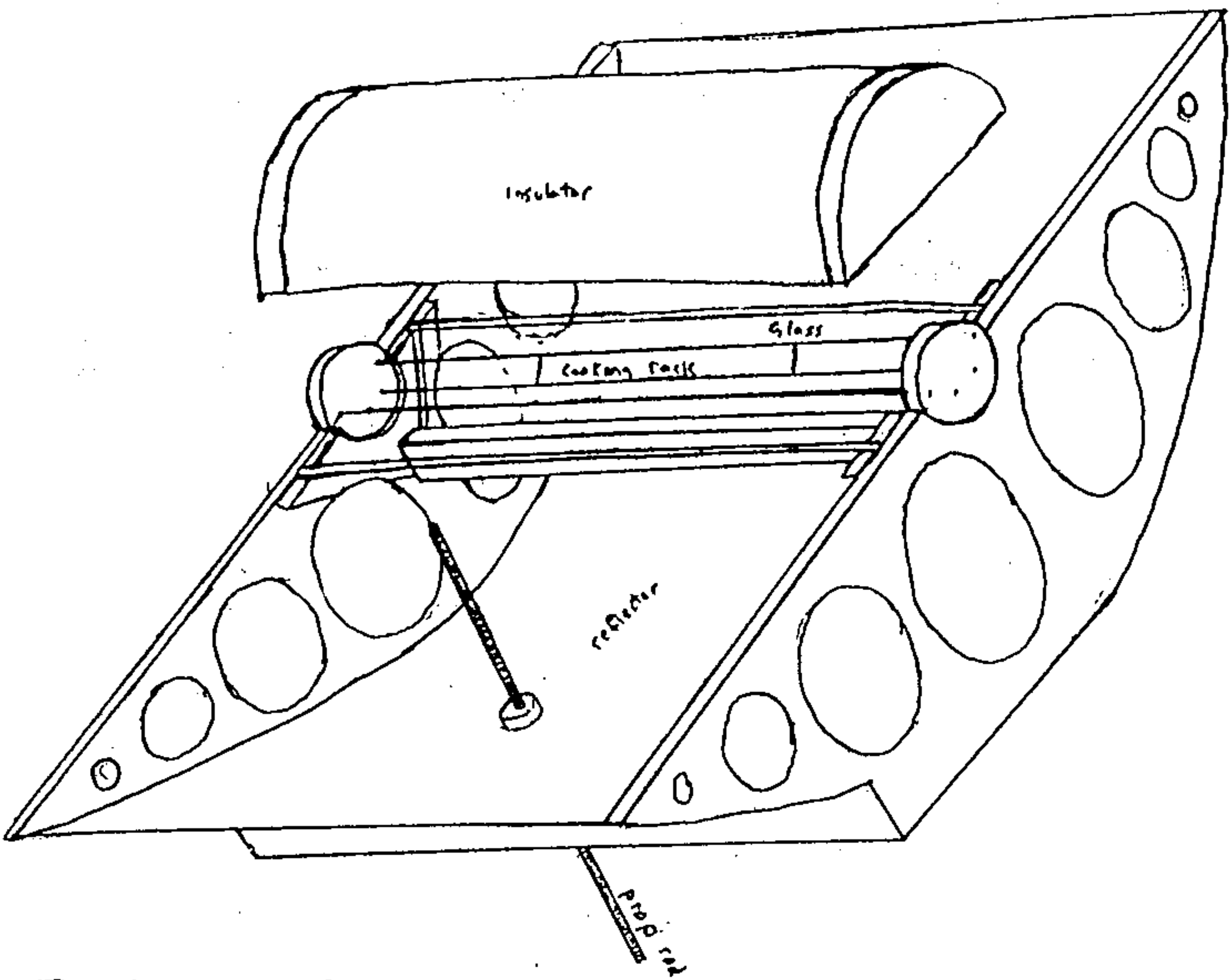
7. Glue pieces 1a – 3, 2a – 4 and 5 together as shown in the main diagram. With pieces 1a – 3 and 2a

±X inches	Y inches
0	0.00
2	0.08
4	0.33
6	0.75
8	1.33
10	2.08
12	3.00
14	4.08
16	5.33
18	6.75
20	8.33
22	10.08
24	12.00


1st

Measurements Diagram

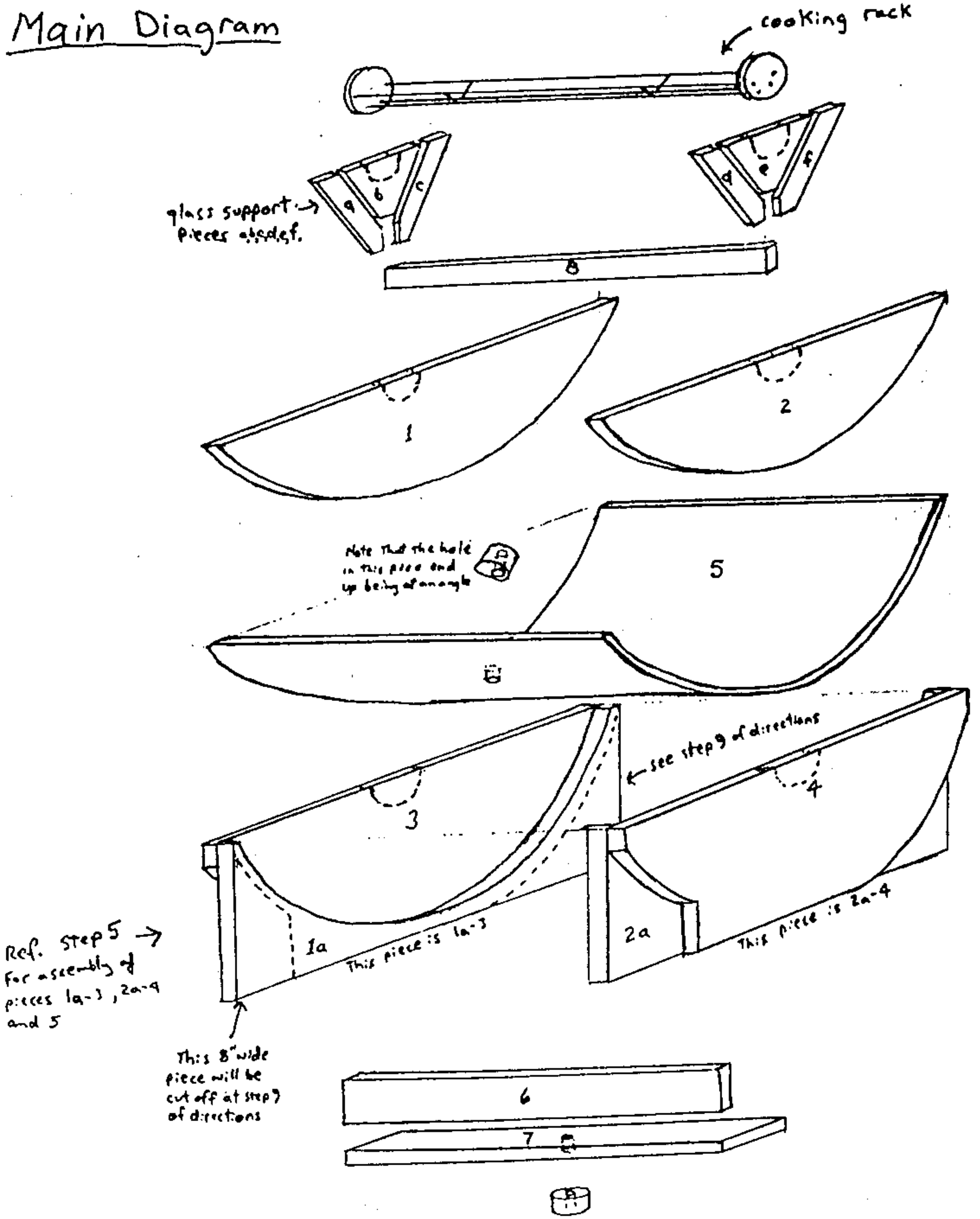




THE YELLOW CRADLE

by Jeff Gilbert
409 Christopher Ave, #22
Gaithersburg MD 20879
(301) 258-0728

Main Diagram



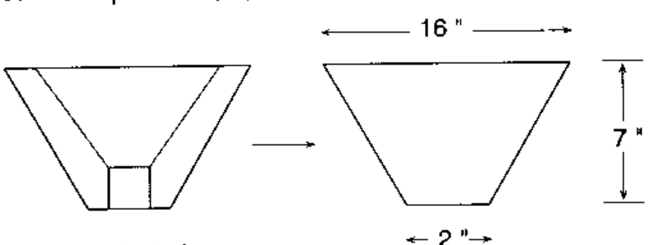
– 4 parallel and 18 inches apart, lower piece 5 between 1a – 3 and 2a – 4 so that it bends and rests on the ledges formed by 1a and 2a. Note: This step may require two or more people, however, one person can do it with some ingenuity, props and tape.

8. Glue pieces 2 and 3 in place as shown in main diagram. Be sure to push pieces 2 and 3 down firmly, sandwiching piece 5 in place.

9. After glue has dried, turn the assembly over and cut pieces 1a and 2a to follow the contour of pieces 3 and 4.

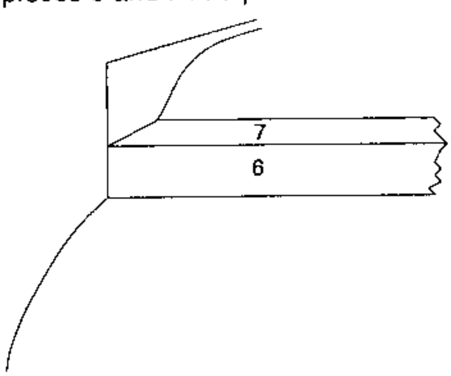
10. Glue heavy duty foil onto inner surface of reflector. Note: An alternative way to secure the foil is to paint the inner surface and apply the foil while the paint is still tacky. I recommend this way because it tends to secure the foil better.

11. Mark and cut out the rest of the pieces according to the measurement diagram. See diagram below for details on pieces a, b, c, d, e and f.

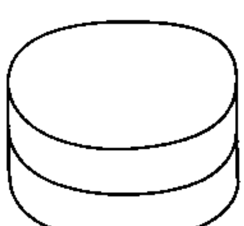


Leave whole for now

12. Glue pieces 6 and 7 into place as shown below.



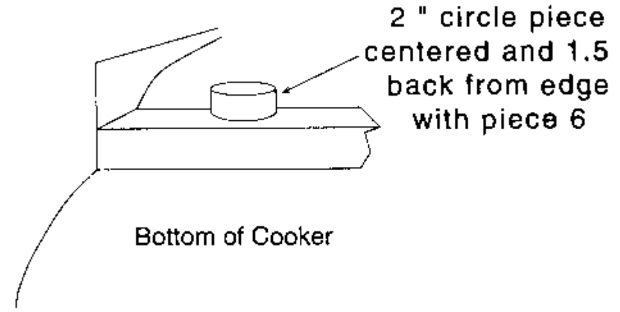
13. Glue two of the 2 inch diameter circles together to make a 2 inch circle of double thickness. Repeat this step for the other two circles.



14. Repeat step 13 for the 5 inch circles.

15. Glue three of the 3 inch x 18 inch pieces together (faces together).

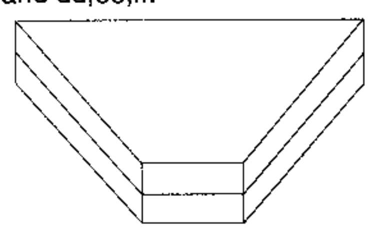
16. With reflector assembly up-side-down, glue one of the 2 inch circle pieces to piece 7 such that it is in the middle of piece 7 and centered 1.5 inches from the edge where piece 7 joins piece 6.



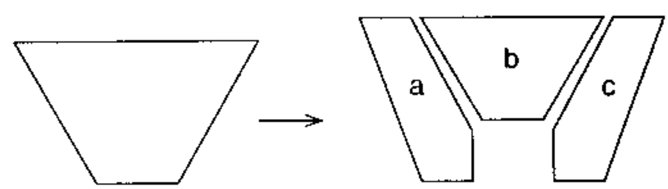
17. After glue has dried, drill a 3/8 inch hole vertically through the center of the 2 inch piece and down through the reflector surface.

18. Glue the other 2 inch circular piece over the hole that you just drilled through the reflector surface. Position the 2 inch piece high on the slope of the reflector so that when you drill through it from the other side, the bit will come through near its center. Then drill the hole all the way through.

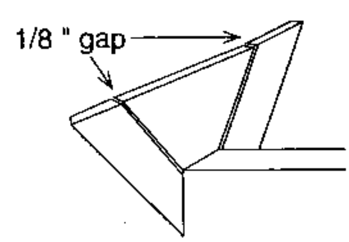
19. Glue pieces a,b,c and aa,bb,cc together. Repeat this for d,e,f and dd,ee,ff.



20. After the glue dries, make the cuts separating pieces a, b, c, d, e and f as well as the notch that fits piece 8. See main diagram if you get confused.



21. Glue pieces 8, a, b, c, d, e and f into place leaving a 1/8 inch gap between pieces a and b, c and b, d and e, and f and e. See diagram below.

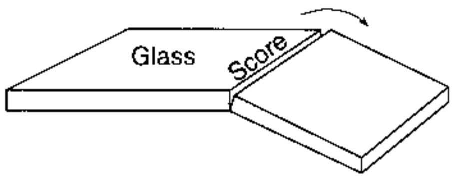


22. Drill small holes in the two 5 inch circles and insert metal rods (coat hanger wire or whatever is available) to form the cooking rack.

23. Fashion an insulator lid out of corrugated cardboard such that it forms an 8.5 inch diameter half cylinder that's about 1 to 1.5 inches thick and cover with foil (use glue). Bending the cardboard over a cylinder works well. This lid could also be box shaped.

24. Cut two pieces of glass to fit into the 1/8 inch slots formed by pieces a–b, c–b, d–e, and f–e. The dimensions are about 17.75 x 5.5 inch. These pieces of glass need to be tailored to avoid gaps that would diminish the performance of the cooker. Slide them into place. Cutting glass is easy, however you do need a glass cutter. All you have to do is score a straight line on the surface and break the glass along the score.

25. Cut out 5 inch half circles to fit the cooking rack.



26. The cutout circles on the sides in the main diagram are purely decorative .

Using the Yellow Cradle solar cooker

The Yellow Cradle cooker is simple to set up.

Step One: Insert a 3/8 inch threaded steel rod (or something similar) into the hole in the reflector surface. The angle of the cooker can be adjusted to track the sun by lifting or lowering the cooker on the rod. The position will become secure by pulling the foot of the rod out a bit.

Step Two: Insert cooking rack. The angle of the rack can be adjusted to keep a level cooking surface by rotating it.

Step Three: Place cooking pot on rack and place insulating lid on top.

The angle of the cooker should be adjusted every 15 minutes or so to keep maximum light focused on your pots.

Performance: This cooker has been tested. It took one hour and forty-five minutes to boil water at sea level with a clear but hazy sky in Washington DC. The maximum temperature recorded was 260°F.

Access

Jeff Gilbert, 409 Christopher Avenue, Gaithersburg, MD 20879 • 301-258-0728

11: **Cardboard Solar Cookers & Food Dryers. Gujarat Energy Development Agency. Sayajigunj, Vadodara 390 005, Gujarat India.**

SOLAR KABAB GRILL

We know that the sun's rays are focussed at the focal point of the parabolic curve. If a thin rod can be positioned along the focal line of a cylindrical parabolic reflector, and food is placed (or pierced) on the rod (e.g. apples, potatoes, kababs, etc.), the food would be cooked by the heat generated through solar radiation.

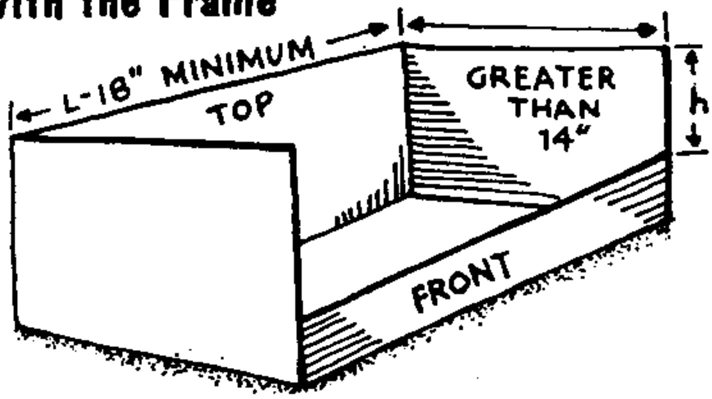
Just like the Solar Cooker, you can even make a Solar Grill. Sunlight hits the reflective tin foil surface and focusses on the kababs held in the centre.

You will need

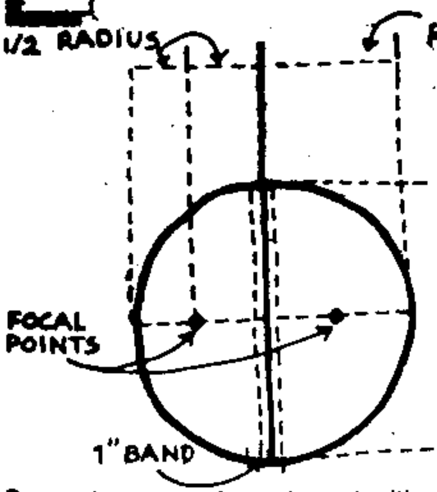
- TIN FOIL
- CARDBOARD BOX
- A THICK WIRE
- CARDBOARD

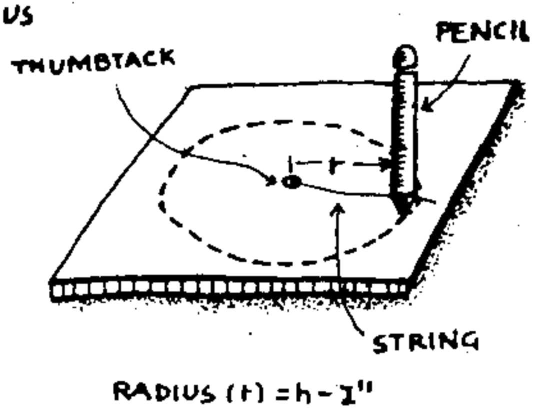
1 Begin with the Frame

You'll need a cardboard box that is strong and in good condition. A long, rectangular box will work better than a short, square one. Cut the top and front out of the box as shown. The size of this box will determine the size of your cooker.



2 Next, the Semi- Circular Ends

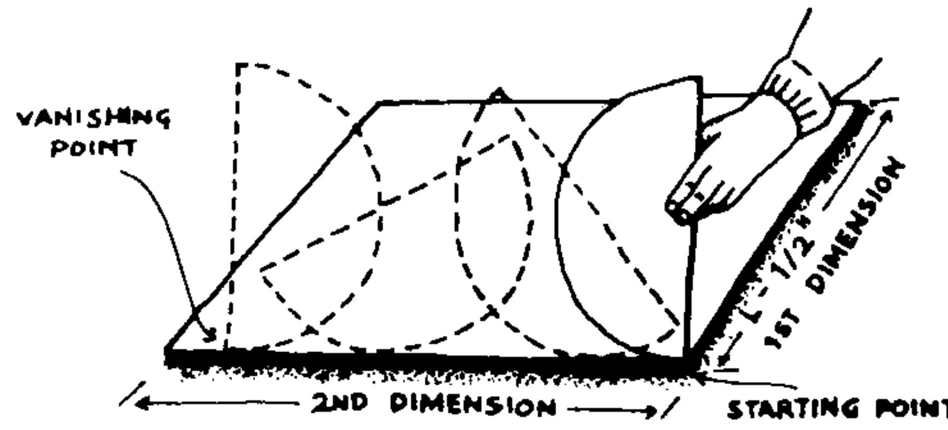




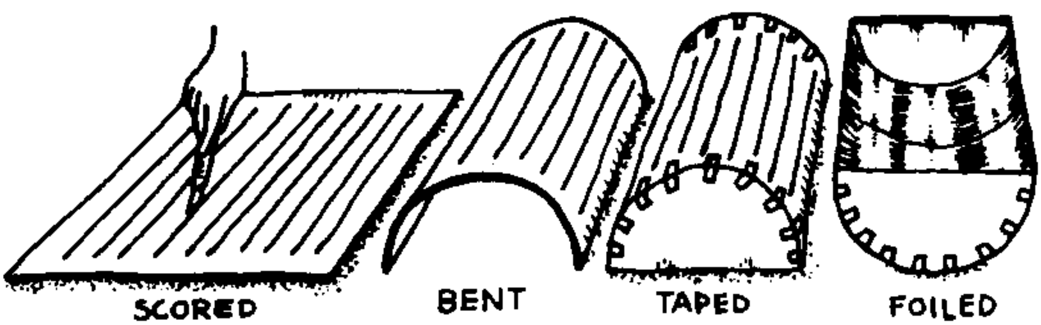
Cut a circle out of cardboard with a radius that is 2.5 cm less than the height of the front opening (h) of the frame box. Locate the focal points as shown and cut out a 2.5 cm band, centered along the diameter.

3 Then, the Curved Surface

You'll need another piece of cardboard for this part. The first dimension you need is about 1.5 cm shorter than the length of the frame (L). The second dimension is a little more difficult. Start at the point of the parabolic end piece as shown and roll the curved edge along the other unmeasured edge of the cardboard. Be careful not to slip or scoot it. Mark where the other point ends (and maybe add about 1.5 cm). This distance is your second dimension.



4 Scoring and Taping

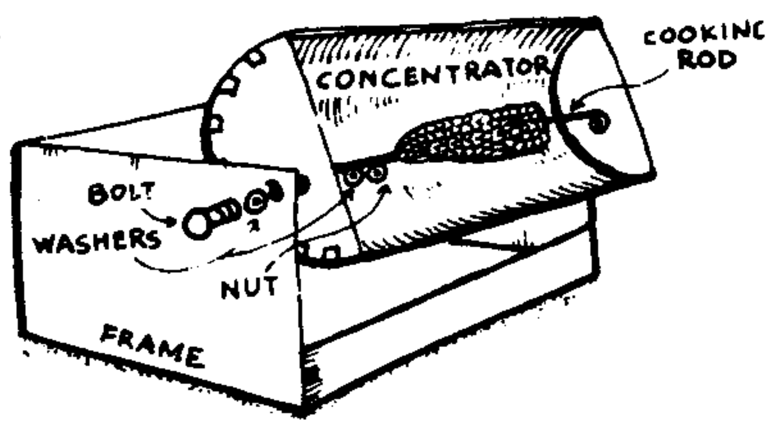


After cutting this piece to size, score one side (but don't cut through) every 4 to 5 cm with lines as shown so that it will bend easily around the end pieces. Tape the end pieces to the curved piece and cover the inside with aluminium foil. Rubber cement works well for this but just be sure to read directions.

Take an unpainted thick wire and hold over a flame to burn off any excess oily substance, then push wire through the focal points of the curved concentrator to make the cooking rod.

Connect the concentrator to the frame with bolts, nuts and washers as shown. Stick the kabab in the skewer and fix it on the grill as shown.

You can get pre-cooked non-vegetarian kababs (Venky's, Alan Mans, etc.) and grill them or you can get your mother to help you make them. For vegetarian kababs, mash together two cups of boiled vegetables (carrots, french beans, cauliflower, peas), one large boiled potato, a teaspoon *garam masala*, salt to taste. Mix in 2 teaspoons of *rawa* (semolina) or dried bread crumbs. Roll into balls and stick them on the skewer.



BASKET BARBECUE

Y*ou can use the heat from the Sun to cook food and prepare a feast for yourself.*

The tin foil of the Basket Barbecue reflects the Sun's rays like a mirror and concentrates them on the food to be cooked. The heat warms the food and even cooks it if the which means that the solar radiation is sufficient.

Commercial concentrating solar cookers are based on this principle and are constructed so that sun rays are focused on a focal point at specific angles. Moreover very high temperatures can be achieved if solar radiation falling onto a large area is focused on to a smaller area. The cooking vessel is placed at this focal point and food is cooked. We have to track the mirrors for better results as the sun moves across the sky.

You will need

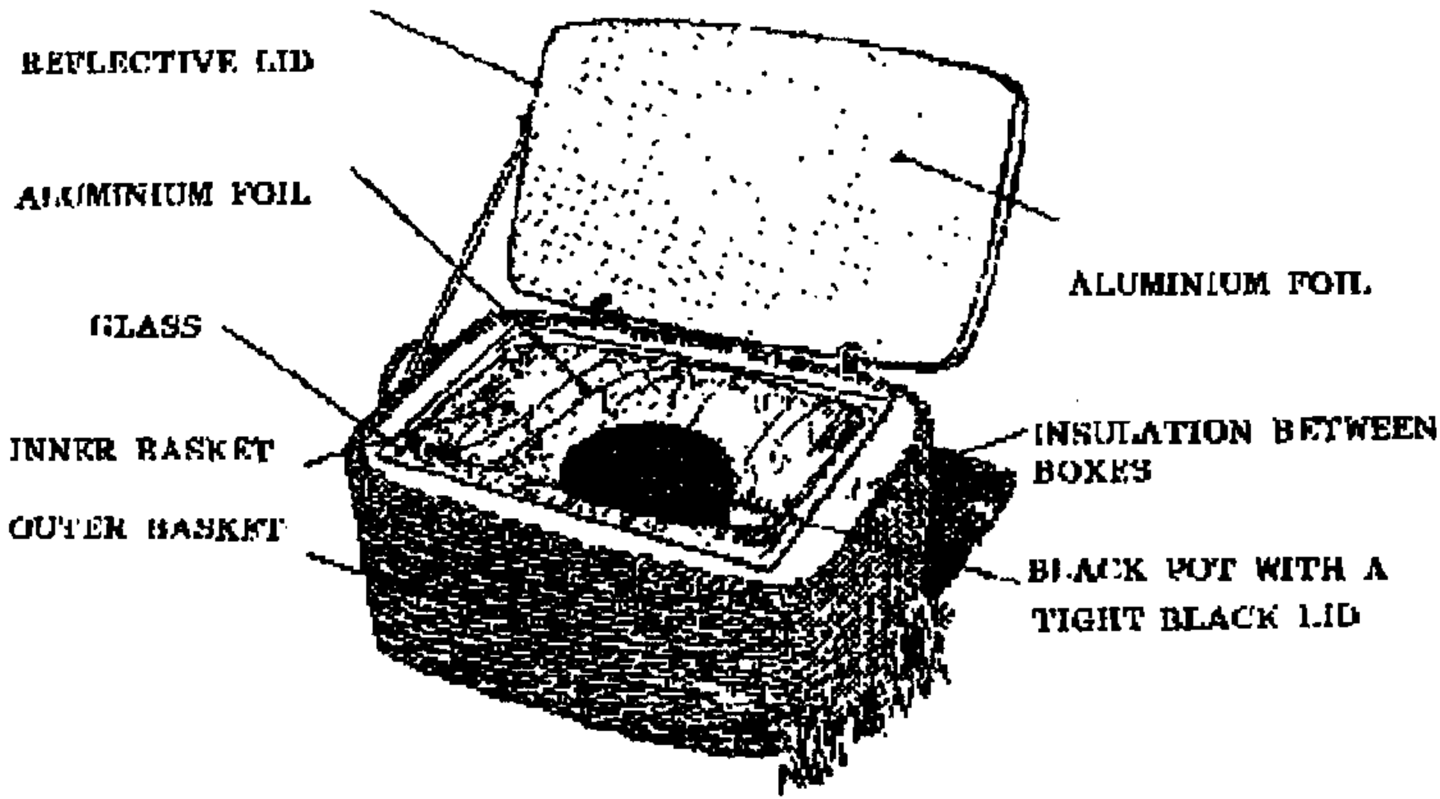
- A SMALL POTATO
- TIN FOIL
- A ROUND BASKET OR A ROUND METAL BOWL
- A LONG NAIL OR FORK
- STICKING TAPE

1 Preparing the Barbecue Basket

Line the basket with the foil with its shiny side outwards. Smoothen the foil with as few wrinkles as possible and tape it in position. It helps to put a liners under the foil.

Push the nail or fork through the middle of the basket and fix the small potato to it.

Set up your cooker facing the sun and to get the best results, you should do this on a very hot day around noon. Turn the basket to face the sun as it moves across the sky. Your potato will soon be baked and ready to eat.



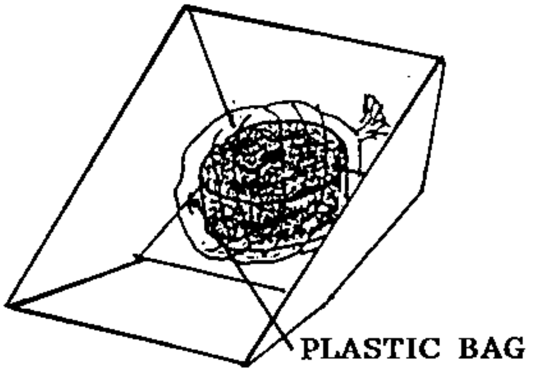
REFLECTIVE LID
ALUMINIUM FOIL
GLASS
INNER BASKET
OUTER BASKET
ALUMINIUM FOIL
INSULATION BETWEEN BOXES
BLACK POT WITH A TIGHT BLACK LID

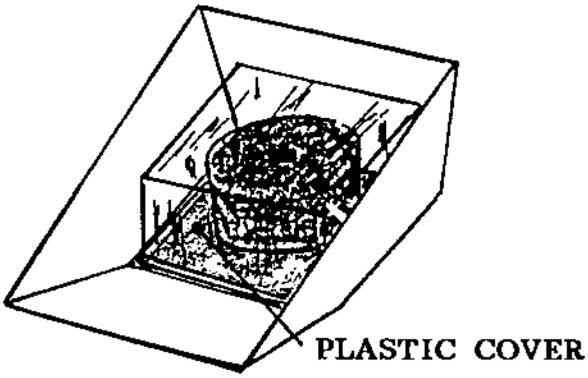
Solar panel cooker

Panel cookers, like parabolic ones, concentrate solar radiation. Their reflector consists of one or more flat surfaces that do not focus radiation, but that can re-direct a part of the radiation onto a cooking pot which is covered with a transparent cover like a plastic oven bag or a portable cover of plastic or glass.

When the solar radiation meets a dark utensil inside the cover, the heat will be trapped there. The black metal plate under the pot carries the heat to the pot and increases the temperature within it.

The panel-type cooker Coo-Kit has been succesfully used by thousands of families in the Kenyan refugee camps at Kakuma and Dadaab. The cooker presented here has been compared with Coo-Kit cookers in the same circumstances with better results.





Short tips for cooking with a solar panel cooker

-The panel cooker works slowly and you need more time and patience for cooking.

-Place the cooker so that the lower side faces the sun. You only need to change the direction every 1-2 hours. If you must be away longer, pre-set the cooker in the middle position for the time you will be away.

-Put a black pot with a lid into the middle of the cooker, inside a closed plastic bag or, if you have the cover, put it over the pot. You can leave the cooker alone for several hours; there is no danger of over-cooking.

-Stirring and mixing during cooking decreases the temperature, so you should stir as infrequently as possible.

-Add about 50% to the cooking times on page 11, and avoid hard-to-cook foods. The largest amount of food you can cook is about 1.5 kg.

-Pre-soak dried beans and lentils, etc. for one day before cooking.

-Sterilizing water takes about one hour for 1 litre and 2 hours for 2 litres. The water remains usable for one day if it is kept in an unopened pot.

-For baking you need good conditions and long cooking times, but if you are patient it is possible.

How to build a panel cooker

Take 5-8 mm thick cardboard, mark and cut as in the drawing.

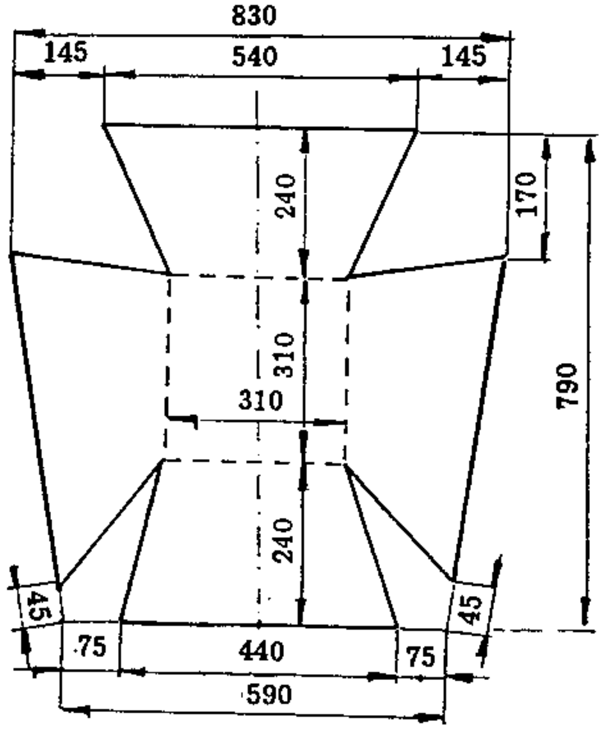
Use a blunt instrument and straight wooden bar or ruler for bending folds for the sides of the box.

Tape the corners together on the outside with any kind of tape.

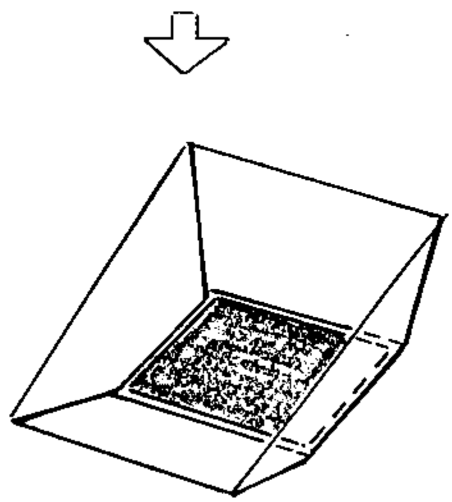
Then glue aluminium foil to the inner sides of the box. Leave a little strip of foil over the edges for the outer side.

Take a metal plate 280 x 280 mm, about 1 mm thick and paint it black.

Put some thin insulation material, grass or wood etc. under the cooker for extra insulation.



Plastic bag and cover



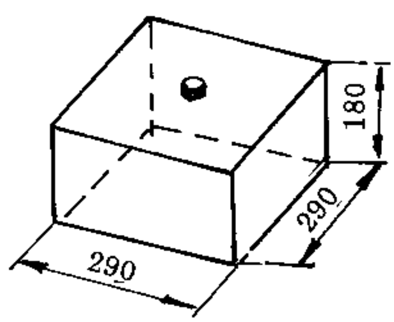
You can clamp a normal clear plastic bag made for roasting food around your pot, **which absolutely must be black!**

Closing and opening the bag is quite unpractical and not very hygienic because some food will stay inside of the bag.

Therefore a plastic cover is more hygienic and handy; you can easily stir the food and see what is happening in the pot.

Cut pieces for the sides and top from about a 1 mm thick polycarbonate sheet. Tape the corners together with heat-resistant and transparent tape.

Screw a wooden knob into the middle of the top.



For making a panel cooker, you only need a pen, scissors, measure, knife, ruler and a home-made cardboard spatula. **-Happy Building!**

The Bernard Solar Panel Cooker

A simple, portable model that may open new horizons

It is generally assumed that a solar cooker should have some minimal capacity in order to work properly. For instance, in the booklet *Your Own Solar Box* , Solar Cookers International (SCI) recommends an inner box at least 45 cm X 55 cm (18" x 22"). The result is a rather large box, well suited to family use, but which can prove unnecessarily cumbersome in some cases

Smaller cookers would be appreciated by the following:

- people living or traveling alone,
- people living with their family but needing a special diet,
- elderly people who feel reluctant to carry a heavy box,
- teenagers wishing to build and experiment their own first cooker.

If you belong to one of these categories, here is how you can build a cheap and fairly efficient small cooker.

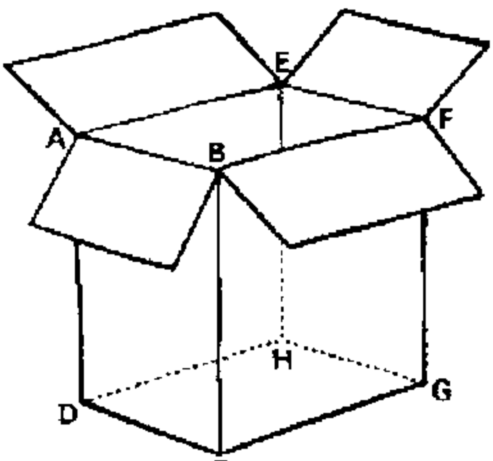


Figure 1

Choose a cardboard box (figure 1) with the height BC greater than the width DC. For example, in my own cooker BC = 30 cm (about 12"), DC 23 cm (9") and CG 25 cm (10").

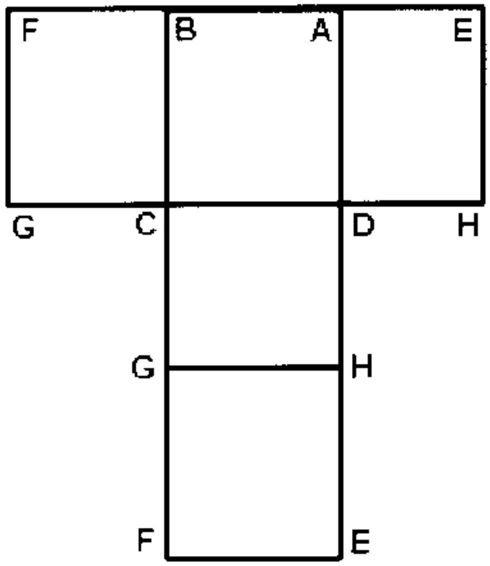


Figure 2

Cut the flaps off the box. Then cut the seams along FG and GC. Do the same on the other side along EH and HD. The carton folds out to a flat assembly of five rectangles as shown in figure 2 (Letters appearing twice on this figure indicate two points which were the same point before cutting). If the cardboard is thin, reinforce the rectangle CDHG by gluing another rectangular piece of cardboard onto it to better insulate the bottom of the pot. Then glue aluminum foil to one side of the five rectangles (the inside of the original box).

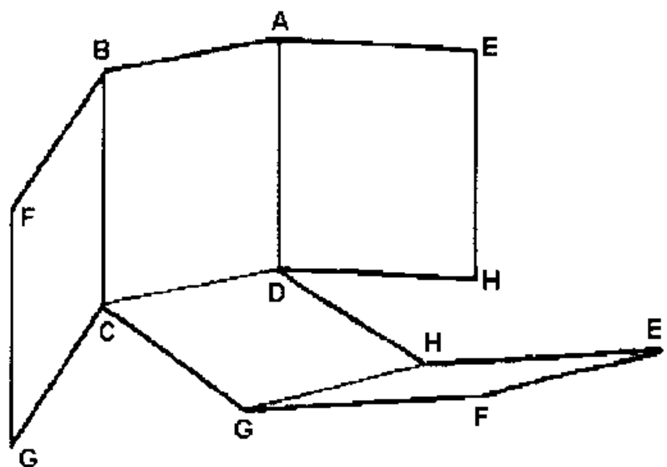


Figure 3

Now, keeping the rectangle CDHG horizontal on a table or on level ground, position the other rectangles as shown in figure 3. The front "mirror" EFGH is tilted about 30 degrees above the horizontal plane (Put a rock or other object under it). The "wing mirrors" BFGC and AEHD are vertical, the angles GCG and HDH being about 45 degrees. A few rocks as shown in figure 4 will be helpful, especially in windy weather.

The black cooking pot is put on the horizontal base CDHG and covered with a colorless glass salad-bowl [or oven cooking bag, see next article, ed.] replacing the glass window of a classical box cooker. To avoid convective heat losses, the diameter of the salad-bowl should not exceed the width CD.

A more convenient way of keeping the reflective system in good shape is to mount the panels on a wooden board in which you will drive a few nails on each side of GC and HD to maintain the wing mirrors in their correct position (see figure 5).

Although this cooker uses (slightly) concentrated sunlight, it is not necessary to worry about a constant tracking of the sun. A big vertical nail at the front of the board can act as an "orientation indicator". Its shadow should be seen on the white triangular piece of paper glued on the board (figure) and whose 30 degree angle roughly corresponded to 2 hours of absentee cooking in my experiments. Most of the following results have been obtained without any readjustment of the cooker orientation.

All cooking was done in an aluminum pot painted black. Scrounged glass jars may be used, even without the salad-bowl, but cooking times are increased.

The latitude of Paris is about 45 degrees. When cooking at lower latitudes the vertical reflectors become less effective; it remains to be tested whether this design will work as well there. On the other hand, people living at latitudes above 40 degrees could find it more efficient than a simple, one-reflector box cooker. I'm interested in knowing the results obtained by readers who live in other parts of the world.

Roger Bernard can be contacted at

La Association Lyonnaise pour l'Etude et le Developpement de l'Energie Solaire. A.L.E.D.E.S.
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Barbara Kerr Tests The Solar Panel Cooker

I am really excited by the opportunities opened up by Roger Bernard's panel cooker design. We have known that multiple reflectors can be used to concentrate solar radiation, but until I watched my lentil stew bubbling under the glass salad bowl, I did not see this as a serious cooker. Suddenly, I realized that an oven cooking bag could be used in place of the salad bowl. This would provide a very abbreviated solar "box." All we have learned over the years with box-type cookers could be helpful in utilizing Solar Panel Cookers (SPCs). Now we may have both our "oven" and our "hot plate."

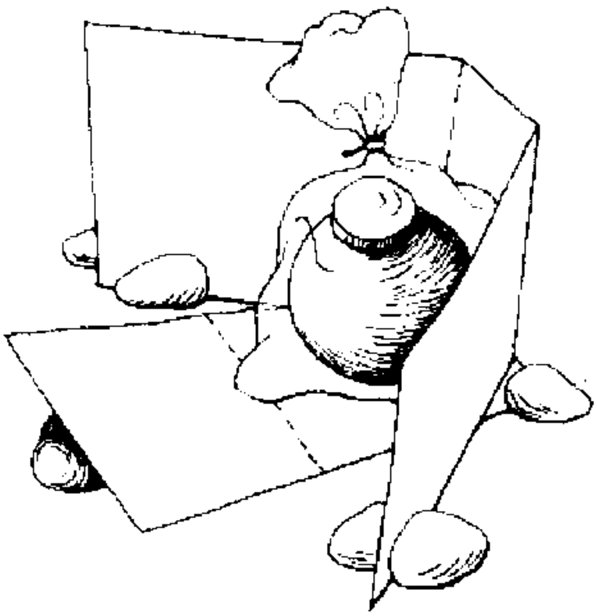
By limiting ourselves to flat foil-covered panels, the danger of eye damage is greatly reduced but remains a problem. Retinal damage, which can occur when sunlight shines into the eyes, is not painful. You cannot tell it is happening, but a retinal burn produces permanent damage and can result in blindness. Be extremely careful if using anything that concentrates the light or reflects the sunlight directly into your eyes.

The first cooker I made based on Roger Bernard's specifications would not fold neatly. The illustrations show a slight modification of Roger's design. Since the panels are all the same size, they fold to form a flat packet which is so small and light-weight that it can be used by backpackers and others who do not have space for much storage. The extra cuts and folds also provide areas where rocks can be placed to anchor the panels without blocking any sunshine. Our winds are fierce and unpredictable! I have found that a cardboard SPC in this configuration tolerates the wind very well.

Place the cooking pot in an oven cooking bag with the opening at the top so you can open the bag, check the food and seal it again without disturbing the cooking. And that part of the bag is usually dry. This is important because food in a panel cooker usually does need to be stirred and checked, since the heat is not as even.

First I closed the baking bags with clothes pins--too heavy and bulky. Then with paper clips tore up the baking bag which otherwise was good for many uses. Then with a thin piece of wire worked well but the twisted wire broke after several uses. Now I am using wire but simply wrapping it tightly around the baking bag top, without twisting. Since there is no pressure, it works fine and the twist ties last a long time.

Too often I have found jars or pots have vigorously boiled over, spilling juice and making a mess. Got to remember to allow more space at the top to contain a boil, at least until I get a handle on when this is going to happen. A delightful problem. Food does not have the delicately enhanced flavor of SBC cooked food, probably because of the higher temperatures.



Then I noticed a cold spot on the foiled reflector directly under a pot and remembered the advantage the University of Washington engineers found through elevating the SBC tray off the cardboard bottom. I looked around the kitchen for an "elevator" and seized on canning rings. It is clear that pots heat faster when sitting on a canning ring than when sitting on the foiled cardboard. Darkened canning rings work better than shiny, of course. But the center is dark and I wondered if it would help to get light to shine under the pot. I put three little pebbles, dark and oiled, under a pot. That seems to work even better. I like that . . . three little pebbles used in memory of the historic three stone fire that has served humanity for thousands of years. Women, nostalgic for the wood fire where there is no more wood, might even take tiny pieces of wood and form a little "fire" within the pebbles under the pot. It would keep us from feeling so torn away from roots.

Solar cooking continues to get simpler. I have put major attention on simple solar cooker designs for 20 years, working to have them easier and more accessible to everyone. Today, I held a Solar Panel Cooker and realized our 20 year mountain of work had truly brought forth a mouse. A mighty mouse! Simplicity is so difficult...difficult to see, not difficult to do, once the idea forms. I think that box-style cookers will remain part of the solar kitchen where time, material and circumstances dictate, but the SPC has opened up a new level of simplicity.

We are doing pretty well with reducing the materials needed to solar cook. If only we could eliminate the need for oven cooking bags of heat-resistant nylon. I used regular kitchen plastic bags and they seemed to hold up under the heat for several cooking times. But January 12 was brighter, the air was warmer, and three different kinds of regular plastic bags melted. I guess we will have to stick with baking bags . . . too bad. But the baking bags I started with two months ago are still in good shape, having cooked many dishes and been washed and dried many times. Perhaps they can be obtained wholesale and distributed one or two at a time where they are not available in stores. We should be able to get them wholesale if someone puts a little effort into it.

It seems that "open-box" cookers will now be an integral part of serious solar cooking. It will just take finding out specifically how to use them.

Please send your findings and comments to me as well as to Roger Bernard. We'll keep everyone else up-to-date through Solar Box Journal.

Barbara Kerr
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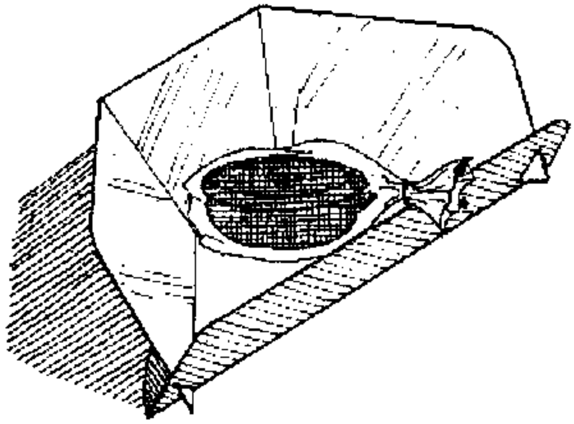
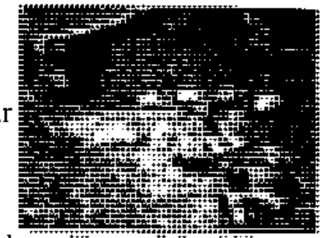
Taylor, Arizona 85939 USA

For questions or comments, contact bkerr@cybertrails.com

The "Cookit" Foldable Family Panel



The Foldable Family Panel is neither a "solar oven" or "curved concentrator" but a happy hybrid. Its utter simplicity belies its powerful cooking power. Its low cost brings solar cooking to a much wider market of people.



It is handy for cooking food, baking breads, pasteurizing water, and teaching the basics of solar energy.

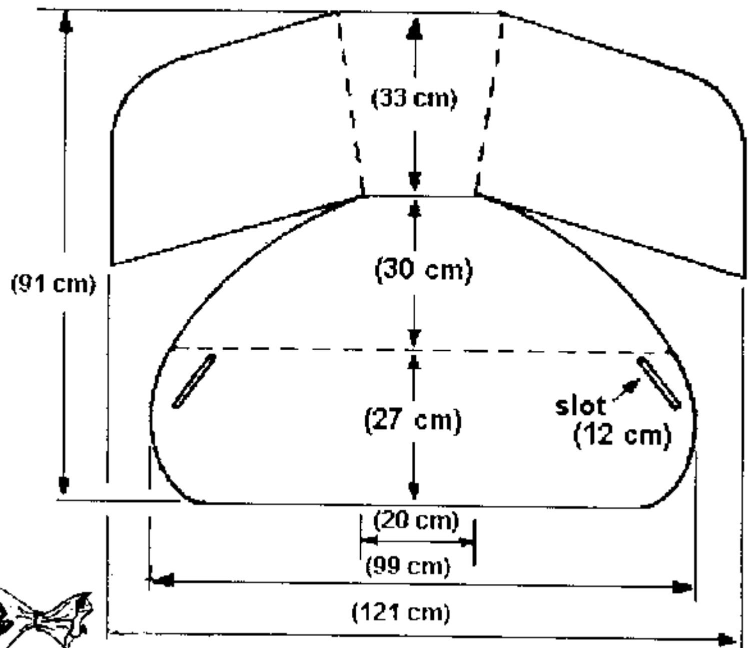
Co-developers are Roger Bernard of France and Barbara Kerr of the USA, with work also by Edwin Pejack, Jay Campbell, and Bev Blum of Solar Cookers International. Extensive field tests in the USA and with refugees in Kenya confirm its performance, convenience, low cost, acceptance, and adaptability to diverse needs.

Construction Plans

Start with a big piece of cardboard about 1m x 1.33m (3'x 4'). Cut and fold as shown. The angles and folds shown are best, but small variations are OK.

Hints: To make clean straight folds in cardboard, first make a crease along the line with a blunt edge such as a spoon handle, then fold against a firm straight edge.

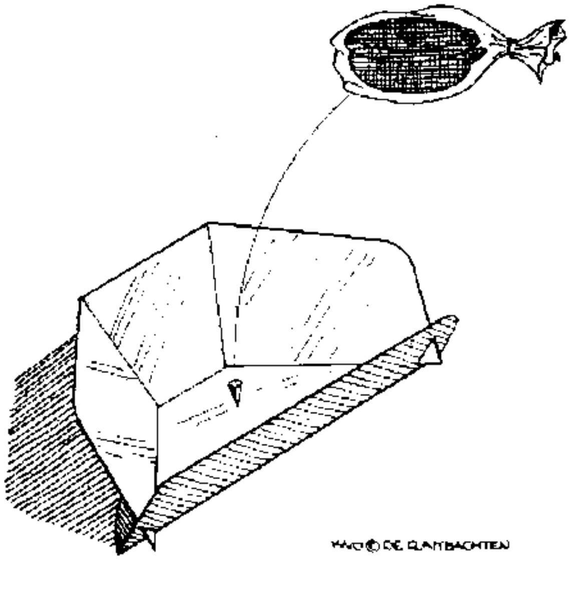
Make the slots a little too small and narrow so that they fit snugly to hold up the front panel.



Glue aluminum foil on the side that will form the inside surfaces when the oven is set up for cooking.

To set up, lay panel flat with shiny side up. Fold up front and back parts and fit back corners into the slots in front.

You're ready to cook! Put your food into a dark-colored pot. Then place the pot inside a plastic bag (an oven cooking bag will withstand the heat best). Close the open end of the bag and place pot and bag into the center of the cooker.



CooKit Plans

The CooKit is typically made of corrugated cardboard with shiny foil laminated to the top side. Draw the cooker to the dimensions indicated and cut around the perimeter. Fold on the lines. Insert tips B and C into slots D and E, respectively.

Use a dark pot around 10 inches in diameter enclosed in a heat resistant plastic bag. Place the pot as indicated by the circle.

Face the cooker towards the sun and tip up the front panel as appropriate for the altitude of the sun.

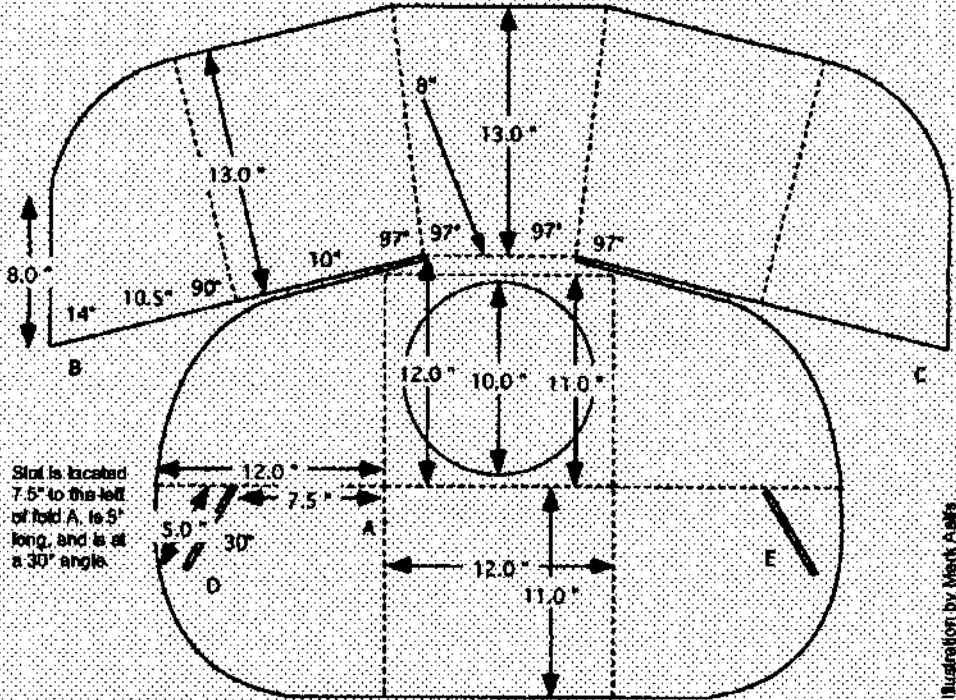
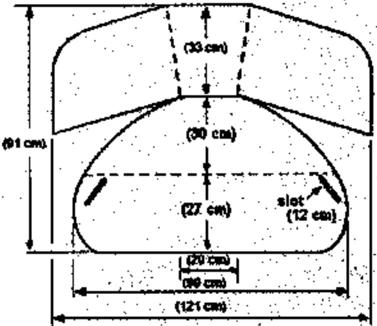
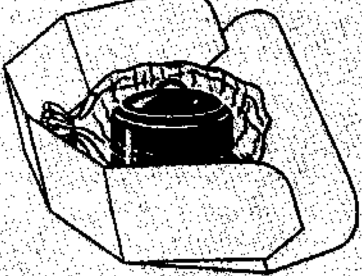


Illustration by Mark Aalfs

"CooKit" We couldn't have done the project without the new design. That's really the bottom line. For the cost of one box cooker we could have 25 panel cookers. We were able to spend all our time on how to use the cooker. We didn't spend any time on construction. You just fold it up and insert the two tabs into the slots and that's it.



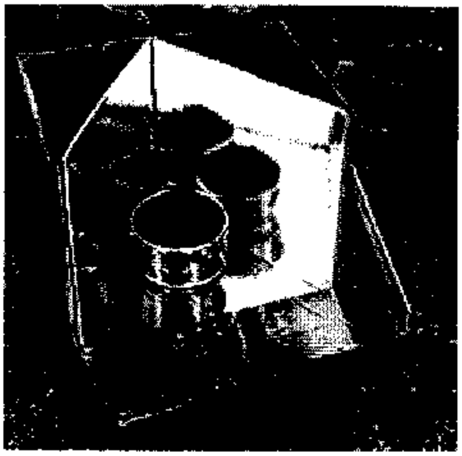


Production of the Cookers The cardboard manufacturer takes a large roll of corrugated cardboard, laminates aluminium foil on one side, and sprays a waterproofing lacquer on the other side. This is then die-cut to form the cooker, complete with the folds and slots. Then they are bundled into lots of 25 (which is about as large as one person can handle).

Left: Roger Bernard's "Salad Bowl Cooker" is simple, effective, and inexpensive. An overturned glass bowl creates the oven space.

Improving the Solar Panel Cooker

Roger Bernard offers a new compact reflective cooker design



I have been very impressed to read, in SBJ #17, that the solar panel cooker (SPC) idea, as publicized by Barbara Kerr and myself in the preceding issue, had met with an abundant response. Even negative results can be of interest when we seek to understand them. For instance, in the comment. "I used a "turkey -size" oven cooking bag and a dark ceramic teapot. Nothing!", there are two interesting clues. First the ceramic teapot was not a good choice because ceramic can be a bad conductor of heat [depending on its density, Ed.]. Food can remain lukewarm, even if the pot is very hot on the outside. And secondly, a turkey is an enormous bird, and using a bag appropriate to hold it may mean that the quantity of food could have been too big for the cooker.

Let us not forget that the SPC was designed as a substitute for the traditional box for small quantities of food. The dimensions given for my prototype in SBJ #16 are appropriate only when cooking for one person.

During the 1994 summer, I somewhat improved the SPC's convenience and efficiency by introducing two changes: a new system for creating the greenhouse effect and a more compact design.

Undoubtedly, oven bags are unbeatable for their lightness, but in my city (Lyon, 500,000 inhabitants) there are no oven bags available in the supermarkets. On the other hand, Pyrex salad bowls are very easy to find everywhere in France--even in small towns. Their price (about $4 US) is ten times the price on an oven bag, but they can be used hundreds of times for solar cooking as well as for other purposes in the kitchen. For traveling, however, they are relatively heavy and cumbersome.

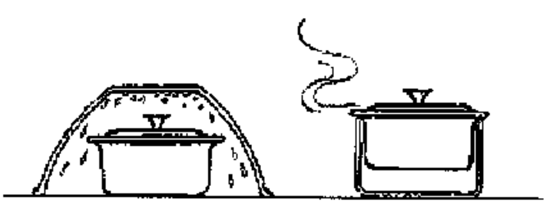
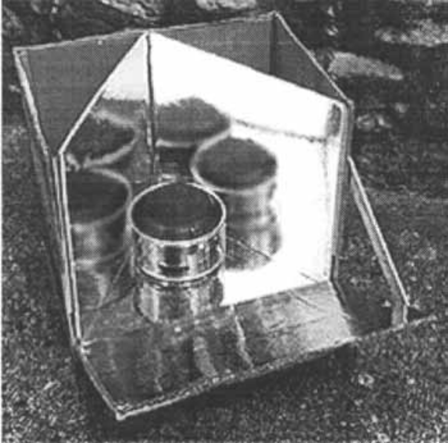


Figure 1

Salad bowls and oven bags share the following disadvantages: they hamper access to the food, and they retain the moisture coming from the heated food and need periodic drying [see Tips and Tricks. Page 3]. These drawbacks can be avoided if we put only the lower part of the cooking pot inside of a glazing (figure 1), instead of the whole pot with its lid.



This can be done by placing the dark pot into a glass dish whose diameter is slightly larger than that of the pot.

Obviously the advantages of such a system are partially offset by extra heat loss from the uninsulated lid. By raising the pot off the ground a further gain is achieved. In fact, my experiments have shown that cooking times with this new system are no longer than with the original design with a salad bowl up-turned over the pot.

In order to improve stability, I reduced the number of panels from five to four. A pleasant surprise was that the removal of the central back panel not only resulted in a more compact and stable cooker, but also improved the efficiency of the reflective surfaces, by permitting multiple reflections between the two remaining vertical panels. This peculiar assembly I propose to call a "reflective open box" (ROB) to distinguish it from the original solar panel cooker (SPC).

Construction

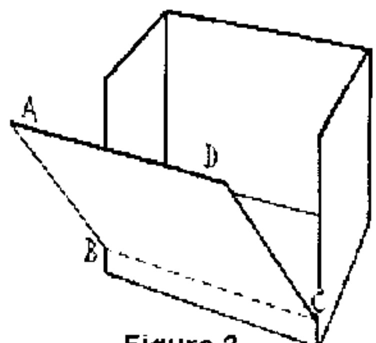


Figure 2

To make an ROB, start with a rectangular, rather tall, cardboard box (see below for dimensions). On one of the broader sides, draw a horizontal line (BC) about two inches above the bottom (figure 2) and cut the seams along AB (stop at B) and DC (stop at C). Fold down the front panel ABCD using BC as a hinge. Stack a few rectangular pieces of cardboard in the bottom of the box, to raise the floor level up to the level of BC.

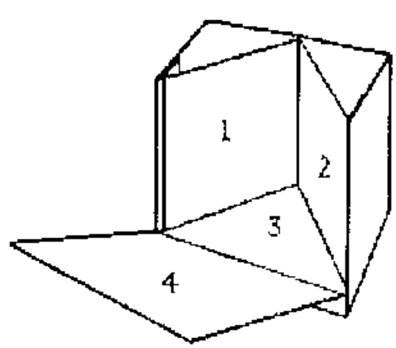


Figure 3

Cut and fold another piece of cardboard so that it can be inserted into the box to form panels 1 and 2 in figure 3. The angle formed by these panels is adjustable at time of construction. Smaller angles concentrate the sun more, but require more frequent adjustment to follow the sun. A good compromise seems to be any angle between 60 and 90 degrees. Cover this piece with aluminum foil and glue or staple it in place. Apply aluminum foil to panels 3 and 4 as well.

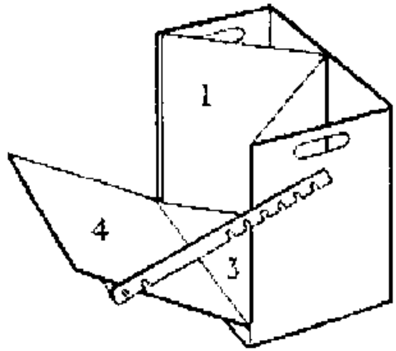


Figure 4

The ROB shown in the photograph has the following over-all dimensions: Length: 46 cm (18"), Width: 32 cm (12.5"), and height: 42 cm (16.5"). These dimensions correspond to a reflective area of about 5,000 sq. cm. (770 sq. in.) which proved sufficient to cook for two persons.

A wooden prop can be used to adjust the front panel (figure 4). The single notch near panel 4 is used to lock this panel in a closed position for storage. Rocks can be placed in the triangular chambers behind panels 1 and 2 to stabilize the cooker in the wind.

In summary, the ROB seems to be a more convenient and efficient design that could replace the original SPC for regular home cooking. Of course, the latter equipped with an oven bag remains a better design if a light-weight, foldable cooker is needed.

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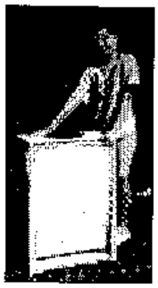
The Nelpa Solar Panel Cooker

by Roger Bernard

In the last issue of the Solar Cooker Review, Barbara Knudson was quoted as saying, "Solar Cookers are more apt to be adopted when people are desperate, but do we have to wait until the whole world is desperate before we adopt this?" This important question calls for another one: What could we do to make solar cookers more convenient without making them too much more complicated? The Nelpa solar panel cooker presented here grew out of an attempt to answer these questions.

It might be useful to understand how this new panel cooker relates to my original Solar Panel Cooker (SPC) and Solar Cookers International's (SCI) derivative, the Cookit panel cooker. Figure one shows the SPC without its optional front panel. It consists of four panels with a inverted clear glass salad bowl resting over the cooking pot on the bottom horizontal panel. As SCI has shown, a plastic bag can be used in place of the glass bowl with very good results.



Now imaging that we turn the entire assembly upside down so that the bottom panel is now on top (hence the name "Nelpa" which is a sort of an inverted form of "panel"). As you can see, I have cut a hole in this panel, allowing the pot to be inserted from above. I have placed a reflector below to bounce the light rays into the inverted panel assembly.

Here are the main consequences of this design change:

Advantages

1. Since the pot lid is outside of the glazing, the food remains perfectly accessible to the cook for tasting, seasoning, stirring, etc.
2. For the same reason, the steam emitted by the heated food does not condense on the inside of the glass or plastic.
3. The salad bowl (or plastic bag) is mounted permanently in place, so there is no need for cleaning or drying and little chance of damage.
4. The suns rays hit directly on the pot's sides and bottom which are in contact with the food. This direct contact is more efficient than heating the pot lid, which is often the case with other designs.

The horizontal panel can be enlarged if necessary to act as a table for food preparation.

Disadvantages

1. A fraction of the sunlight is lost by its having to reflect off the bottom panel to reach the panel assembly. No surface is 100% reflective.
2. Some heat escapes from the un-insulated lid and along with steam that escapes from it.
3. The whole design is a bit more complicated and requires more frequent adjustment to follow the sun.

Figure 1 shows nine-year old Amélie cooking lentils with a Nelpa cooker. It is equipped with a three-mirror reflector whose wooden frame is attached to the front legs of the cooker by two bolts. It can be tilted according to the altitude of the sun. It is balanced to remain in any chosen position. The best angle between the central panel and the side panels depends on the diameter of the pot and its distance from the central panel. This can be adjusted by sight by moving the side panels until a reflection of the pot is seen in each one.

It may be noted that effectiveness of this design declines as the sun reaches 90° since the top panel tends to shade the bottom reflector at high sun angles. This should not be too inconvenient since in temperate latitudes the sun never reaches this height, while in the tropics cooking would usually be completed in the morning before the sun gets too high. And of course cooking could continue in the afternoon.

After cooking is finished the Nelpa can be collapsed by flipping up the reflector. His prototype, built with foiled cardboard panels and mirrors, weighs six kilograms (about 13 lb.) and is not much more cumbersome than a suitcase.

In summary, simple and cheap panel cookers like the SPC and the Cookit remain the best for emergencies and mass diffusion, but people who can afford a more elaborate cooking device might prefer the Nelpa for its convenience.

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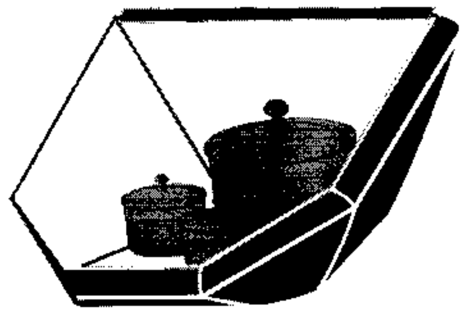
France

The Sunstove ©

Solar cookers are regarded by many as a potential solution to the **fuelwood crisis** in rural areas - especially in Africa. Deforestation damages the environment - sometimes irreversibly. It also implies that nearly every month more time must be spent than the previous to collect sufficient fuelwood, and places an onerous burden especially on women in rural areas[5].



The *Sunstove*, which since 1992 is being manufactured and developed in South Africa[1], is today the best solar cooker worldwide in several key respects. This despite the fact that it is by no means the most thermally efficient solar cooker yet made[1]. Thermal efficiency in itself has proved insufficient[2] for a solar cooker to be acceptable and useful to the most important target group of users - the rural and peri-urban poor. The *Sunstove* excels in the following key respects:

Price

At less than R200 for a durable cooker capable of taking 3 pots at a time, it compares very well with even the *materials cost* ($80 - 100) of cookers manufactured in an extensive program[3] in Central America. These materials had to be subsidized 100-300% to be affordable to the target market.

Robustness

The unit is the **toughest** that money can buy. On more than one occasion units were lost from vehicles travelling at 120km/hour on a freeway. Some damage was visible, but all units were still functional after such accidents. Falling from about a metre's height onto a hard surface has little or no effect on the units. As solar cookers will also be used in remote locations, this ruggedness is important.

User friendliness

In contrast to other solar cookers, where the orientation must be adjusted around 2 axes [4], the *Sunstove* is merely turned on its smooth flat base (around a vertical axis) towards the sun. One need not even bend down to do this - a foot will do! **Orienting towards the sun is much less frequent** - every 2-3 hours, as against every 20-30 minutes for most other solar cookers[4].

It is, furthermore, nearly **impossible to burn food with the *Sunstove***, or to let it boil over. This is because the thermal flux is much lower, and comes mainly from above (also from the sides). *Food is stirred only once,* if at all. To cook a large pot of mieliepap (maize porridge) - a staple[5] of rural Africa - requires 10-20 times **less woman-hours than on an electric or gas stove**. Instead of stirring for 30-60 minutes[6], a ¼ minute now suffices. Because the cooking process is slower, the end result is better[6].

Water use

Because of the lower heat flux and minimal stirring, evaporization is minimal, and **less water is used** (for mieliepap about one third as much, and none for fresh vegetables). In arid rural areas, where water is carried over long distances[5], this can be important. In rural settings water-borne diseases such as cholera can take on epidemic proportions. The *Sunstove* can readily **pasteurise water and milk**. User friendly pateurization temperature indicators are being developed.

Wonder (Hay) Box

The 40mm fibre-glass thermal insulation of the *Sunstove* makes it suited to being used as a *"Wonder Box"* - for example, to **keep a large amount of food warm or hot** till an hour or two after sunset. For this a twice folded blanket (4 layers) must be placed on the glazing of the *Sunstove*. Food heated to cooking temperature will continue to cook food after sunset or on rainy days in a *Wonder Box*.

Eye friendly

In contrast to some other solar cookers, the *Sunstove* is safe and indeed comfortable for the eyes of the user. It is a pleasure to use, and the light *Sunstove* (4 kg) is already being used by **potjiekos** enthusiasts, **caravaners** and **campers**. With potjiekos one must remember that the heat now comes mainly from above and the sides - not from below. The arrangement of the food layers must therefore be modified accordingly. Many families today cook their main meal, with a variety of dishes, in the *Sunstove.*

Acceptability to the market

For any product this is the crucial test. Of the latest 2 models, about 8 000 have been sold. Current *sales* (at above production cost) average about 200 per month. *Sunstoves* have been sold to customers from 12 countries in Africa. At the Transvaal Provincial Administration's Witvinger Nature Reserve, 6 different types of solar cookers from various parts of the world were tested under practical conditions, and several types were built. It was found that not a single model could compete with the *Sunstove* for user acceptance.

Compact Transport / Storage

The *Sunstove* can be supplied with the translucent lid & hinge separate. (It is fixed by 5 screws). In this way 5-10 or more units can be stacked spoon-wise into one another for compact transport and storage. Each unit weighs only 4kg.

History

Richard Wareham from Milwaukee, USA designed the Sunstove - in South Africa. The excellent *Solar Cooker Manual* from *Brace Research Institute* (McGill Univ, Canada) guided an ongoing quest for a more user friendly, rugged & affordable solar cooker. Many models were designed & built using different materials and production processes. Of some, a few hundred were made and marketed, plus 1 000 of a truncated conical model in 1993. The experience so gained has each time been utilized to further improve the design.
Mr Wareham also sponsored these prototypes, as well as the tooling cost of the current South African model. These inverted truncated pyra mids (see diagram) were first produced (end of 1993) by Sinclair Perry - who contributed his knowledge of production technology to the highly successful current design. Today final assembly & dispatch is by Danie Jacobs in a suburb of Springs.

Acknowledgement

The companies Acrylic Products, Blomo, Owens Corning and CTP Webprinting supply materials and components at low cost, thus contributing towards making the *Sunstove* easily the most cost effective solar cooker available today. Roelf van Weele cuts the thick aluminium base plates for the slightly faster model. The Sunstove is now entering production in Calcutta, India - funded by Rotary International.

Technology Development

At the Department of Physics of the University of Pretoria we have been privileged to further improve the *Sunstove* - which is already the world's best. Aspects investigated were aimed at:

- improving the thermal performance / cost ratio;
- making the unit even more user friendly;
- making it suited to further applications - see "water use" above;
- developing suitable black pots and other accessories.

Notes

1. The most thermally efficient solar cooker is of the vacuum tube type - which retails at several thousand *Deutschmark* apiece. These units (& less expensive ones using silica

aerogel transparent insulation and/or selective coatings) store heat and permit relatively high temperature cooking even *after* sunset. They cost 25 - 110 times as much as the *Sunstove*. These and some other solar cookers can reach high er temperatures, and boil a given amount of water in a shorter time.

2. See for example A A Eberhard, Technological Change and Rural Development: A Case Study in Lesotho. Ph D Thesis, University of Edinburgh, 1982. And: Dissemination of Solar Ovens in Lesotho: Problems and Lessons. p2754-2758, Proc 8th Solar World Congress, Perth 1993. Pergamon.

3. D M Kammen & W F Lankford, Cooking in the Sunshine. *Nature*, **348** (385-6) 1990.

4. With the parabolic dish type, the entire unit must follow the sun around 2 axes - about every 20-30 minutes. With the box-type cooker with external mirrors the mirror tilt angle needs frequent adjustment according to the height of the sun above the horizon. *And* the entire unit must be turned on its base towards the sun every 30-60 minutes.

5. M Sc thesis, Cecile Thom (University of Cape Town, 1994): *The application of biogas technology in South Africa for small-scale energy production.*

6. JA de Villiers (author & publisher), Cook and Enjoy It.

P O Box 21 960,
1515 Crystal Park.

Tel & Fax (011) 969 2818

Registered as a section 21 (non-profit) company represented by Mr Wareham, Mrss Margaret Bennet and Liz Perry of Gauteng, Mathilda Roos of Bloemfontein, and others.

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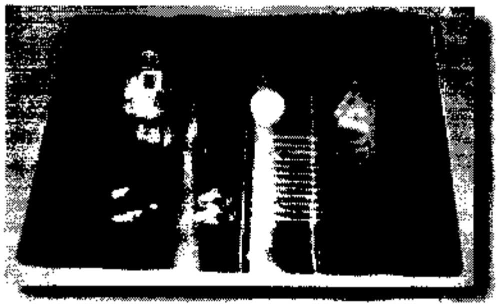
HOW TO MAKE A SOLAR COOKER

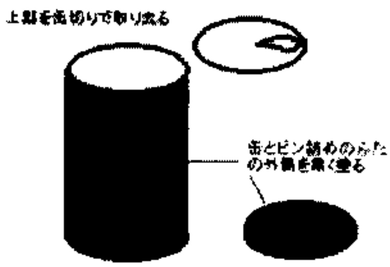
Mini Panel Cooker

<Materials>

Aluminum or steel beverage can (500ml)
Clear PET bottle (1.5 or 2 L)
Metal lid of glass jar that fits top of a can
Two paper clips or clothes pins
Aluminum tape or adhesive tape
Black Marker (non-xylene type if available)
Laminated aluminum sheet about 55cm X 70cm
(If one piece of aluminum sheet is not available, use cardboard and glue aluminum foil, or connect several juice cartons.)

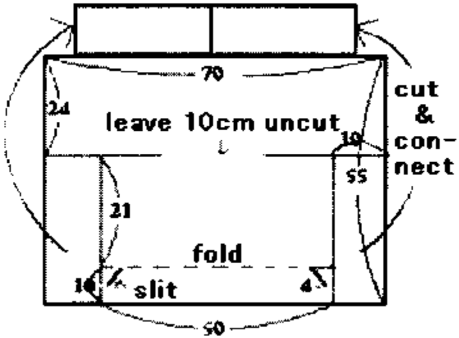


1. Cooking Pot: Cut off top of the can and paint outside and the bottom with black marker. Paint outside of the metal lid of jar also.

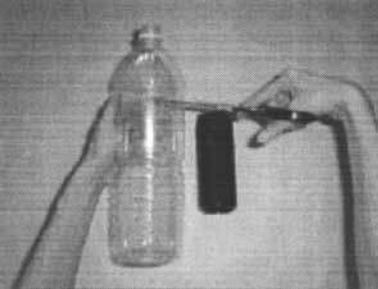


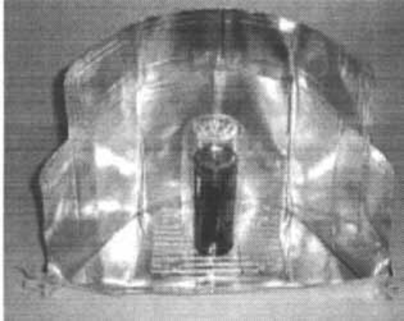
2. Insulator: Cut off top of the PET bottle at the level of 3 cm taller than the can.

3. Panel Cooker: Cut aluminum sheet as shown in the drawing. Connect cutout sides to the back panel with tape. Insert corners of both sides into slits and pinch with paper clips.

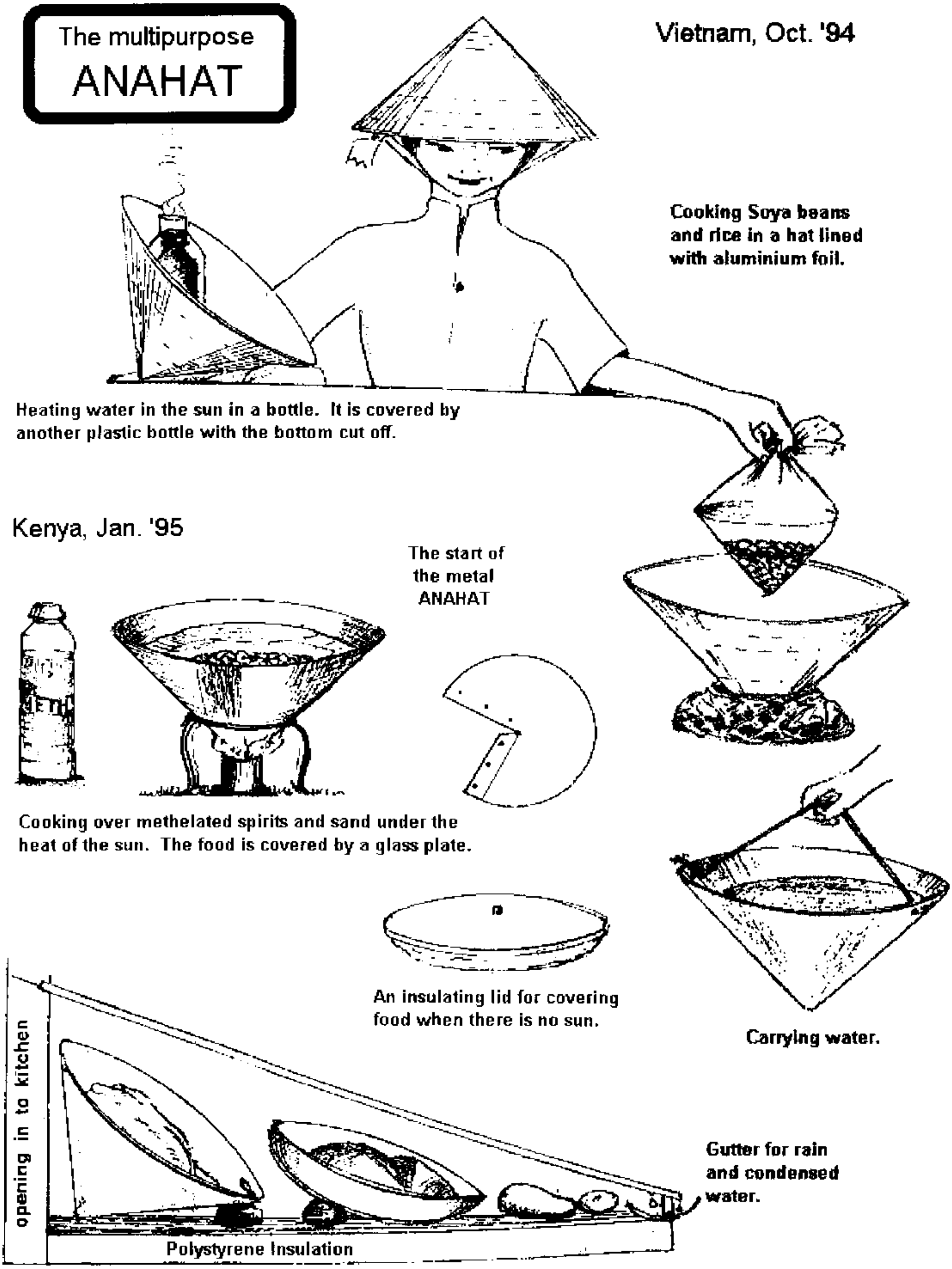


4. Place cooking pot in the center of panel cooker and cover it with insulator. It will heat up faster if you put a small cake rack or a few pieces of sticks under cooking pot and insulator.





The multipurpose ANAHAT



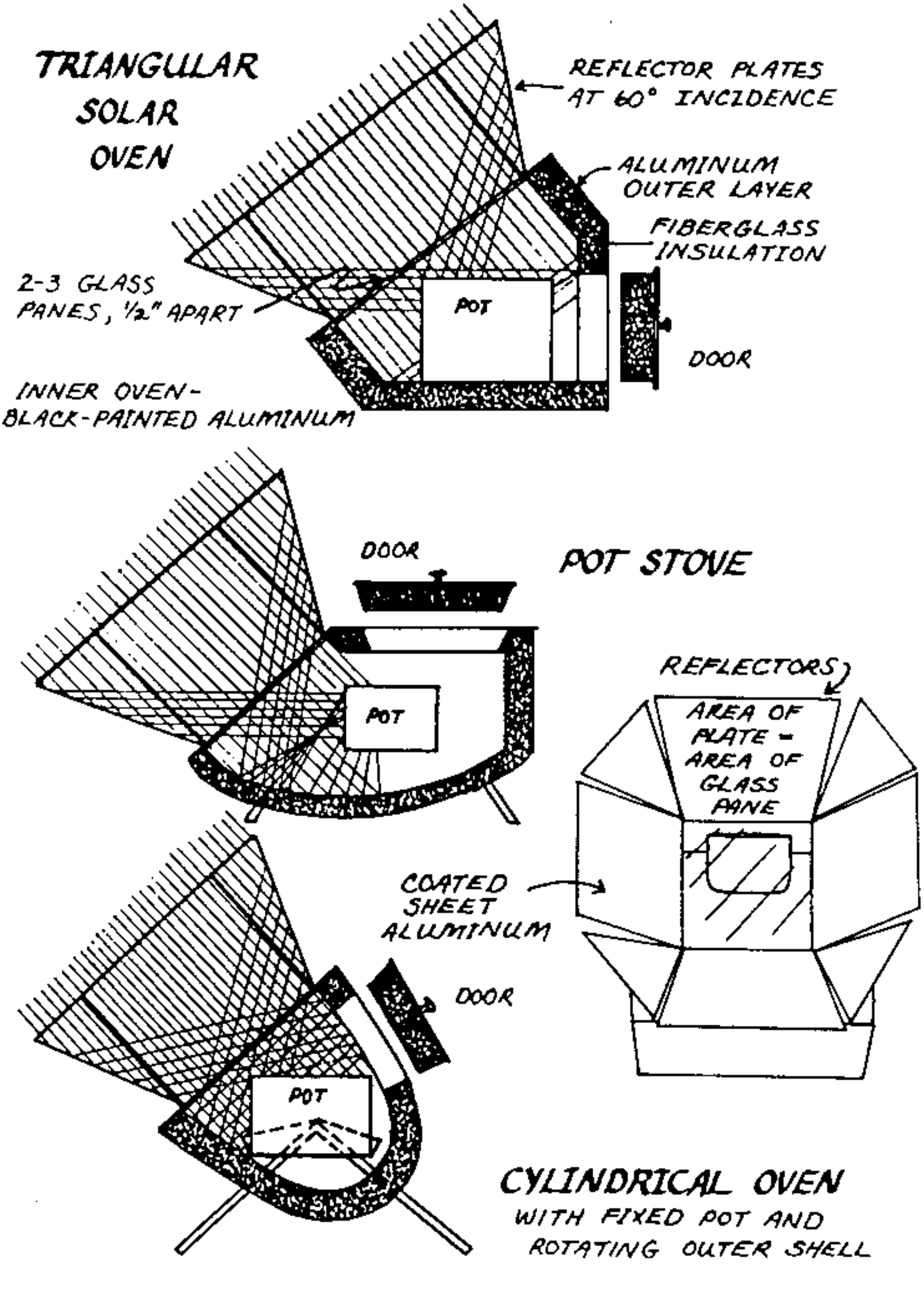
http://ourworld.compuserve.com/homepages/cleovoulou/anahat.gif

Actually the direct focusing is not the most intelligent way to use solar energy. A better way is to use a heat storage device, which can be sand or soil in a black metal box. By sinking the reflector below ground level the cooker can be very neatly arranged to cook food quietly and steadily without any danger of burning the food.

Solar cookers can take three forms depending on whether they use parabolic reflectors, plane reflectors or lenses. A cooker using a parabolic reflector can be made from an army surplus search light. In case you cannot get one of these the parabolic mirror can be made, in segments, from aluminum sheet. A parabolic mirror with a diameter of 3½ feet and a focal length of 18 inches will focus enough heat on the base of a Dutch oven to cook almost anything, provided the mirror is adjusted from time to time to compensate for the earth's movement and the altered angle of the sun. It is possible also to build a parabolic mirror in the form of a trough about 4½ × 9 feet. The formula of curvature of such a mirror is $y^2 = 120x$.

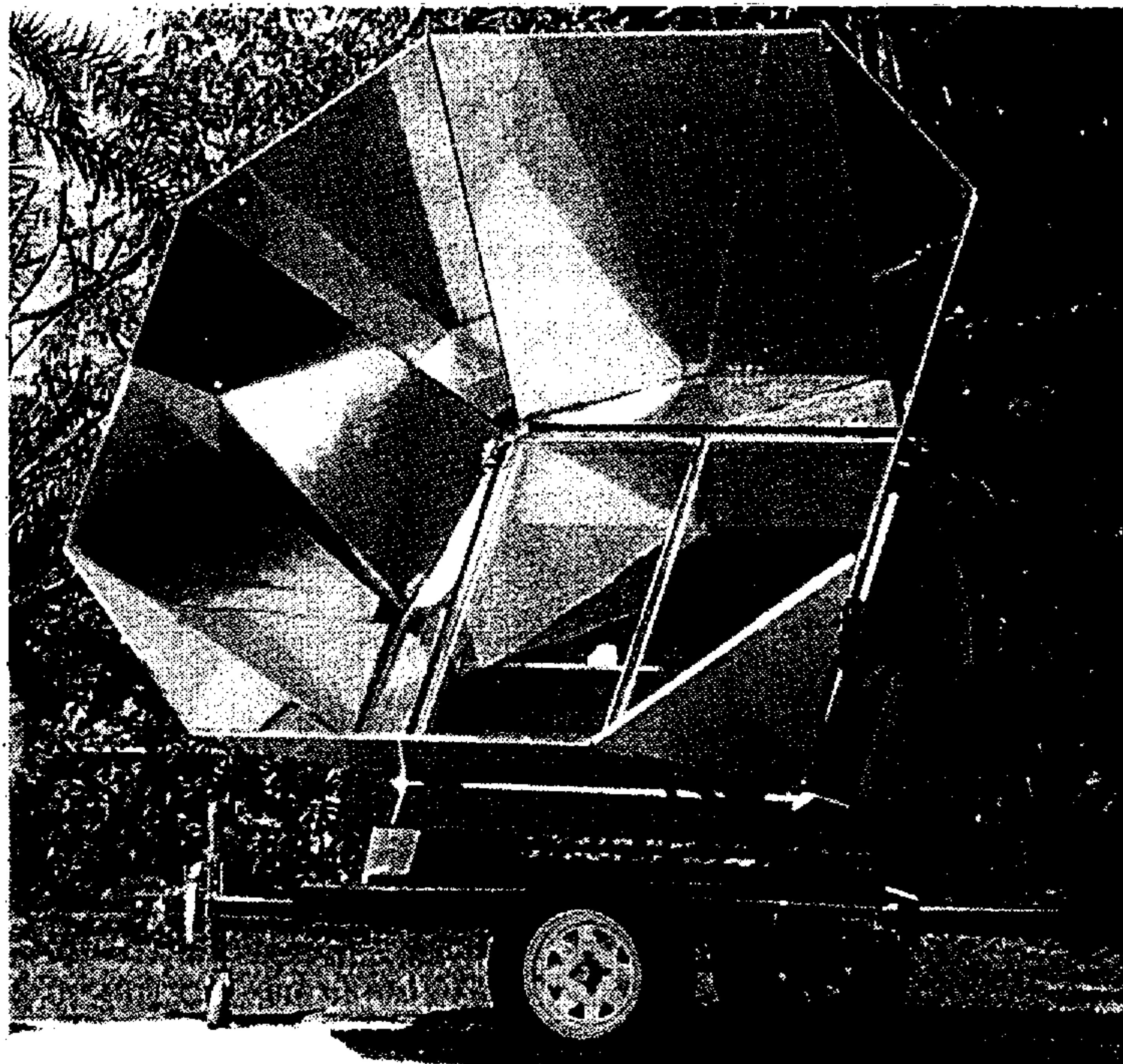
Simpler to make is a plane reflector cooker of the type developed by Dr. Maria Telkes. It involves eight flat sheets of polished copper or aluminum mounted on a hinged frame at such an angle that the sun's rays are directed onto an oven in the center of the array. The oven should be black to absorb the heat. With this device oven temperatures of 400° F can be attained (fig. 14).

A still simpler arrangement is to heat a fire pot by means of a Fresnel lens. These flat plastic lenses can be obtained from Edmund Scientific Co., 150 Edscorp Building, Barrington, N.J. 08007. The 19½ × 24¾-inch lens can be arranged to throw solar heat on an insulated fire pit of sand or onto an insulated oven. If the lens is adjusted to focus more sharply it can be used as a solar furnace.



SOLAR COOKERS (Maria Telkes Design)

17: Catalogue # March 1995. Real Goods. Ukiah California USA 1995.



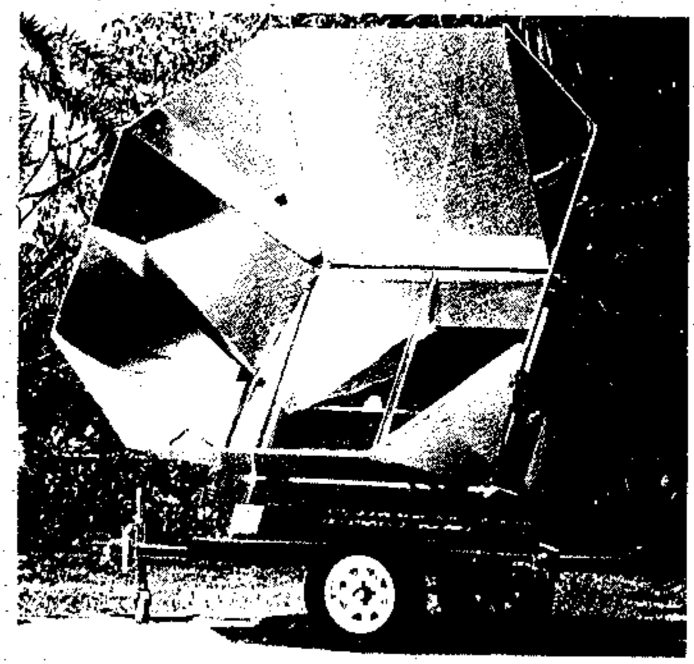
Feed A Village

Above: Tom Burns' huge "Villager" oven next to a more traditionally sized "Sun Oven."

Solar Cooking From Wisconsin To Jamaica

When Tom Burns retired from 35 years as a restaurateur, he combined his creativity with his humanitarian leanings and developed a way to harness the sun's energy for cooking and boiling water. His lightweight and portable Sun Oven provided the perfect answer to several problems in developing nations: sparse fuel supplies, poor sanitation, and lack of technical expertise.

"Through no fault of his own," says Tom, "the citizen of the developing world has a very short-term view of things—getting through the day, somehow. He ravages the landscape in his endless quest for fuel, cutting down trees indiscriminately, creating deserts where once forests reigned. This brings about erosion as wind and rain remove the topsoil, and the cycle of deprivation begins. No crops, no fuel, endless migration to open up new areas, then actual climatic change and even starvation."



Feed A Village

There is also a larger, mobile version of the Sun Oven. This unit will bake 50 loaves of bread at a time, making it ideal for use in villages, refugee camps and schools. The Villager weighs about 700 pounds and looks like a huge satellite dish. It can also purify hundreds of gallons of water or sterilize a small hospital's supply of medical instruments. Temperatures inside the oven can reach up to 400 degrees F in about 10 to 15 minutes.

Burns worked closely with Sandia's Solar Thermal Design Assistance Center for testing and design refinement. So far the Sun Oven has been exported to over 100 countries. The oven was used at a base camp 17,600 feet up Mount Everest and by military personnel during the 1991 Persian Gulf War. The company's first facility was in Wisconsin and they have now built an additional factory in Jamaica to be closer to Caribbean and Latin America markets.

■ **63-356 Villager Sun Oven $8,665**
(Please call or write for specifications and additional shipping charges.)

18: Solar Cooking Manual. Brace Research Institute. Quebec Canada 1982/1997.

SOLAR COOKER MANUAL - Brace Research Institute - 1982

Type SOLAR OVEN - TELKES TRIANGULAR MODEL

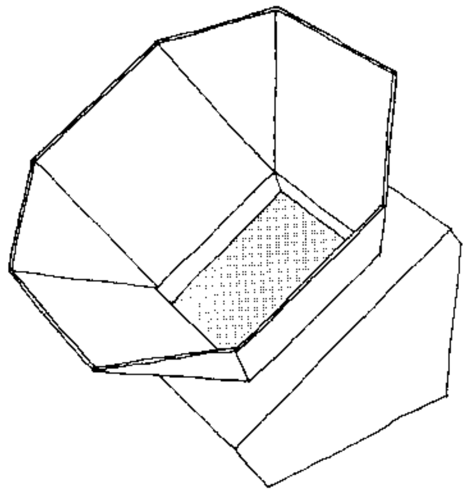
Features Designed especially for equatorial latitudes with the window tilted at 30° from the horizontal. Highly polished aluminum sheet or foil is used for the reflective surfaces. A black absorber plate immediately behind the glazing absorbs solar radiation and distributes heat to the other interior walls of the oven, and thence to the cooking pot, by conduction and radiation.

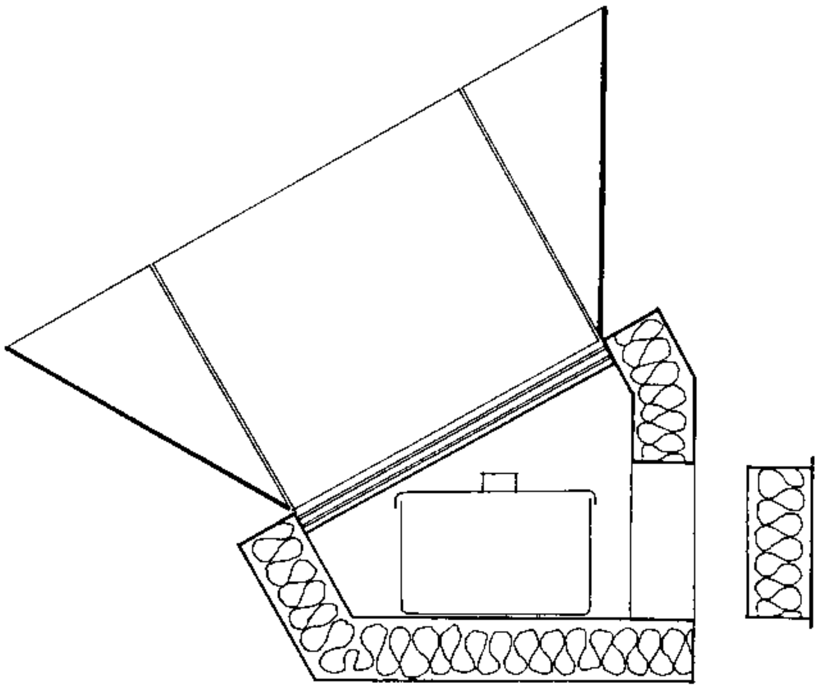
Status Many prototype and operational field ovens of this type have been built by a variety of researchers and other users since the design was first described by Dr. Maria Telkes in the early 1950's.

Description The triangular oven's main features are given in the following sketch The inner oven liner is made of sheet metal with all seams well attached by riviting or double bending to provide good heat transfer. This inner liner is in good thermal contact with the black painted absorber plate which is immediately behind the glass window. The external covering is made of thin sheet metal or other suitable material, such as thin wood, plywood or even waterproofed cardboard. The space between these coverings is filled with an insulating material (glass wool, etc) capable of withstanding temperatures up to 300 °C. The window can be double or triple glazed (although double glazing is sufficient), and the reflector surfaces are of highly reflective sheet aluminum. Glass mirrors are too heavy and require additional framing which can increase costs. More recently developed aluminized film plastic sheets, appropriately supported, can be used as the reflective surfaces. Four plane mirrors are mounted at 30° from the normal to the window.

A plug-type door permitting entry to the cooking chamber is located in the back wall of the oven. The inner side of this door is lined with reflecting material while the remainder of the oven inner liner can be any colour since colour has no effect on radiation emission in the long infra-red.

The oven is made with a cooking space sufficient for the needs of a family, with a "window" area of approximately 0.2 square metres. The entire oven is portable and weighs 7 to 10 kg. The window of the oven must always face the sun. As the sun altitude changes throughout the day, the solar oven must be tilted accordingly. Suitable legs or spacers can be used to tilt it.





Performance	On clear days, cooking time is reported to be approximately the same as with conventional cooking fires or with kerosene or gas burners. On hazy or partly cloudy days, the cooking time is considerably longer. On clear days oven interior temperatures of 210 °C are common.

Advantages

- Can bake, roast and boil foods.
- Does not require exact focussing and orientation.
- Can be used to cook even in relatively cold, sunny weather.
- Two or three pots of food can be cooked at the same time, depending on the size of oven built.
- Food can be kept warm for a short time after sunset.
- Easy to use.

Disadvantages

- Materials for construction are not always easily available.
- Costs are somewhat higher than for hot-boxes.
- Cooking has to be done outdoors.
- The oven has to be frequently oriented and tilted toward the sun. If the tilt is more than 20°, food placed in a large container may spill. This limits the Triangular oven's usefulness to periods of the day when the tilt will not be excessive.
- Unstable in windy weather.

Costs No costs are given.

Materials of Construction Glass, sheet metal, insulation, reflecting sheet aluminum or other suitable mirror surface, flat black paint.

Dimensions 0.8 m x 0.8 m x 0.8 m with mirrors extended. Larger ovens can be built.

Location Originally developed at New York University, New York, N.Y., U.S.A. Many experimenters throughout the world have subsequently built and operated similar solar ovens.

Climatological Requirements The Triangular Solar Oven uses both direct and diffuse solar radiation. The "window" permits the entry of diffuse or sky radiation and direct radiation from the sun, in addition to reflected direct radiation from the mirror surfaces. Diffuse radiation is scattered by the mirror so only a fraction of this is reflected to the black absorber plate.

Clear, cloudless days permit best cooking performance, however, cooking can be undertaken at a slower rate on hazy and partly cloudy days.

Practical Operation There is no information available on how many of these units have been constructed, nor is there any information on the longevity and usefulness of the ovens as substitute cooking systems.

Cooking Information No specific information is given. However, some indication can be obtained from another Telkes oven - the "Cylindrical Oven".

Operating Conditions The "window" of the solar oven should always face the sun. As the altitude and orientation of the sun change continuously during the day, the solar oven must be tilted and re-oriented accordingly. Care must be taken not to tilt the oven too far (in excess of 20° to 30°), since food in larger pots may spill out. Changes in tilt and orientation will be necessary every $\frac{1}{2}$ to 1 hour. Telkes reports that stirring of food is unnecessary since the surfaces of the food pot are heated uniformly and can never reach high enough temperatures to produce scorching. This may or may not be true. It is possible that certain types of food may not require stirring. On the other hand, thick stews and milk products require regular stirring, often at lower temperatures than those obtained in a solar oven, in order to obtain better heat transfer and distribution throughout the cooking material.

Estimated Life 5 to 10 years with proper maintenance and cleaning of mirrors.

Comments on the Cooker The Triangular oven is the simplest to fabricate of the three Telkes ovens described in this survey. However, its major drawback is its inability to track the sun at high solar altitudes due to excessive tilting of the oven and thus spillage of food. Triangular ovens can be designed with higher solar altitudes in mind. However, these will be relatively less effective at lower solar altitudes.

These ovens are difficult to use in windy conditions because the large, light mirror surfaces catch the wind and make the ovens very unstable.

References

Telkes, Maria, Solar Stoves. Trans. of the Conference on the Use of Solar Energy, Vol. 3, Part 2, pp. 87-98, Tucsan, Arizona, 1955.

Telkes, Maria, The Solar Cooking Oven, New York University College of Engineering Research Division, New York, Jan. 1958.

F.A.O. Report on Tests Conducted Using the Telkes Solar Ovens and the Wisconsin Solar Stove over the period July to September, 1959, E/conf. 35/S/116, U.N. Conference on New Sources of Energy, Rome, 1961.

Contact People

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Killeen, Texas 76541 U.S.A.

Unfortunately Maria Telkes, a great pioneer in Solar Cooking Technology, has passed away.

Type SOLAR OVEN - TELKES POT STOVE MODEL

Features Designed to permit cooking from the top. Inner surface of oven is reflective. The cooking pot is pivot mounted inside the oven so that any tilt of the oven from horizontal through vertical, to follow the sun, will have no effect on the horizontal position of the cooking pot.

Status Several prototype and operational field ovens of this type have been built by a variety of researchers and other users since the design was first published by Dr. Maria Telkes in the early 1950's.

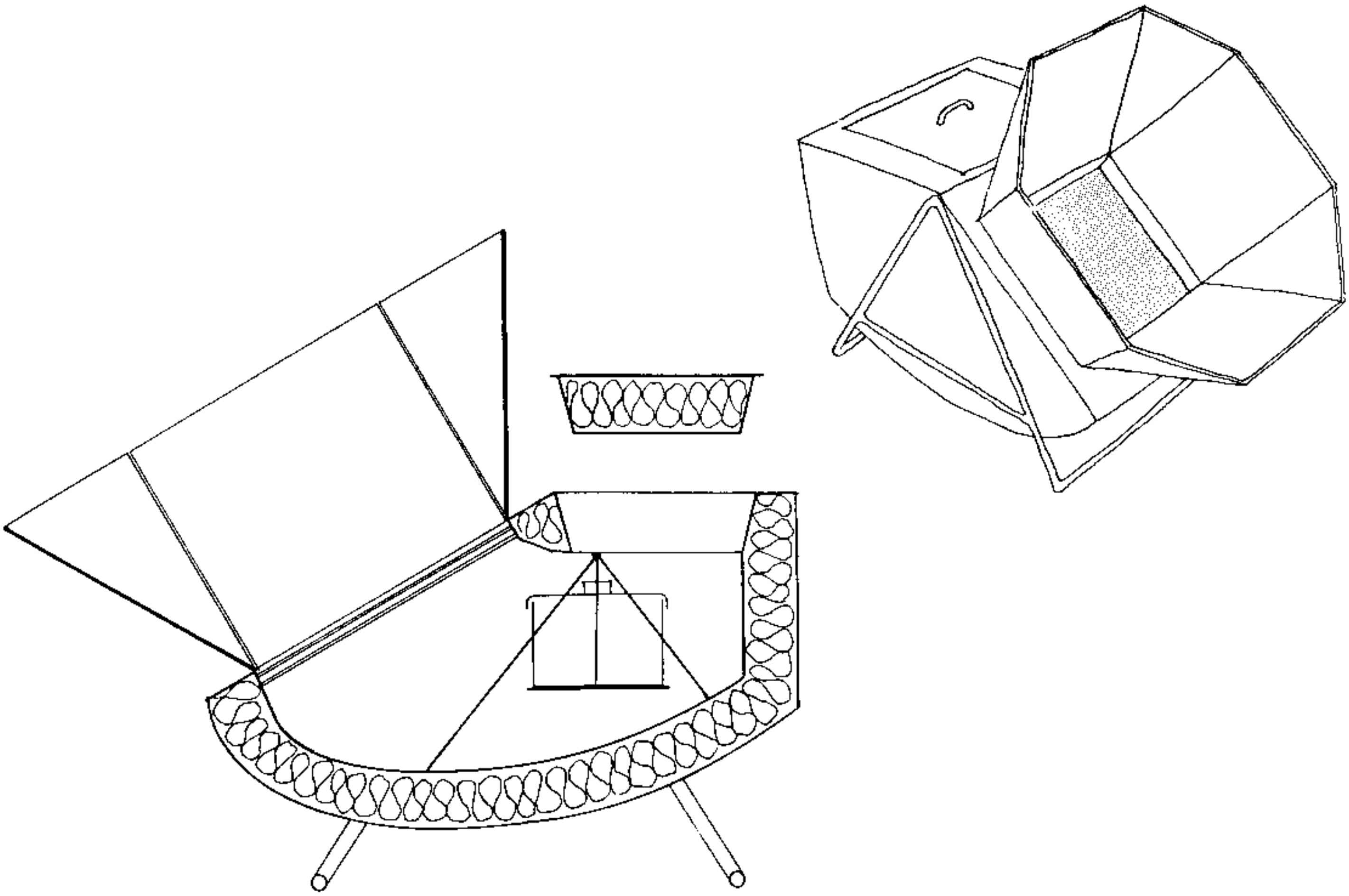
Description The Pot Stove has been designed so that the pot is pivoted inside the oven in specially designed pot holders and platforms, and can swing over an angle of at least 60°. The interior of the oven is lined with reflecting surfaces which are positioned so that they reflect the maximum solar radiation on to the cooking pot. The external covering for the oven is any suitable material such as thin sheet metal, wood, plywood or waterproof cardboard. The space between the inner and outer liners is filled with an insulating material capable of withstanding temperatures up to 300 °C. The window is usually double glazed and the reflector surfaces are of highly polished sheet aluminum or well protected and supported aluminized film plastic sheets. Four plane mirrors are mounted at 30° from the normal to the window and triangular mirror sections can be inserted in the gaps left when the four larger mirror sections are installed in operating position.

The plug-type door above the cooking pot is well insulated, fits very tightly into the opening and is made to lift easily to permit access to the pot.

The oven is generally suitable for one larger cooking pot. The window area is approximately 0.2 square metres and the oven is portable, weighing just slightly more than the Triangular oven.

The surface of the cooking pot must be covered with a dull black coating to absorb solar radiation.

The Pot Stove is mounted on a stand which can be low for those who prefer to cook in a squatting position, or it can be high for those who prefer sitting or standing while cooking. The stove can be tilted to follow the sun's position in the sky. The appropriate tilt is maintained by a peg attached to one of the stove legs. The peg fits through the leg and into one of a series of holes appropriately drilled into the side of the outer surface of the oven.



<u>Performance</u>

On clear days, cooking time is approximately the same as with conventional cooking fires or with kerosene or gas burners. On hazy or partly cloudy days, the cooking time is considerably longer. On clear days, oven interior temperatures of 210 °C are easily obtained.

<u>Advantages</u>

. Can bake, roast and boil foods.
. Does not require exact focussing and orientation.
. Can be used to cook even in relatively cold, sunny weather.
. Permits cooking from the top - i.e. stirring of food can take place while the pot is still in the oven.
. The stove is mounted to permit easy focusing adjustments.
. Food can be kept warm for a short time after sunset.
. Easy to use.

<u>Disadvantages</u>

. Somewhat more costly than Triangular stove due to increased size of the oven.
. Generally suitable for cooking only one pot of food at a time.
. Cooking has to be done outdoors.
. Spilling of food may result in the deposition of food on the internal reflector surfaces.
. The oven has to be periodically oriented and tilted toward the sun.
. Materials for construction are not always easily available.
. Unstable in windy weather.

Costs No costs are given.

Materials of Construction Glass, sheet metal, insulation, reflecting sheet aluminum or other suitable mirror surface, flat black paint.

Dimensions 1.0 m x 0.9 m x 0.8 m with mirrors extended.

Location Originally developed at New York University, New York, N.Y., U.S.A. Many experimenters throughout the world have subsequently built and operated similar ovens.

Climatological Requirements The Pot Stove uses both direct and diffuse solar radiation. For further information see Climatological Data for the Telkes Triangular Model.

Clear, cloudless days permit best cooking performance , however, cooking can be undertaken at a slower rate on hazy and partly cloudy days.

Practical Operation There is no information available on how many of these units have been constructed, nor is there any information on the longevity and usefulness of the ovens as substitute cooking systems.

Cooking Information No specific information is given. However, some indication can be obtained from another Telkes oven - the "Cylindrical Oven". The contents of the cooking pot became heated somewhat more rapidly than in the Triangular oven, because heat is delivered directly, by reflected radiation, to the pot.

Operating Conditions The windows of the Pot Stove should always face the sun. As the altitude and orientation of the sun change continuously during the day, the solar oven must be tilted and re-oriented accordingly. Re-orientation is a simple matter of adjusting the position of the legs of the oven to permit the window to face the sun. Tilting is likewise a simple matter. The tilting peg is removed, the oven tilted until the window is perpendicular to the sun's rays, and the peg is re-inserted to lock the oven in position. The oven orientation and tilt have to be adjusted about every one half to one hour.

For comments on stirring, see the Telkes Triangular Model.

Estimated Life 5 to 10 years with proper maintenance and cleaning of interior reflective surfaces. If spillage of food occurs often on the reflective surfaces inside the oven, the effect of the dirt and the action of cleaning it off will gradually reduce the reflectivity of the reflector surface. This may decrease the useful life of the oven to much less than 5 years.

Comments on the Cooker The requirement for top cooking made it necessary to increase the volume of the oven, in order to place the pot under a suitably located door. This increased volume leads to increased heat losses from the oven walls as compared with the Triangular oven, and increased materials and fabrication costs.

These ovens are unstable in winds due to the large area of extended mirror surfaces.

Food in this oven can be stirred at any time since heat transfer to the pot is by reflected radiation to all sides and bottom of the pot and very little of the heat transfer is due to convection of hot air within the oven. Water or food can be boiled briskly and the boiling continued, even if the oven cover and pot lid are removed for a short time.

References — See "Solar Oven - Telkes Triangular Model", page 51.

Type — SOLAR OVEN - TELKES CYLINDRICAL OVEN

Features — The inner surface of the oven is reflective. The cooking pot is in a fixed horizontal position, attached to the oven's supporting legs. The shell of the oven can be rotated to virtually any position, tilting the window from vertical to horizontal, to follow the sun.

Status — Several prototype and operational field ovens of this type have been built by a variety of researchers and other users since the design was first published by Dr. Maria Telkes in the early 1950's.

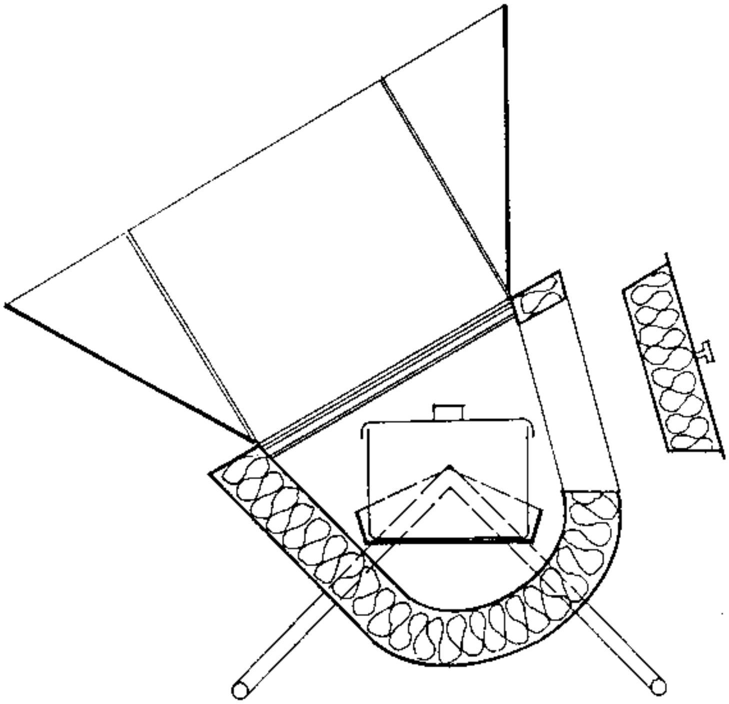
Description — Several varieties to this model have been built. The unit described here makes use of a black painted stationery cooking platform inside the rotatable oven shell. The cooking platform is attached through the outer shell, to the oven's support legs and the oven shell can be rotated into any position relative to these legs, tilting the window from vertical to horizontal.

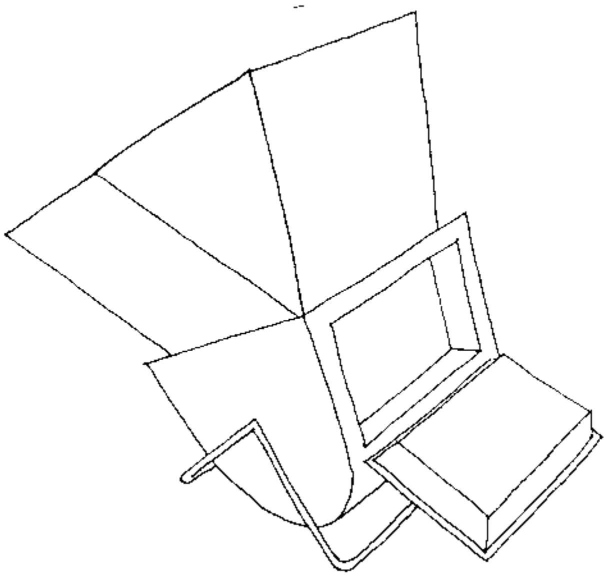
The interior of the oven is lined with reflecting surfaces to direct solar radiation to the cooking pot. The external covering for the oven is any suitable weatherproof material such as thin sheet metal, wood, plywood or waterproof cardboard. The space between the inner and outer liner is filled with an insulating material capable of withstanding temperatures up to 300°C. The window is double glazed and the reflector panels are of highly polished aluminum sheet or well protected and supported aluminized film plastic sheets. Four plane rectangular mirrors and four triangular mirrors are mounted at 30° to the normal to the window.

A plug-type door is mounted in the back wall of the oven. This door is well insulated and tight fitting.

The oven can be long in the axial direction and thus can be suitable for several cooking pots. The window area is approximately 0.2 square metres and the oven is portable,weighing less than the other ovens of the same window area.

The surface of the cooking pot must be coated with a flat black coating to absorb solar radiation.





Performance On clear days, cooking time is approximately the same as with conventional cooking fires or with kerosene or gas burners. On hazy or partly cloudy days, the cooking time is considerably larger. Clear day oven interior temperatures of 220°C are readily obtainable. According to Hoda (1977), the cooking time for a pot of rice in the summer is 45 minutes, and in the winter is 90 minutes.

Advantages

- Can bake, roast and boil foods
- Does not require exact focusing and orientation
- Can be used to cook even in relatively cold, sunny weather
- Two or three pots of food can be cooked at the same time, depending on the size of oven built.
- Some heat can be stored, mostly in the heated food and water, thus permitting the preparation of food in partly cloudy weather.
- Food can be kept warm for a short time after sunset.
- Is very simple to orient toward the sun.
- Lowest materials cost of the three Telkes ovens described herein.
- Easy to use.

Disadvantages

- Materials for construction are not always easily available.
- Cooking has to be done outdoors.
- The oven has to be periodically oriented and tilted toward the sun.
- Spilling of food may result in the deposition of food on the interior reflector surfaces.
- Unstable in windy weather.

Costs

Rs 400/- or $60.00 U.S. according to Hoda, 1977.

Materials of Construction

Glass, sheet metal, insulation, reflecting sheet or other suitable mirror surface, flat black paint.

Dimensions

0.9m X 0.9m X 0.8m with mirrors extended.

Location

Originally developed at New York University, New York,N.Y.,U.S.A. Many experimenters throughout the world have subsequently built and operated similar ovens.

Climatological Requirements

See Telkes Triangular Stove

Practical Operation

There is no information available on how many of these units have been constructed, nor is there any information on the longevity and usefulness of the ovens as substitute cooking systems.

Cooking Information

Foods that have been successfully cooked in this oven include the following:

Boiled Foods - Soups, meat or fish stews, rice, macaroni, fresh and dried vegetables, jams and fruit preserves. Cooked with very little added water, vegetables were excellent in taste, texture and colour.

Baked Foods: Breads of all types, rolls and cakes.

Roasts: Chicken, meat loaf, pot roast, veal, pork and roast beef.

Special foods cooked included oriental dishes and Navajo Indian dishes.

Operating Conditions

Operation is similar to the Telkes Pot Stove, the major difference being that the tilt is adjustable through a greater range of window slopes, from horizontal to vertical.

Estimated Life

Five to ten years with proper maintenance and cleaning of interior reflective surfaces. If food often spills on the interior reflective surfaces, even though the dirt is cleaned off, the reflectivity of these surfaces will decline. This may decrease the useful life of the oven to much less than five years.

Comments on the Cooker

These ovens are unstable in windy weather due to the lightness of the oven and the large area of extended mirror surfaces.

Of the three Telkes ovens described here, the Cylindrical oven is the least expensive from a materials point of view. It has the least heat loss area, thus it should be expected to give the quickest cooking results.

Reference

Solar Oven - Telkes Triangular Model and Solar Cookers and Water Heaters by Nigel Florida, Appropriate Technology Series, Bardoli, India, 1974.

Solar Cooker by M.M.Hoda, Appropriate Technology, Vol.4, No.2.

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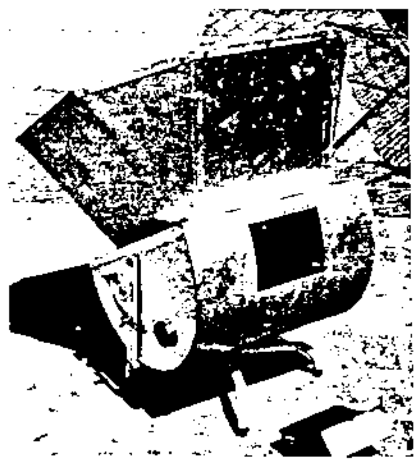
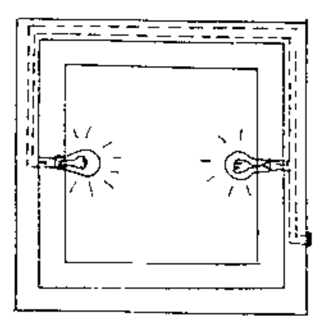


Type HOT BOX - WITH REFLECTOR MIRROR AND LIGHT BULB ASSIST

Features Essentially a modification of single reflector hot box, carried out by M.M. Hoda, Director of Appropriate Technology Development Association, Lucknow, India. When there is no sun, the cooker is connected to the electrical mains, which lights up two 100 Watt light bulbs. An insulating sheet is placed underneath the glass cover and the mirror lid is closed.

Status Four prototypes have been built and are being tested in Lucknow in Hoda's house and the ATDA office, and are showing remarkable results.

Description The light bulb solar cooker is a wooden box filled with fibre glass insulation material and an aluminum tray painted black inside, which holds four cooking pots of one litre capacity each. Two 100 Watt bulbs are fitted on two sides. This box is closed on the top with a wooden frame fitted with two glass sheets in parallel at a distance of ¼". Underneath the glass sheet lid one removable asbestos sheet is provided, which is removed when the cooker is used with the sun. On the top a mirror is fitted which can be inclined at any angle my means of a travelling guide and a wing nut (see figure below). Under sunny conditions, this cooker is similar to the hot box with single reflector. At night or on cloudy days, the cooker is connected to electricity. An asbestos sheet is placed under the glass sheet and the lid closed.



Performance Cooking is slow, but needs little attention. Some foods can be cooked in less than 2 hours using the light bulbs only, using an electricity consumption of 400 Watt-hours. Unlike conventional solar cookers, it gives reproducible results because of a constant supply of 200 Watts of energy. This cooker can also be used for measuring energy required to cook various types of food.

Four dishes can be cooked at one time. The maximum temperature attained in the cookers without food, using two 100 Watt bulbs, was 135 °C. The temperature attained using solar heat varied but on a bright sunny day it attained 140 °C, and with food material, up to 120 °C.

Advantages

- No attention needed when cooking
- Can be used with sun, as well as electricity when the sun is not shining
- No need to track the sun
- Easy to operate and maintain
- Can be used for purposes other than cooking, e.g. drying fruits and vegetables, heating water
- Can be built with readily available materials

Disadvantages

- Cannot fry food or cook chapatis, a local unleavened bread
- Heavy, it cannot be moved by women
- Risk of breaking of glass

Costs At 1982 prices, $60 (U.S.), with bulb and wire, plug attachment.

Materials of Construction Wood, glass, aluminum sheet, aluminum pots, glass wool insulation, mirror, paint, rubber packing, handle, hinges, castor wheels, electric bulbs, electrical wires, socket, plug.

Dimensions 0.8 m x 0.8 m x 0.5 m

Location Lucknow, India

Climatological Requirements Sun cooker requires direct sunlight. Cloudy weather will limit the temperature.

Cooking Information The author indicates that many varieties of Indian foods were cooked successfully in 4 prototypes, in sun as well as with electric bulbs.

Comments on the Cooker This cooker can be used as a solar cooker when the sun shines and as an electrically heated insulated hay box when the sun disappears behind clouds or in the evenings and early mornings. The heat generated by the light bulbs is low intensity, thus cooking will be slow when the light bulbs are on. The electrical parts of this cooker make its application suitable only to areas with electricity. Notwithstanding this limitation, this cooker is very interesting in that it illustrates the thought that is being given to multiple energy-source cooking systems.

Comments on the Cooker (contd)	The adaptation to electricity is simple enough, however, potential users should be aware that in many developing country situations, village electricity systems are designed for household capacities of less than 200 Watts.
Estimated Life	15 to 20 years. Glass may break but can be easily replaced.
Reference	Hoda, M.M., Bulb and Solar Cooker, Proceedings of Energex 82 Conference at Regina, Canada, 1982.
Contact	M.M. Hoda Director, Appropriate Technology Development Association Lucknow 226001, India

Indigenous Materials Solar Cooker Contest

Kathleen Jarschke-Schultze

and Therese Peffer

Above: The solar cooker cookoff at SEER '92. Front left is Maria Gonzalez's portable cooker, front right is Jay Campbell's "hole-in-the-ground" cooker, center is Lu Yoder's parabolic cooker, and further back is Michael Diogo's carrizo- mud-and-tin can box cooker.
Photo by Therese Peffer

The sun shines on the rich and poor, hungry and well-fed alike. In the United States, a growing number use the sun's energy to cook food, with solar cookers built from scrap and low cost materials, such as cardboard, foil, and glass. What are some low cost or scrap materials in other countries that could be used to make solar cookers? In *Home Power* issue #28, we asked readers to design and build a solar cooker using materials readily available in a developing country of their choice.

We received numerous phone calls; eight entries made their way to HP Central. Alan Nichols sent his design for a tracking solar cooker. Another reader sent a sample of fiber cement that could be formed into walls for a cooker. Philip Hodes' simple waterproof cooker required a plastic milk crate, plastic mirrors for reflectors, and foil-backed foam for insulation.

We chose four cooker designs to build for the cookoff Saturday at the Solar Energy Expo and Rally 1992 in Willits, California. The four finalists were chosen based on their use of simple, "low tech" materials and included a bamboo-type box cooker, a hole-in-the-ground model, a parabolic design, and a foldable cooker.

Judgment Day

We built the four finalists' models from their instructions.The top four designs were judged on validity of materials, ease of assembly, clear instructions, ruggedness, beauty of design, and ability to cook food. Each cooker held a yam, and equal amounts of black beans and brown rice cooked in black painted jars. The cookers were placed in the sun at 10:30 am and adjusted throughout the day until 3:00 pm.

Our four judges were Paul Mellersh, Board of Directors SBCI; Johnny Weiss and Felicia Trevor of Solar Technology Institute; and Kathleen Jarschke-Schultze. C. Jay Campbell's hole-in-the-ground design took 1st place, winning a Solarex MSX-60 solar panel. Michael Diogo placed 2nd with his carrizo cooker, winning a PowerStar

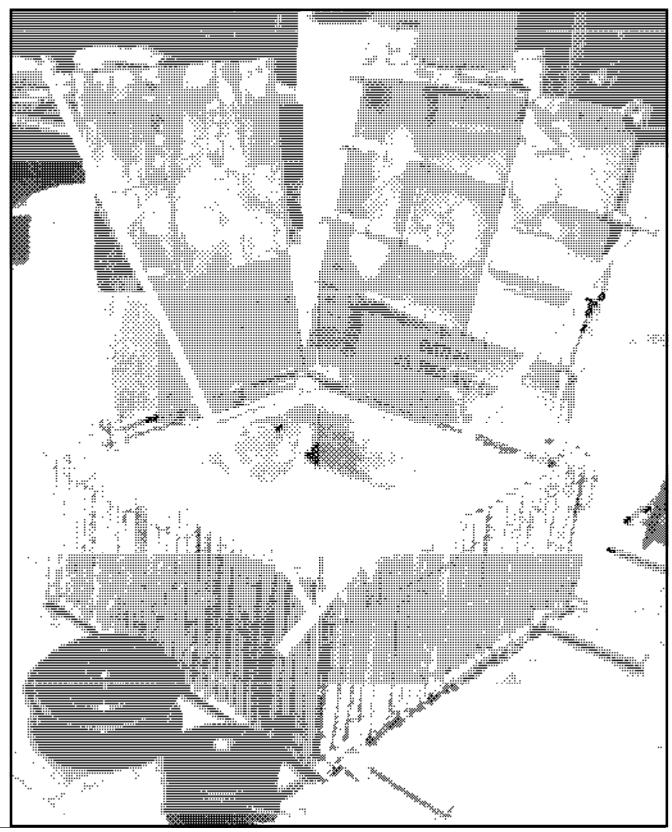
200 inverter. Maria Gonzalez's foldable design won 3rd place, and Lu Yoder's frustum-based model placed 4th; they chose either an Osram compact fluorescent light or a Kyocera Jetski PV module as their prize.

The Top Four

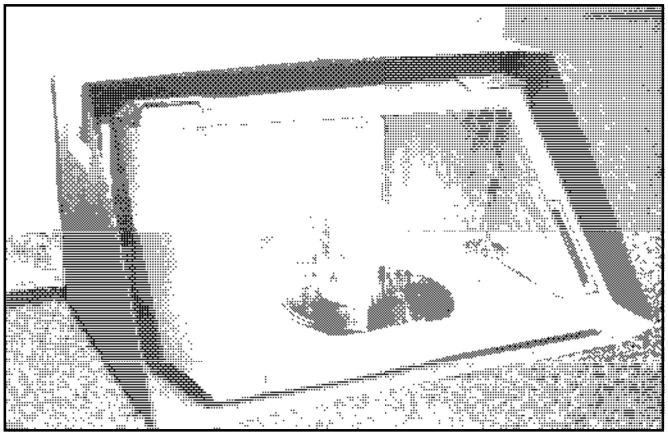
Jay Campbell's design, targeted for Guatemala, was beautifully simple. His cooker required a hole in the ground insulated with newspaper, and a conical reflector to concentrate the sun's rays onto the black plastic pan holding the cooking pot. Jay used a junked car's side window for glazing and fashioned reflectors from cardboard and aluminum foil. Jay's design scored high on all criteria; the lowest scores were for ruggedness, because of the cardboard. We couldn't dig a hole at SEER, so we used a cardboard box filled with newspaper. Judges' comments, "Good instructions, could be totally pictorial, maintained heat well." Overall score: 258.5

Above: Jay Campbell's cooker won first place. Photo by Jay Campbell

Below: The weather-proof carrizo cooker from Michael Diogo took second place. Photo by Michael Diogo



Michael Diogo, from Baja California, Mexico, scored high in material use, ruggedness and clear instructions with his box cooker built from carrizo (a native plant similar to bamboo). He wired lengths of carrizo to make the walls and floor of the interior and exterior box. Dried grass was stuffed between the boxes for insulation. The interior box was daubed with mud and black magnetic sand was poured on the bottom. Michael removed the bottoms of over 100 bottles before finally succumbing to sheet glass for glazing. For reflectors, he cut open rectangular tin cans and banged them flat. Michael wrote that two years ago, 300 cardboard and foil cookers were donated to the Baja natives, but not one is left today. "No time was spent training the people to use the oven and adapt it to the traditional methods of preparing foods." He mentioned that the little huts people live in are "made of cardboard and plastic wrap, leak like sieves and there is no room inside for a solar oven to take up precious space." Michael designed his cooker with native materials to survive outdoors. Building the cooker was labor intensive. Judges' comments, "Very imaginative and elegant in design." Overall score: 202.5

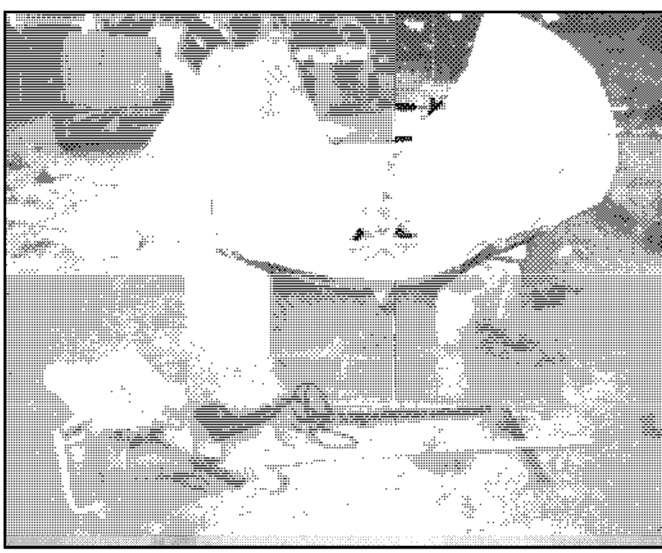


Top: Maria Gonzalez's foldable cooker placed third.
Photo by Maria Gonzalez

Maria Gonzales' triangular cooker uses velcro straps so it unfolds flat for travel or storage. She uses cardboard for the interior and exterior boxes, and adds foil and glass to the interior box which holds the cooking pot. The insulation between the boxes can be a blanket, newspapers, or whatever is on hand. Maria's cooker consistently scored high on ruggedness and beauty of design. Judge's comments, "Great idea, may need to be tilted back in countries close to the equator. Clean design." Overall score: 185.5

Lu Yoder wrote that since he'd never been to a developing country, his Liberation Technology: "no weld" solar cooker design was made from materials readily scavenged from an Albuquerque, New Mexico barrio. Tools were bartered or bought at the local flea market. He used three frustums, or cone reflectors, to approximate a parabola. A metal conduit frame supports the aluminum foil and cardboard reflectors. Lu wrote that there are rich and poor in all countries of the world. "The poor in both countries stand to benefit very much from technology which partly frees them from the toil of gathering fuel and destroying their own ecosystems...." He pointed out that the world's resources would be most affected if we changed our cooking habits in the U.S. "Solar cookers made from secondary and low cost materials have the potential to help people in all parts of the world struggle for economic justice." While scoring high on most criteria, Lu's design scored low on ease of assembly and clear instructions. Judges' comments, "Attained highest temperature, instructions hard to understand." Overall score: 161

Below: Lu Yoder's parabolic cooker came in fourth place.
Photo by Lu Yoder



The Winning Design

As promised, here are the plans of the winning design by Jay Campbell. Jay has travelled extensively to Guatemala. "On my recent visits, however, I have become very disturbed by the ever rising tree line around the cities. The hills are literally bald up to a certain altitude. As heating is only an issue in the highlands, much of the tree loss is due to cooking.

"Guatemala has a pleasant, springlike climate year round....Even during the rainy season, the sun shines most of the day, with about 3 hours of cloud cover. This pattern is typical throughout the interior of Mexico and Central America.

"Guatemala has a well developed plastics manufacturing sector. All types of plastic containers, bags, toys and household items are available at low prices in the many village markets. One of the most ubiquitous items is known as a PALANGANA (pronounced just like it looks, accent on the PA). It resembles a common oil change pan here, but is far more than that. Bathing, food preparation, laundry, storage, and coffee picking are typical uses. Two small ones suspended from either end of a stick forms the standard market scale. They come in a variety of sizes, cost from $0.50 to $2.50 U.S., and are used in every household. The palangana is truly an indigenous part of Guatemalan life.

"Construction time for the prototype was 6 hours. Total cost as built was $2.75. Maximum temperature witnessed was 150°C (300°F), but the temperature was still climbing at this point. Time to bring 1 liter of 20°C water to a full boil was 61 minutes. As designed, there is a maximum 4:1 ratio concentration of incoming radiation. When pointed at the sun, this would provide over 1000 BTU's per hour. Based on the boil test, about a third of that actually gets into the food. In actual use, 1 1/2 liters of black beans (the staple food in Guatemala) cook nicely when left unattended for the workday.

Rationale

"The heart of this cooker is a black palangana. The oil drain pan I bought in the U.S. is a little thinner and shallower than standard, but worked well with a cardboard heat shield in the bottom. In country, I would use a larger version to increase the volume. The glass used is from the side window on a junked car, another common item in the country. Standard window glass would work fine, but would probably cost more. All other materials—cardboard, foil, glue, string, and newspapers—are readily available in any population center in the country, for a low total cost. There is no hardware required, as the glass slides in and out of the cardboard frame like a drawer.

"The conical reflector captures just as much energy as the same sized parabolic reflector. The difference is that where the cone reflects all light into a relatively wide area, the parabola reflects it all into a single point. For food preparation, the wider area is preferable. An inclined base is used to correct for both latitude and seasonal changes. For anywhere out of the equatorial region (±10°), the tilting spacer is worth the effort. It can double the amount of incident radiation, and allows for tracking the sun. The tilt angle in the photo on the next page (22°) was built for my latitude (34° N), and should work well in Willits in August. For use in Guatemala, the tilt angle should be needed only during October–March, and would be 26°.

"Geometrically, a circle is the most efficient shape for a container, having the maximum possible area inside for a given amount of perimeter. What this means for cooker designs is that a maximum of sunlight will enter the oven while a minimum of heat will be lost through the sides. Also, the circular reflector is a good concentrator—by doubling the diameter, the energy input is quadrupled. The circular geometry maximizes the energy input for a given quantity of materials.

"I must justify the use of 'high tech' foil. It is widely available, and used in such small quantity that a single roll can make 9–10 reflectors. Split open aluminum cans (also widely available) worked about as well, but are very labor intensive to prepare. They are available for free, however. The stated goal of this contest is to use local materials. For Guatemala, foil is such an item.

"Another feature is the outer box—just a hole in the ground. Some siting considerations must be made (shading, local elevation, drainage), but no more than for other types of solar cookers. The main advantage is that almost anybody can afford a hole in the ground. A lining would be recommended for long term use, but is not essential. Tightly crumpled newspaper provides the insulation between the palangana and the ground. Newspaper may not be the best insulator, but by making the hole a little bigger and adding more paper, it can have a competitive R value with any insulated box.

Materials and Tools

Materials include: a palangana or shallow plastic pan, cardboard, foil, glue, string, glass, and newspapers. Tools: Sharp stout knife, sharp stick, straight edge, pencil, shovel, and instructions.

Construction

"Obtain palangana and a piece of glass which will completely cover it.... I recommend an 18–24 inch diameter pan for sufficient volume. Directions are given based on whatever sized parts you can acquire.

Cone

"Get a large piece of cardboard, or make one out of several smaller pieces. Lay out a [string] as long as 4 diameters of the tub. See Figure 1. Draw an arc from the center of the line, connecting the two ends, and cut out. Lay out a similar arc [1 diameter smaller], and cut it.

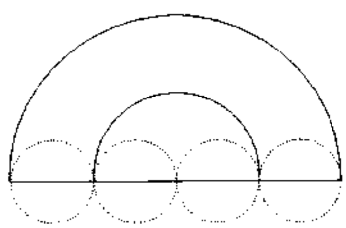


Figure 1

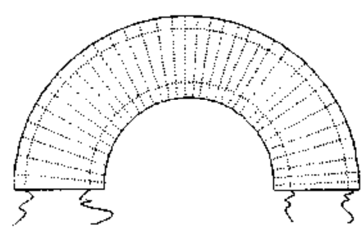


Figure 2

"Cut (score) the surface layer of the arc as shown in Figure 2 so that it can be rolled into a faceted cone. On the same side, score an arc near the two edges, and push a string into this cut. By pulling the strings tight, the cone will cinch up like a barrel. Paste foil completely over the unscored side and edges, and trim off excess.

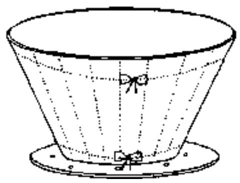


Figure 3

"Now pull up the strings and tie them off. Cut a ring to fit around the small end of the cone, as shown in Figure 3. Glue this in place. Punch 8 small holes spaced evenly around the ring. The cone is now done. This simple geometric layout produces a perfect 60° cone for any sized palangana, which will give a 4:1 concentration of incoming radiation. A 60° cone is not the optimal angle, but is close. Due to its simple pattern, however, it cries out to be used for this application.

Tilt Angle

"Lay out another line 4 diameters long. Cut and fold the pattern shown below, then glue into a square (a little tab helps). The tilt angle should optimally be the latitude of the site, for year round use. Two different ones could be used to improve the efficiency, one for March 21–September 20 (Latitude minus 12°) and one for September 21–March 20 (Latitude plus 12°). Punch 2 small holes at the bottom of each side, as shown below.

"Turn the cone upside down and set the angle on top. Thread a string through the holes in both the cone and the base to tie them firmly together (see Figure 5).

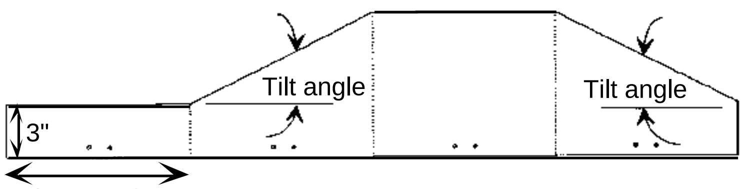
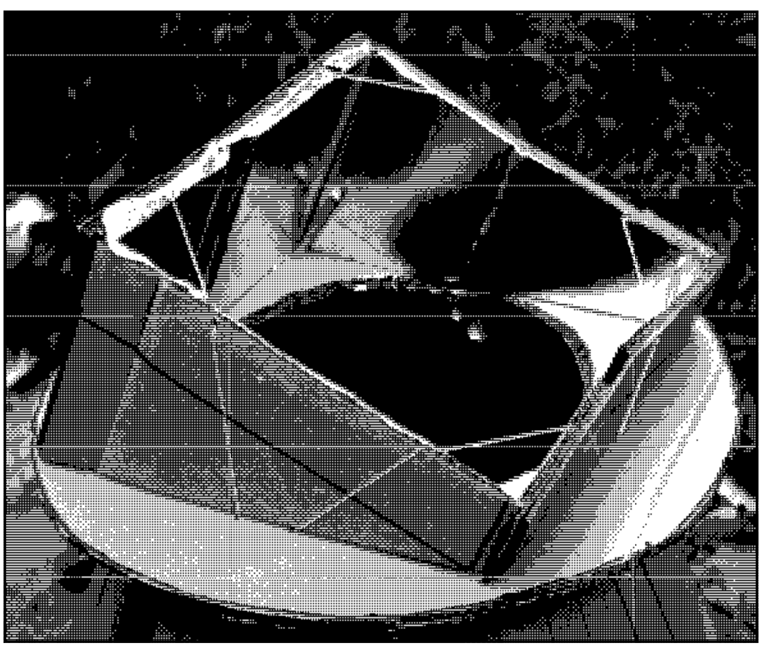


Figure 4



Above: The tilt angle installed on the cone. Photo by Jay Campbell

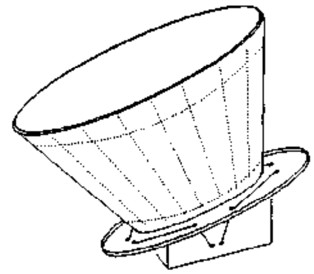


Figure 5

Frame

"[This is] a drawer slide. The glass will go in and out one edge, and seal on the top, bottom, and other edges. It must be made for a specific piece of glass in order to seal well. In a large piece of cardboard, cut a hole to the size of the palangana body. The [pan] should fit completely inside, with the lip seated well on the cardboard. See Figure 6. Stack up cardboard to be slightly above the lip. Set the glass on top of this buildup, centered over the palangana. Cut strips of cardboard to outline the glass. Cut a final piece to cover the whole stack. Cut a round hole the size of the palangana in the top piece. Once all pieces have been dry fit, glue them together as assembled. The glass should slide freely, but should not be loose. Use one of the cutout holes as a heat shield at the bottom of the palangana. This will help diffuse the concentrated energy which could damage the plastic. Also, the piece just below the glass can be made to any thickness, making the cooking volume larger.

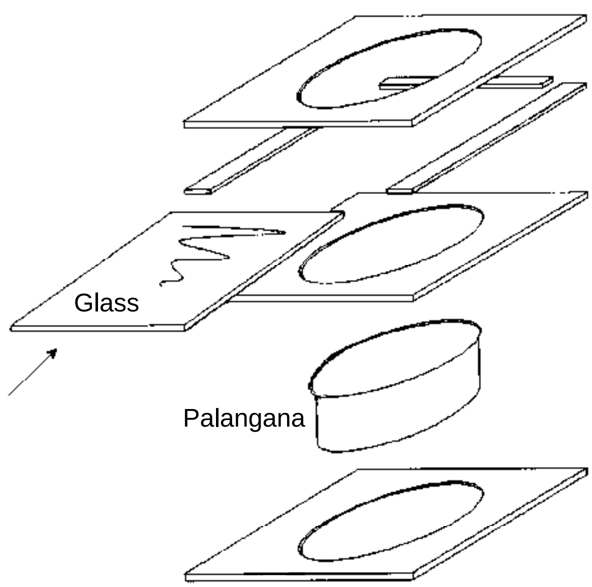


Figure 6

Assembly

"Dig a round hole, about 10 inches larger in diameter than the palangana. Level out the ground around the hole. Place frame over hole, without glass or palangana. Pack newspaper around the inside of the hole, stepping on it and stuffing as much as possible without interfering with the palangana. Place in palangana, slide in glass and set cone assembly on top (see Figure 7). The reflector can be weighted down with rocks around the base, or by tying 3 tethers to stakes in the ground. High winds are not a real problem in the interior of Guatemala, so only rocks were used during testing.

Use

"Tip the reflector onto its side. Slide the glass back and put in the food. Slide glass back snugly into frame, and replace the reflector. The reflector can be rotated to follow the sun without disturbing the food or cooker. It's important to tip the reflector for access, to avoid looking straight into the cone. To fully utilize the volume advantages of this design, round cookware should be used.

Above: After the hole is dug and lined with crumpled newspapers, the pan is placed in the hole. The frame with the glass is placed over the hole and the cooker is ready to have the cone placed on top. Now we're cookin'!

Photo by Jay Campbell

Conclusion

"This is a simple, inexpensive, rugged cooker, easily constructed of local materials. It can meet the cooking needs of a typical family in Guatemala throughout much of the year.

"This has been a very educational project. I appreciate your posing this problem as a challenge, and getting the creative juices flowing. Win, lose or draw, I am a confirmed solar cooker, and will continue to develop the concept and promote its use. Hopefully, this contest had the same effect on others.

"I claim no financial interest in this design. Anyone is free to duplicate, distribute or modify it at will. Covering expenses is reasonable, but I only request that it not be produced for a profit."

Contest Conclusions

Jay Campbell's cooker was taken to an Earth Stewards/Peace Tree gathering and shared with people from fourteen different countries. The plans will be made available to all who wish to help spread the design to indigenous people everywhere.

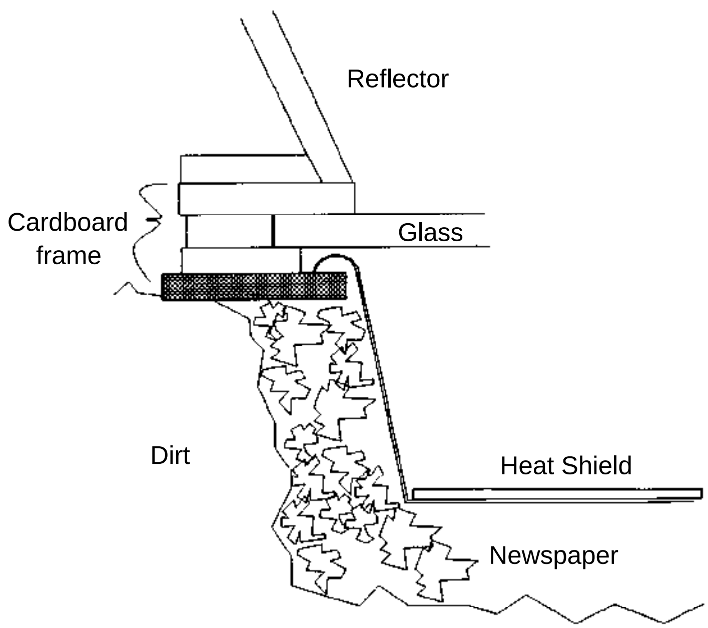


Figure 7

Congratulations to all of our entrants for your time and creativity! For you readers who had an idea for a solar cooker, but did not think you had enough time to develop one, there is always next year's competition. Look for the details in the next issue of Home Power. Go for it.

Access

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Michael Diogo, c/o Bill Keys, 8111 Stanford, #159, Garden Grove, CA 92641

Maria C. Gonzales, 48 Sycamore #3, San Francisco, CA 94110

Lu Yoder, 315 Harvard Dr. SE, Albuquerque, NM 87106 • 505-265-3730

Milk crate oven: H. Philip Hodes, 3137 Capri Rd., Palm Beach Garden, FL 33410

Tracking solar oven (plans available for $2): Alan Nichols, 4220 N. Bear Canyon Rd., Tucson, AZ 85749

Above: Solar cookers ready to shine in HP's Solar Cooking Contest. Photos by Richard Perez

A Kitchen in the Sun

Therese Peffer

We've all heard the saying about too many cooks in the kitchen. But what happens when you move your kitchen into the sun? You get a myriad of solar cooker designs, great food, and lots of fun in the sun. We found this out recently at Home Power's 2nd Annual Solar Cooking Contest.

Last February, we offered a challenge to our readers: design and build a simple, cheap, and easy to use solar cooker that works well. The rules were simple: the cooker had to cook, meaning it should boil water. The cooker should use common tools and materials appropriate to your area. Durability and easy duplication would score high points.

And our readers responded. We received twelve cooker designs for the contest. Of these twelve, three contestants sent their cookers. Two cookers arrived at the contest with their designers. We built three designs for a total of eight entries in the contest. (We built the designs appropriate to the contest — original designs that were easy to duplicate with complete instructions).

The day of the contest

Saturday, July 31, dawned clear and bright — a beautiful day for the cooking contest. By nine am, solar cookers covered a fair portion of Camp Creek campground. Besides the eight contestants, we had eleven other solar ovens smiling at the sun. Jim Shoemaker from Redding brought his cardboard and foil Sun Star type cooker. The Solar Man himself, Phil Wilcox, brought two solar ovens. One small commercial cooker, a Sunspot, could easily fit into a backpack; the other design was part of a U.S. Air Force survival pack in the '50s! Yes, solar cooking has been around for awhile. We also had four Sun Ovens, a Sun Chef, and three other homemade models cooking ribs, peach cobbler and other tasty goodies.

By ten o'clock, we placed a cup of pre-soaked pinto beans and a cup of rice in each of the contesting cookers. One result of having this number of solar cooks — you get an incredible variety of cookers! Each cooker reflected the designer's carefully spent time, creativity and imagination; no two were alike. Walking around the cookers, you could hear how the cookers sparked the imagination of all those who came. We looked, appreciated, and used other's creations as a stepping stone for our own solar cooker dreams.

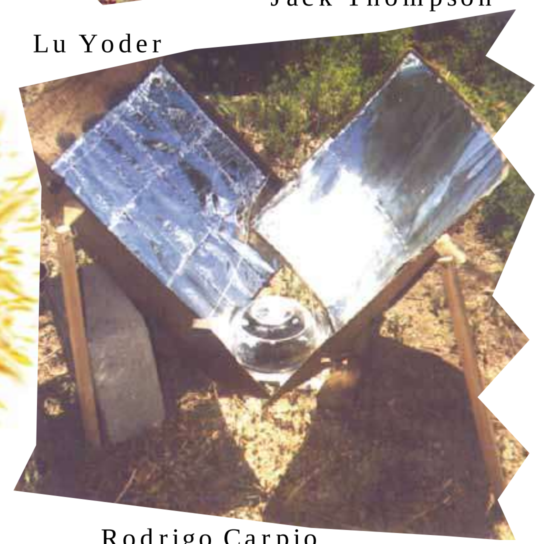
Dan Freeman

David Baty & Cody Brewer

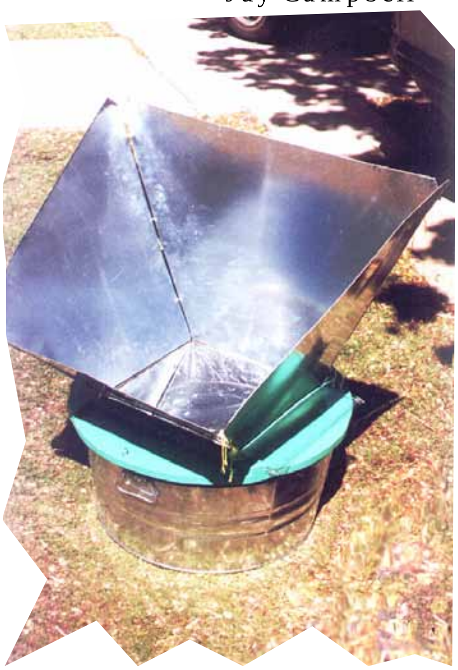
Jack Thompson

Bohuslav Brudik

Lu Yoder



Jay Campbell



Peter Pearl

Rodrigo Carpio

The Contestants

Unfortunately, we don't have the space to fully cover the designs for every cooker. What will have to suffice is a brief description, photographs and the designer's name and address (at the end of the article). So take a close look at the photos and be inspired by the ingenuity of the designers! Keep in mind next year's contest…. As with last year's contest, the first place cooker design is described in full.

The parabolic cookers added a new dimension to the contest — they really cook! Two cookers used parabolic dishes to reflect and focus the sun's energy onto a cooking pot.

Jack Thompson from San Diego, California sent a design that used a cardboard-ribbed foil-covered parabolic dish. A galvanized pipe frame held the dish and cooking pot. Kathleen and Bob-O built this cooker from Jack's plans and "rib" template.

The other parabolic design arrived with David Baty and Cody Brewer, who hail from Berkeley, California. Their cooker consists of a four foot diameter sand & cement dish that rests in an old car tire. They used aluminum flashing for the reflective interior. David and Cody had already impressed us the day before by making espresso in their parabolic cooker. On contest day, their rice and beans kept boiling over and needed additional water a few times. Both parabolic cookers cooked the rice and beans to perfection in less than two hours. This left plenty of sun time for a solar cooker first for all of us at the contest — solar popped popcorn!

Lu Yoder from Albuquerque, New Mexico sent a simple design that used two 2 foot by 3 foot cylindrical concentrators. His plans called for a flexible substrate such as hard plastic, thin plywood or masonite covered with a reflective material, such as polished aluminum cans. The panels were curved to concentrate the sun's energy on a cooking pot that sat on an insulated box on the ground. We made the cooker with masonite and aluminum litho sheets from our local newspaper.

Dan Freeman sent his cooker from his home in Peoria, Arizona. Dan's creative portable design used aluminized bubble pack material (similar to Reflectix) as both reflector and insulation. This material was velcroed to a folding aluminum frame. His cooking box sported a unique curved parabolic-section shape.

We were thrilled to receive an international entry. Rodrigo Carpio from Cuenca, Ecuador sent beautifully detailed designs in Spanish for his rugged, but surprisingly lightweight box type cooker. Bill Battagin and I built the cardboard and plywood cooker from Rodrigo's design. The cooker walls consisted of 2x2 wood frames covered with cardboard and then wrapped in foil — light, sturdy insulation. We screwed the walls together to form a box, and finished the outside with ¼ inch plywood. The plans called for the walls to lie inside the box for storage — in storage mode, the cooker was only half the height! We didn't have the materials to finish the box with aluminum sheeting as per plans, so we painted the outside instead. Quite a weatherproof design. The wide flat interior of this box cooker is especially suited for climates near the equator.

From Las Vegas, Nevada came a cooker designed by Bohuslav Brudik. This clever design used a store-bought rectangular bamboo basket, insulated with cotton batting and rags and covered with cardboard painted black. Bohuslav used plexigass for glazing and fashioned reflectors from flattened honey cans supported by dowels. Simple and worked great!

Peter Pearl drove from Bisbee, Arizona to share his solar cooker design and other great ideas. His compact solar cooker had a black beveled steel interior in a small wooden box with a single polished reflector.

And finally, Jay Campbell, who won first place in last year's contest, sent another original cooker from Albuquerque, New Mexico. He designed the cooker using a washtub, insulated with straw, with a box interior. Jay made foldable reflectors of foil-covered masonite. The cheery green cover added to the festive atmosphere at the contest.

The envelope please...

Now the toughest job of all. Six judges walked around the cookers to judge the performance, buildability, ruggedness and beauty of design of each entry (see sidebar for details). Anita Jarmann, Sherri Reiman, Selina S-Wilcox, Karen Perez, Kathleen Jarschke-Schultze, and Dan Lepinski spent a few hours studying the cookers, sampling their fares, and marking numbers on their detailed sheets. Most cookers had no problem with the rice, but the beans presented a challenge. We decided the point system would allow impartial judging. (After sampling the espresso, Karen was a bit biased towards the cement parabolic cooker. As it is, that cooker now resides at HP Central. If you want your own too, see directions on page 34 this issue.)

When the judging was finished and the numbers tallied, we had our winners. Cookers were ranked by total number of points from all judges. Jay Campbell won a Solarex MSX-60 photovoltaic panel for first place with his washtub design. Peter Pearl will be installing a PowerStar 200 watt inverter for winning second place. David Baty and Cody Brewer shared the solar/dynamo radio for winning third place with their cement parabolic cooker. Finally, time to eat rice, beans, salsa, guacamole, hot dogs, ribs, peach cobbler....

Judging the Cookers

Each judge carried a judging sheet for each of the eight contestants. The cookers were given points in four categories: Performance, Buildability, Ruggedness, and Beauty of Design. The four categories in turn consisted of two to five subcategories, worth 15 to 25 points.

Performance of the cooker included how well it cooked, high temperature reached, ease of use, and ease of set-up. Each subcategory here was worth up to 25 points for a total of 100 points for this category.

Elements of buildability consisted of clarity of instructions, easy of assembly, imaginative use of materials, amount of tools needed for construction, and common skills needed for assembly. The subcategories here were worth up to 15 points each, a total of 75 points.

In the ruggedness category, points were given for portability, wind resistance, site preparation needed and moisture resistance. Up to 20 points each were allotted for these subcategories for a total of 80 points.

And finally, beauty of design included physical appearance of the cooker and originality of design, worth up to 25 points each — 50 points total. The most points possible from each judge was 305.

While sometimes it can be difficult to assign numbers to different qualities, we think it allows for easy and fair judging since all the cookers were judged in the same fashion. The details of the judging are provided for those of you interested in entering the contest next year. And, (ahem) we've asked Jay to be a judge next year….

And now as promised, are the details of the winning design by Jay Campbell.

The Winning Design — the Navahorno

This year, I chose to work with a developing country right in my own back yard. I designed and built a solar oven based on the needs, foods and materials common to the Navajo Nation. This stunning land spreads across 24,000 square miles of New Mexico, Arizona and Utah, and is home to more than 175,000 people. Of the 500+ tribes in the United States, the Navajo tribe is the largest, and their landholdings the most extensive. They were chosen for this project not for their size, however, but for their need.

Despite the beauty of the land, life on the reservation is hard. Much of the tribe has never been on the grid, so

The Winning Cooker!

Jay Campbell, Albuquerque, NM

the concept of going off it is meaningless. Wood and propane supply the primary sources of household energy. The climate and terrain of the Navajos are typical of many tribes in the area. The air is dry, vegetation is sparse and the sun shines brightly. Wood is not available in many areas, so it is hauled in from the distant mountains. The tribal government has been promoting solar electricity for some time now, funding small systems at remote sites, and encouraging members to utilize this abundant resource. They will play a key role in the promotion of this oven.

This project would have been impossible without many consultations with JoAnn Willie, a lifelong resident of the rural Navajo land. She is also a graduate student in Mechanical Engineering at the University of New Mexico. Her combination of skills was invaluable in the development, testing and promotion of this oven. The information she gave on materials, foods, cookware and eating habits was all blended into this design, and its ultimate success is hers to enjoy.

The Oven

The oven is built around several common items in rural Navajo life. The outer box consists of a two foot diameter galvanized washtub, commonly used for washing kids, clothes and produce. When they no longer hold water, they are used to feed animals, store wood, and haul whatever needs hauling. These are truly a ubiquitous item in daily living. They are common, abundant, durable and used ones can be found for next to nothing.

Materials and Tools for Jay's Navahorno

Materials	*Tools*
One 2 foot diameter washtub	wood saw
One 15 in. x 15 in. 1/8 in. glass	measuring tape
One 4 ft. x 4 ft. Masonite	paintbrush
One 4 ft. x 4 ft. 3/8 in. plywood	hammer
6.5 ft. old garden hose	razor knife
1/10 bale straw	C clamps
Two small hinges with screws	

also leather strips, white glue, 3/4 in. nails, and aluminum foil

The insulation used is straw. The dry land doesn't provide sufficient grass for grazing, so hay, alfalfa and straw are widely used for fodder. This oven requires about 1/10 of a bale of straw, costing about a quarter.

The inner box is sized around the most common types of cookware — enameled steel stew pots. The volume is large enough to feed a family of six. All other materials are made from commonly available items, down to using leather for hinges and weatherstripping. A piece of garden hose, split lengthwise, is used to seal the inner and outer boxes together.

The collapsible reflectors reduce storage space requirements when not in use. The exposed surfaces are either painted or galvanized, helping to assure a long life. For outdoor storage, however, a cover would be recommended. A door on top swings open for access to the hot section. The reflectors are mounted securely to the door, and have withstood winds of up to 30 mph. The leatherwork is oiled, to protect it from the elements. The colors of this oven represent something the Navajos are world famous for — their turquoise and silver jewelry.

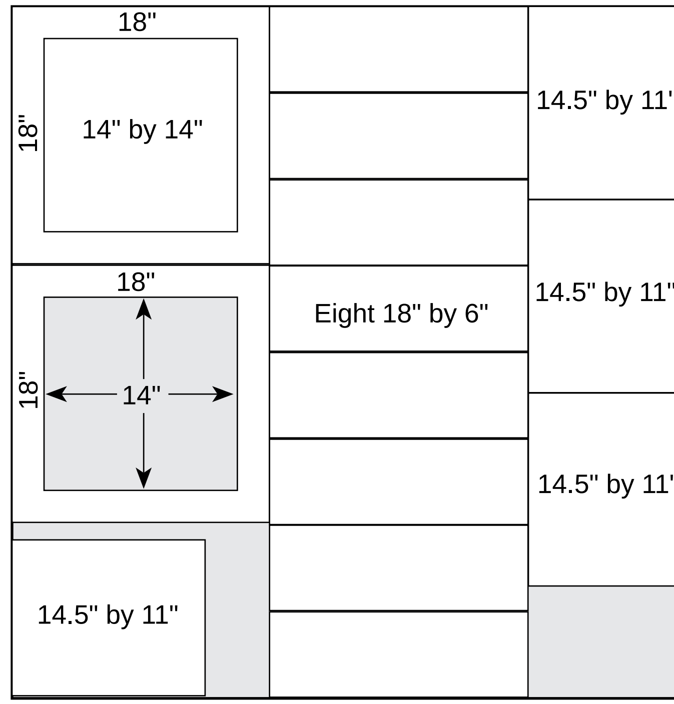
A set of cardboard risers is included to size the cooking space for the cookware. The appropriate riser is placed into the oven, and then covered with a black cardboard square. This way, the food can be raised to the hottest part of the oven, regardless of the cookware.

The highest temperature achieved was 330°F (165°C). The time required to boil one liter of 20°C water was 56 minutes at this elevation (about 6000 feet). The total cost as built is $10.83, assuming a used washtub. A new one would add about $10 to that price. About 6 hours was spent on the actual construction; this could be reduced significantly for any future copies.

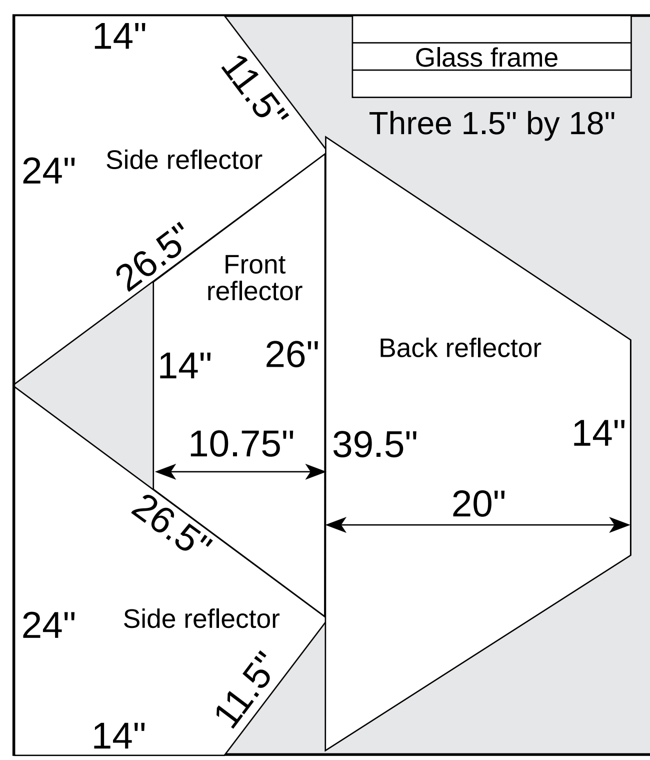
Construction

Gather tools and materials. Measure and cut wooden pieces (right). Put together the inner box, top, glass frame, and reflectors, then assemble these together.

Cut the following out of plywood:



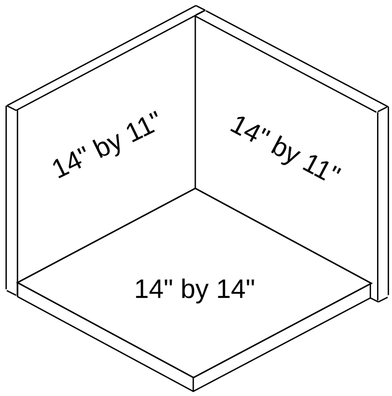
Cut reflectors and glass frame pieces from Masonite:



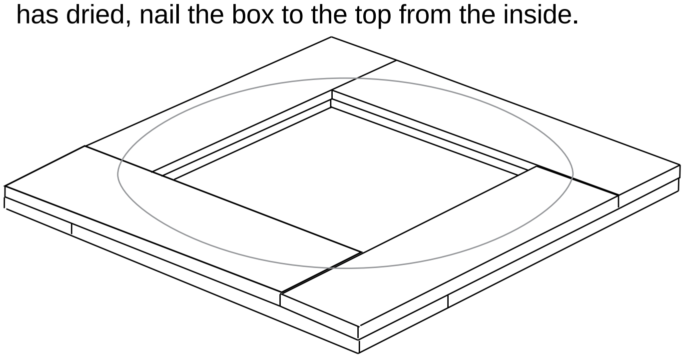
Inner Box

Nail the four sides (11 inch by 14.5 inch) to the edge of the 14 inch square, overlapping the corners as shown top right. Glue joints before nailing together. Cover both the inside and outside of box with aluminum foil, using a 1:1 glue to water mixture and spread with a paintbrush.

Two sides of the inner box glued and nailed to the bottom.
Note overlapping corners.



Top
Turn the inner box upside down. Stack the eight 18 inch by 6 inch strips snugly around the box (below). Once fitted, glue and nail the strips together. When the glue has dried, nail the box to the top from the inside.

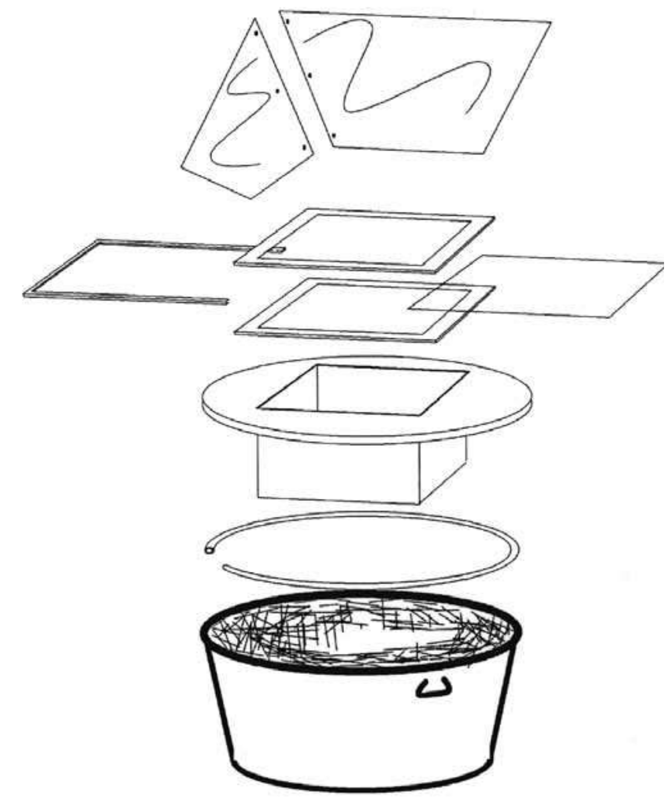


Now set the inner box/top upside down. Place the washtub over it, and center it. Draw a circle around the edge of the washtub. Next, cut a slit in the whole length of garden hose. Nail the garden hose to the top, just inside the circle you just drew. Use one nail every 4–5 inches to assure a strong joint. Once the glue has dried, trim off the excess wood beyond the hose/seal.

Glass Frame
Set the piece of glass on one of the 18 inch squares. Place three 1 inch by 15 inch masonite strips around the glass, snug, but not so tight that the glass is locked into place. Set the other 18 inch square on top. Glue and nail these together. The glass should slide in and out of the frame like a drawer, so it can be replaced.

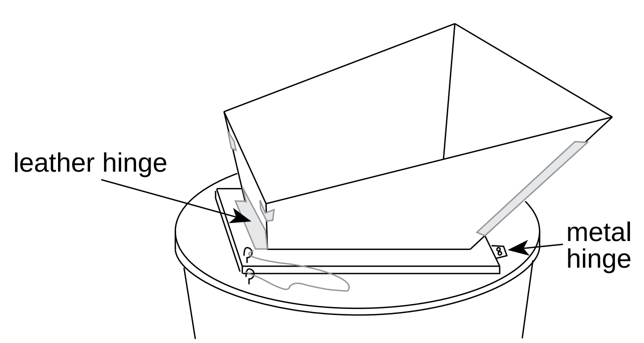
Reflectors
Cover the reflectors with aluminum foil. Once dry, trim the foil back to the edge of the masonite. Align the large reflector and a side reflector (see top right). Cover one side of a leather strip with glue and clamp along the edge of the two reflectors. Repeat with the other side reflector. Align the small front reflector to the edge of the window. Glue a piece of leather to the back of this reflector and the window frame, as a hinge.

The Final Assembly
Use the two metal hinges to attach the glass frame (opposite side from the front reflector) to the top. Glue



strips of leather on the top, where the frame rests. This seals the box from the wind. It should fit snugly and make a continuous ring around the glass. Attach an eye hook to a corner of the frame and another eyehook to the top. Hook a sturdy string through both eye hooks. Now when you open the cooker lid to get to the food, the string holds the frame and reflector.

Use
This oven works similar to most multiple reflector ovens. Food is prepared and placed into the oven, using the appropriate riser to keep the food at the top of the oven. Dark enameled steel cookware (the standard in the area) works extremely well in this oven, but a variety of glass and aluminum has also been used. The oven can be left unattended for long periods, but stays hottest if it is turned every hour or so. The round base and handles makes turning it easy. Like most solar



Above: Note the deep interior of the washtub cooker. Different sized cardboard inserts (bottom right) can be added to raise shallow cooking pans to the warmest part of the oven. The inserts are covered with a 14 inch square of cardboard painted black.

ovens, cooking times are about double those of a conventional oven. Foods which require a long, slow simmer are especially well suited to solar cooking.

Traditional Navajo meals include green chile stew, mutton stew, roast meats, breads and corn mush. A gallon of stew will cook up nicely in an afternoon, as will a few quarts of beans. Cornbread has been baked in this model in about 40 minutes. When the food is ready, the reflectors are folded together. The door swings open and the food can be removed. If desired, the pot can be covered with a couple of towels, and left inside the oven. This way it will retain its heat for quite some time, and even keep on cooking.

Alternatives
The main alternative design tested was with galvanized sheet metal reflectors. The dimensions and overall performance were essentially the same as the model submitted. The increased durability comes at a higher financial cost, and it didn't seem worth it. The masonite reflectors are good enough, and last long enough that occasional replacement would still be cheaper.

Better insulation could be used, but only if it were free or very cheap. The multiple radiant barriers (foil and sheet metal) provide much of the thermal protection, and the straw is only a defense against conduction.

Conclusions
This oven will cook many of the staple foods used in the Navajo Nation. It can be built easily by individuals, or produced in quantities by a small shop, using only basic hand tools.The investment in materials will repay itself in about a month, and continue paying dividends for years to come. The climate in the region will allow its use for over 200 days per year, which can make this a primary, rather than secondary, means of cooking.

Although specifically designed around the materials and foods of the Navajo, it is suitable for use over a wide region. Promotional efforts have begun in New Mexico, and show a strong amount of interest.

Calling all Cooks
Thanks, Jay, and all those who entered or participated in our contest this year. The more cooks that move their kitchen into the sun, the better the broth will be! More people entered the contest this year. We saw a wider variety of cookers from a greater number of people, reflecting their creativity, ingenuity, and love of solar-cooked food. The solar spark catches and spreads to even more people, so put on your thinking caps and start dreaming of your ideal cooker. If you don't know how to use some tools, find someone who does (and make him cookies for a job well done). Build a cooker. Cook your meals without fuel, and keep your kitchen cool in the summer. Enjoy some solar-cooked food (and win a PV module next year).

Access
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Lu Yoder, Liberation Technology, 315 Harvard SE, Albuquerque, NM 87106 •

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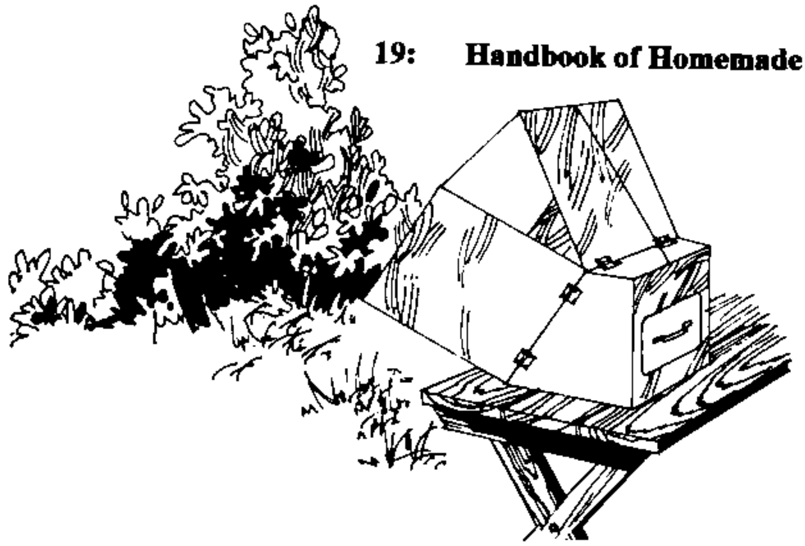
Author/Eater: Therese Peffer, c/o Home Power, POB 520, Ashland, OR 97520 • 916-475-3179



HOW TO BUILD—AND USE!—A SOLAR OVEN

MATERIALS

- 28-gauge galvanized iron (16 square feet)
- No. 6, 3/8-inch sheet metal screws (approximately 24)
- 2-inch fiberglass insulation (12 square feet)
- Double-strength window glass (22 by 24 inches)
- Drawer pulls (three)
- Flat black paint (one spray can)
- 2-inch roofing nails (six)
- Sealer strip (eight feet)
- Aluminum sheet .025 by 22 by 24 inches (four pieces)
- Small turn-buttons with installation hardware (four)

The "greenhouse" effect is well known to those who grow plants in such structures and also to those of us who have left the windows of an automobile rolled up on a warm, sunshiny day. The rays of the sun go through the glass well enough, but the reflections of longer wavelength are unable to bounce back out of the car. The result is aptly described as resembling an oven. And that is just what we're going to build . . . a solar oven that will do a real job of cooking on a clear day, even in winter.

One aim of solar scientists is to provide a means of cooking for those countries in which fuel is scarce or expensive. Dr. Maria Telkes—a well-known experimenter in the field—has designed such an oven, which she feels might be mass-produced at a reasonable price. Our design is copied from the Telkes unit, which has been demonstrated in foreign lands.

Basically the solar oven consists of a box for the food and a glass cover to admit and trap heat inside the container. The box shown is made from galvanized iron but could as well have been aluminum for lighter weight. The reflector panels are of aluminum.

Besides the sheet metal parts, we need a piece of double-strength window glass, a sealing strip for the pane and three handles. We will insulate the box with spun glass material two inches thick for greater heat retention.

It will be a good idea to have all materials on hand before beginning the project. One exception could be the sheet metal for the box, in case you decide to let your local sheet metal shop do the cutting and bending for you. This is a good idea unless you're familiar with metalwork, and will result in a more professional job at little additional cost.

If you want to do all the work yourself, and feel that you can handle the job, this is the way to begin: The bottom of the oven is a rectangle of metal, with the corners notched out to allow bending up flanges all around the sides. These are 3/4-inch flanges and they're bent up 90 degrees . . . except for the front edge, which is a closed (acute) 45-degree angle, one inch long, as shown in the drawing.

The right and left side panels may be cut from one rectangle of metal to save material. Lay them out carefully to prevent waste. Again, 3/4-inch, 90-degree flanges are bent onto the front and top edges of each panel. The back and bottom edges are left flat. Be sure to make the two sets of bends opposite each other so that you'll have a right-hand panel and a left-hand panel, and not two of a kind!

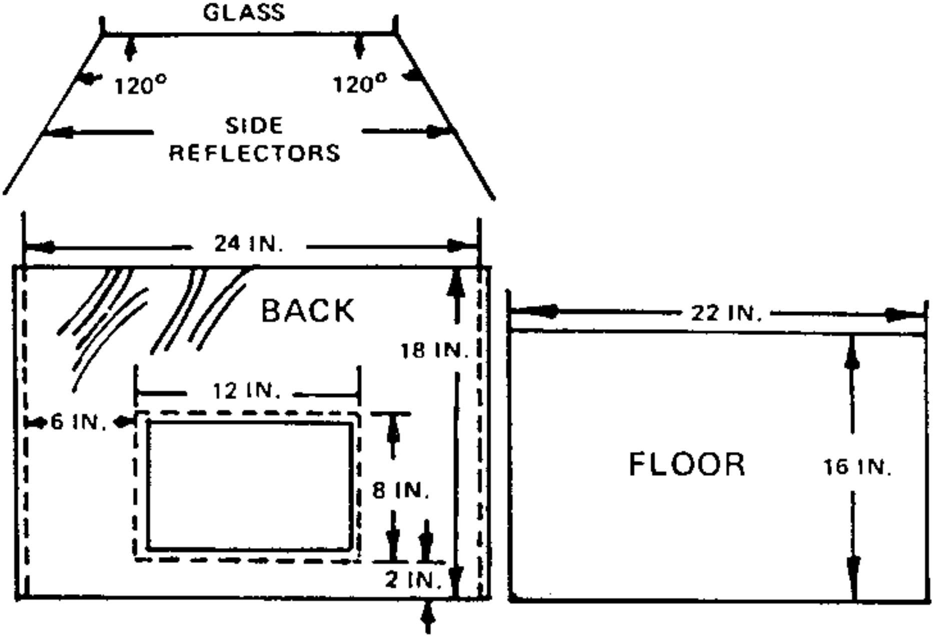
The oven back has 3/4-inch flanges on each side and an opening cut in it for the door. Notch the corners of the opening at 45-degree angles and bend the 1/2-inch stiffener flanges inward. This will strengthen the door opening and also give the back a finished appearance.

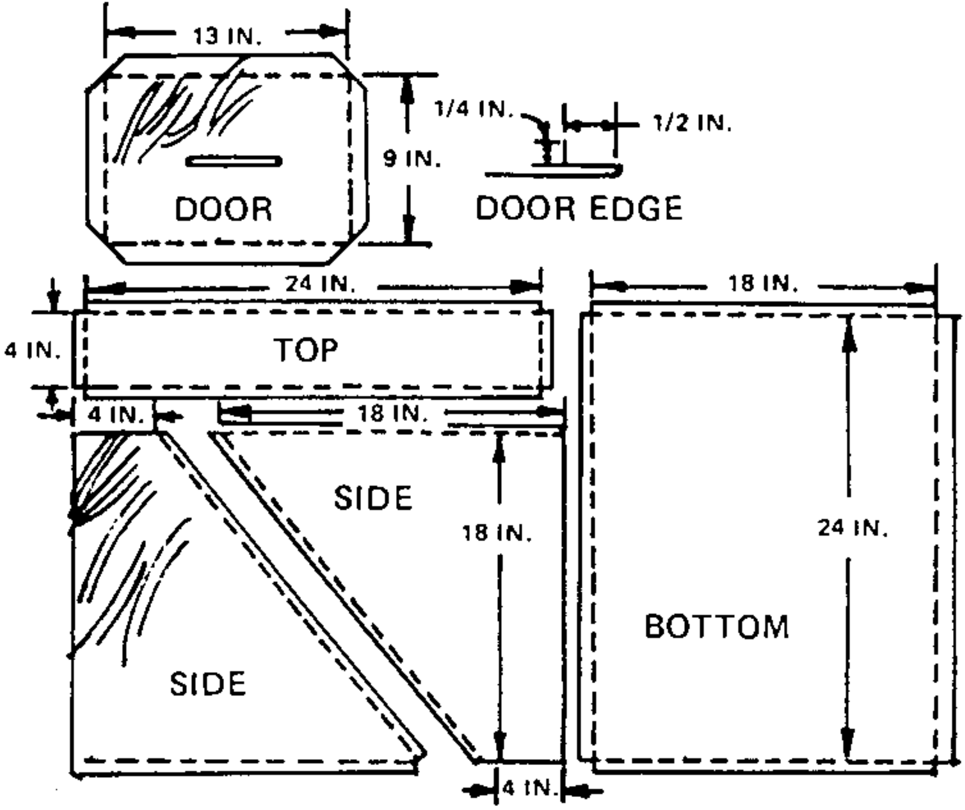
Now make the top of the box. This is a channel with one 90-degree flange (to fit the back) and one open—or obtuse—45-degree flange (to match the slope of the glass). Next comes two 3/4-by-one-inch retaining angles, each 18 inches long (to hold the pane of glass). The box is now complete except for a door.

The door is the only difficult part to make and care must be taken to bend it correctly. The double, or "hemmed", edge strengthens the panel, and the flange which is left standing will fit into the opening in the back of the box. A snug fit here will make for a neat, effective door that seals properly and helps keep the heat inside where we want it.

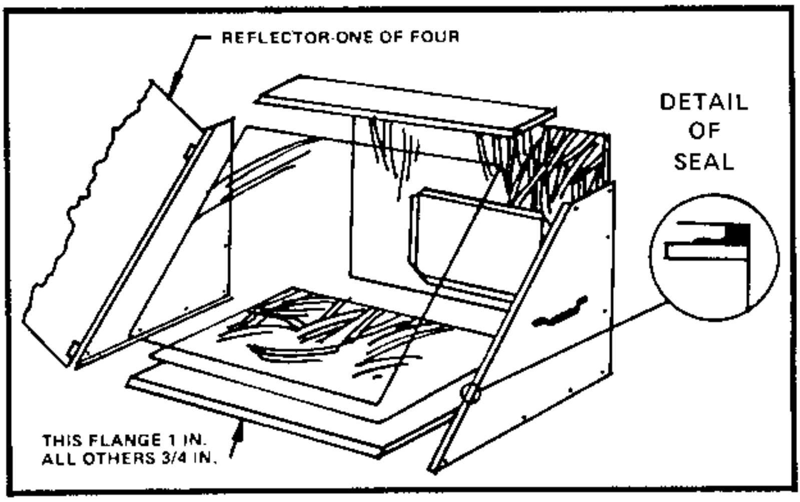
A false bottom is needed to prevent the collapse of the insulation in the floor of the oven. This bottom is a rectangle of metal cut to the size shown in the drawing. Make sure it is not so large that it contacts the front, sides or back of the box. This would cause heat loss by conduction to those parts.

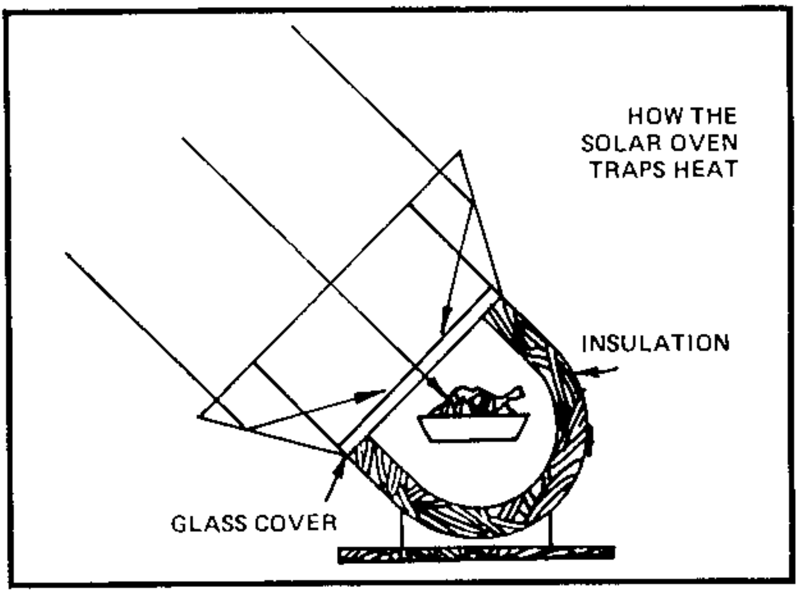
It might be well to mention here that an alternate method of construction can be used that employs a little ingenuity and the "do it yourself" aluminum sheets and angles available at the hardware store. This approach uses flat sheets, with angles attached to them, instead of flanges bent from the sheets themselves. Of course, the 45-degree angles would have to be eliminated, and a slightly different sealing technique used for the glass, but some builders may prefer giving the idea a try.


GLASS
120°
120°
SIDE
REFLECTORS
24 IN.
BACK
18 IN.
12 IN.
6 IN.
8 IN.
2 IN.
22 IN.
FLOOR
16 IN.



13 IN.
9 IN.
DOOR
1/4 IN.
1/2 IN.
DOOR EDGE
24 IN.
4 IN.
TOP
18 IN.
4 IN.
18 IN.
SIDE
18 IN.
SIDE
4 IN.
BOTTOM
24 IN.





Now, with the metal parts formed either in the sheet metal shop or at your own workbench, you're ready to begin assembly of the oven. The simplest way to put the unit together is with 3/8-inch, No. 6 sheet metal screws. They're available at the sheet metal shop, or your hardware store. If you're using aluminum, substitute hardened aluminum screws, since different metals coming in contact with each other may cause a corrosive action.

Mark pencil guidelines 3/8 inch from the bottom edge of the side panels, spaced as shown on the drawing. Center-punch the holes and drill with a No. 40 drill. A hand drill is fine; an electric drill is even better for this purpose.

Now, place the bottom of the oven on a flat surface, and hold the properly positioned side panel against it. Drill through the holes in the side panel and on into the flange of the bottom. It's a good idea to put in a screw as each hole is drilled to insure perfect alignment and prevent shifting of the parts. Notice that the bottom flange overlaps the side but no holes are drilled at this point.

With both side panels attached to the bottom, the back of the box may now be put in place and holes drilled to hold it there. Continue to keep the parts carefully lined up and to insert screws as you progress. The oven is taking shape now, and lacks only its top. Before we put it on, however, we will install the glass in the front of the box. Needless to say, care must be taken during this operation so that the pane will not be broken. Don't cut your fingers on the edges!

Clean the glass carefully with water. Then glue the sealing strip around its edge with cement (Goodyear *Pliobond* works well), following the directions with the adhesive to insure a strong joint. If you were able to find a sealer that fits over the edge of the glass the job will be easy. If you're using the bulb type, additional care will result in a neat assembly.

When the sealing strip is attached and properly "set" the glass may be put in place in the oven. Slide it down through the top, which we have left open for this purpose. For this operation lay the oven on its front face, being sure to have a perfectly flat surface to work on.

We will now install the 18-inch angles that hold the glass in place. Carefully drill holes in the sides of the box as shown on the drawing, locating them so that they will match the angles when the pieces of metal are put in position. Slip the angles through the opening in the top and set them on the glass with the 1-inch leg flat against the side of the box.

Working from the top, or reaching through the opening in the back of the box, press one angle very lightly against the glass. Do not force the glass so that it flattens the sealing strip, because—in addition to its sealing function—this strip acts as a cushion to prevent breakage of the glass. While holding the angle, mark through the holes in the side to indicate the proper location for the holes in the angle. Remove the angle, drill it, then replace the bracket and anchor it with sheet metal screws. Repeat this process on the other side.

With the glass installed, the oven's top may be put on and holes (for screws) drilled through it and into the back and sides of the cooking unit. Notice that the top fits down over the back and side panels.

The oven is now complete except for the carrying handles on each side and a similar handle on the door. These are attached with screws.

Fit the door into the opening and mark the holes for the turn-buttons that hold the door tight. Drill 3/16-inch holes in the back panel, and install the turn-buttons with nuts, bolts and washers. The washers hold the buttons away from the metal so they will clear the hemmed edge of the door.

The spun glass insulation is now cut to proper shape with a sharp knife or linoleum cutter. Use a straightedge for accurate trimming. Plan carefully so as not to waste material. The bottom piece can be beveled 45 degrees at the front if care is taken. Paint the inside surfaces of the insulation with flat black enamel, using—if you like—a pressure can for convenience.

After the paint is dry, the insulation is glued into the box with Pliobond or its equivalent. To do this, remove and set aside the back of the box. Then, positioning the oven with the glass down, cement the top insulation in place first and allow the adhesive to dry. Next, tip the box right side up and cement the bottom insulation in place. Press five 2-inch roofing nails point-down into the insulation and lay the false bottom over them. This bottom piece is painted flat black too. The side insulation can now be cemented into place and the box is complete except for the back.

Cement insulation to the back panel, cut the small rectangle from the opening and place it on the inside of the door. The back may now be carefully put back and the screws inserted that hold it in place. Lay an oven thermometer inside, fasten the door in place, and you're ready for the reflector panels, which are hinged to the box as shown in the drawing.

In tests the box itself will reach an inner temperature of only about 250 degrees. This is because heat loss to the surrounding air prevents the temperature inside from climbing higher. If we could increase the amount of heat going into the box, however, the oven would get hotter. For this reason we add the aluminum reflector plates shown in the drawing. Use Alclad if it's available.

Rivet two hinges to each reflector and be sure to mount two reflectors on the ends and two on the sides. If the Alclad sheets have red lettering on one side, use the opposite surface for your reflectors. Attach the hinges to the box with sheet metal screws. Install the bottom reflector first, then the sides, and finally the top. Besides their primary purpose, the reflectors also protect the glass.

Open the side panels 30 degrees to the received rays of the sun to reflect their heat into the box. This angle will always suffice for the side reflectors if you face the oven directly toward the sun. The 45-degree tilt of the glass is a compromise angle that gives all-around performance. However, a little thought will tell you that for maximum performance the angle of the top and bottom reflectors will vary with the position of the sun in the sky.

The discussion sounds complicated, but in practice adjusting the oven is very simple. Set it out in the open, preferably on a wooden table, and face it toward the sun. Open all the reflectors and swing the top one up and down while you watch the inside of the oven. You'll be able to tell when you have it at the proper angle by the reflection of the sun's rays on the dull black insulation. Bend the end of a piece of galvanized wire to act as a stop, insert this wire into a hole in the top reflector, and wrap the free end around the loosened screw as shown in the drawing.

Swing the side reflectors into position, while you check the angle they make with the glass by means of a cardboard template. Using two wires, attach the movable side panels to the top reflector. Now swing the bottom reflector up while you, again, watch the inside of the oven. When it's properly positioned, fix two wires in place from the bottom reflector to the side reflectors, and your solar baker is ready.

The test oven shown in the illustrations reached a temperature of 350 degrees in 15 minutes. This was in Arizona in mid-January, with the air temperature in the low 60's. The first time it was used, the unit baked a loaf of bread in just over an hour . . . and then cooked a three-pound roast in three and a half hours! A whole meal can be prepared in the solar oven. The menu is limited only by your imagination. ●

BUILDING THE SOLAR OVEN

This do-it-yourself solar oven is much simpler to build than our earlier models. Constructed of plywood, window glass, and any of a variety of insulating and reflective materials, the oven can be completed in a short time by the average handyman or woman. We've even taught elementary school youngsters to make simple solar cookers.

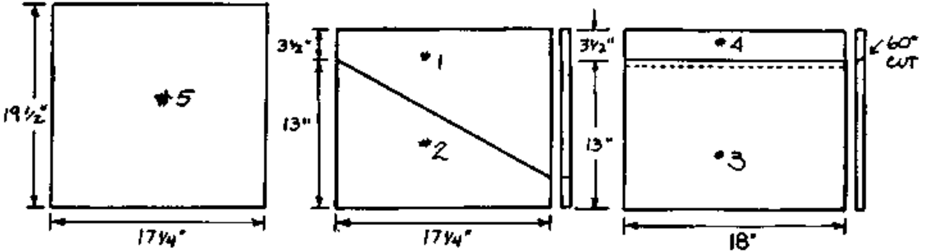
Check the list of supplies and get together the materials you'll need for the oven. Perhaps you have scraps of plywood large enough for the oven—maybe even an old window pane that will do for the glass door. Reflectors can be made from cardboard boxes if you don't want to buy sheets of cardboard. Heavy-duty aluminum foil (the kind you wrap turkey in for broiling) will serve for reflective material to bounce additional heat into the oven, although aluminized mylar is more durable.

Read through the following directions before starting construction, and be sure you have all the materials and that you understand the building process.

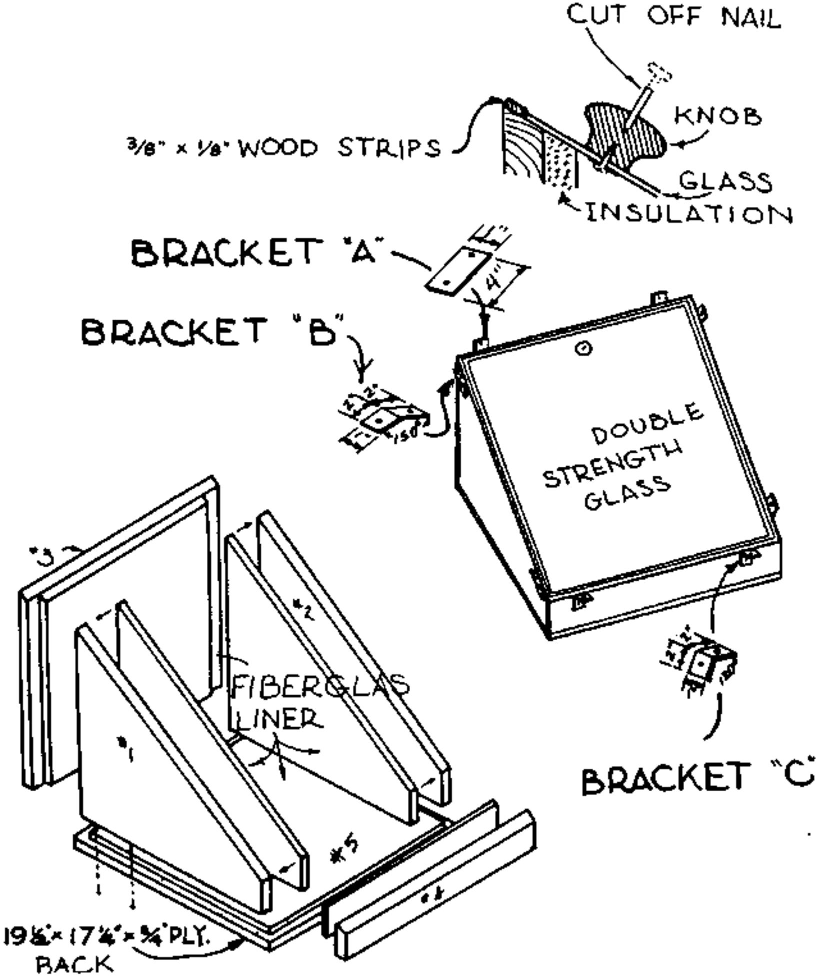
List of Supplies Needed for Construction of Solar Oven

1 pc. plywood 3/4" x 16-1/2" x 17-1/4" (sides)
1 pc. plywood 3/4" x 16-1/2" x 18" (top & bottom)
1 pc. plywood 3/4" x 19-1/2" x 17-1/4" (back)
1 pc. plywood 3/4" x 6" x 8" (stairstep "angle adjuster")
8 sq. ft. 1" foil-covered fiberglass insulation
1 pc. double-strength window glass 18-7/8" x 18-7/8"
4 wood strips 1/8" x 3/8" x 20"
8 pcs. 1/16" thick aluminum or iron 1" x 4" (attachment angles)
4 pcs. cardboard, masonite, or sheet aluminum 18" x 18"
1 roll double-strength aluminum foil 18" wide
1 wooden drawer knob and attaching screw
1 fiber washer to fit drawer knob attaching screw
30 finishing nails 2" long
12 big-headed roofing nails 1-1/2" long
8 round-headed wood screws 5/8", #10
8 round-headed bolts 1/2", #10

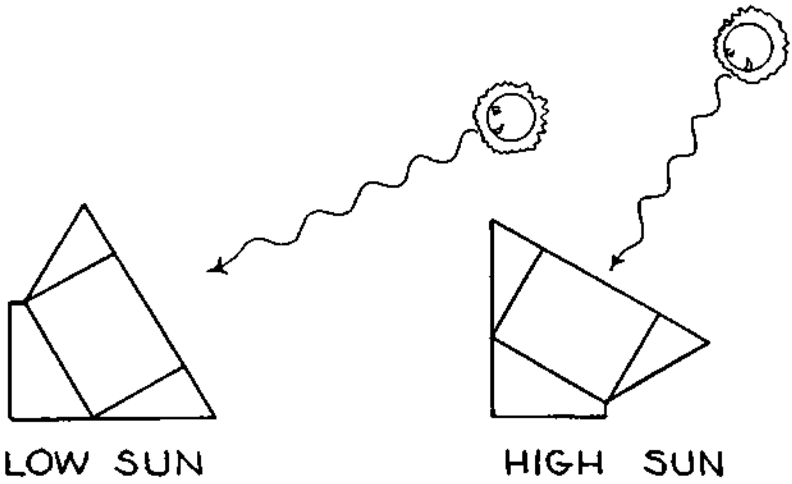
8 nuts #10
8 1" washers, 3/16" hole
1 oven rack 8" x 12"
2 pcs. 1/2" wood dowel, 3" long
2 pcs. 1/8" brass rod, 15" long
1 sheet medium sandpaper
1 can non-toxic flat black paint

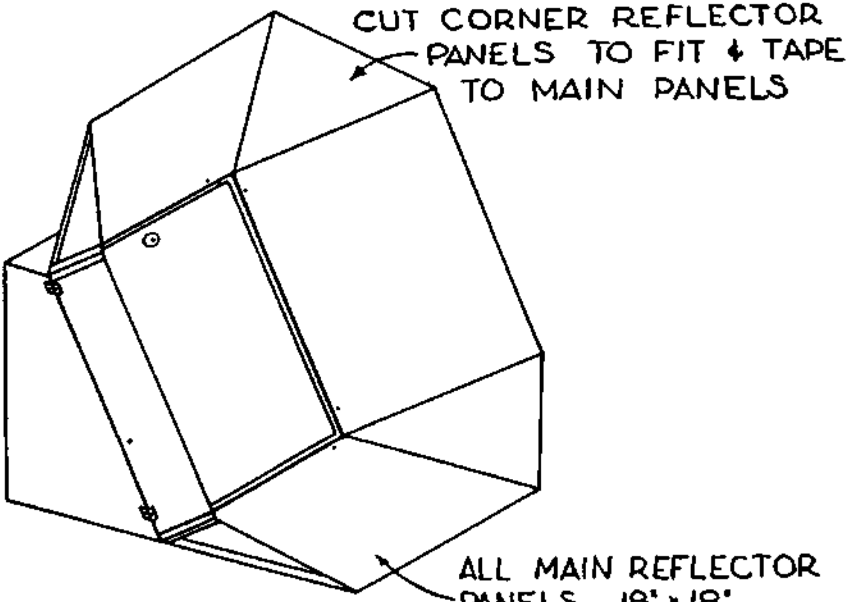


PLYWOOD BACK, SIDES, TOP, AND BOTTOM



CUT OFF NAIL
KNOB
3/8" × 1/8" WOOD STRIPS
GLASS
INSULATION
BRACKET "A"
4"
BRACKET "B"
150°
DOUBLE STRENGTH GLASS
#3
#2
#1
FIBERGLAS LINER
#5
BRACKET "C"
19⅝" × 17¼" × ¾" PLY. BACK


LOW SUN
HIGH SUN


CUT CORNER REFLECTOR PANELS TO FIT & TAPE TO MAIN PANELS
ALL MAIN REFLECTOR PANELS 18" × 18"

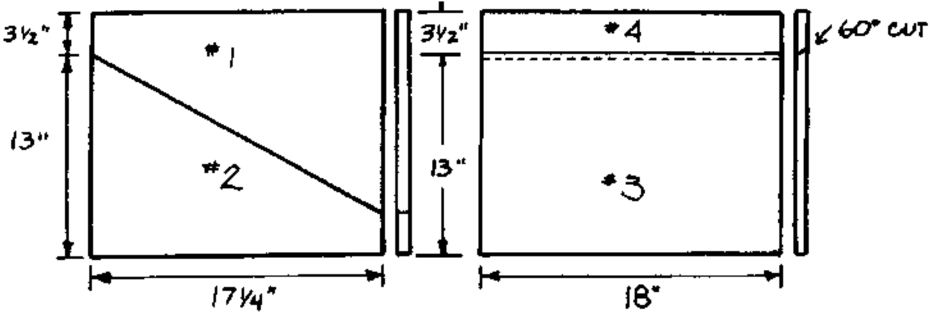
THE OVEN BOX

Make the plywood body of the oven first. Note that the plans show a rectangle from which you cut both side pieces, and another rectangle for the top and bottom pieces. This saves wood and also makes construction easier. A table saw makes nice straight cuts but if you don't have one, don't worry. The oven shown in the photos was constructed entirely with hand tools.

SIDES—PARTS 1 AND 2

Be sure to cut the plywood rectangle that will form the sides accurately so that these parts will fit the top, bottom, and back pieces.

Now draw a line in the proper place to divide the rectangle into the two side pieces. Saw right on the line, using power tools if available. If not, clamp a straight board onto the plywood just on the pencil line. Hold the



Layout for cutting the sides, top, and bottom of oven

Dan using the clamped board guide to help saw the sides accurately.

saw next to the guide and saw straight up and down. When you've completed the cut, the two pieces should match. Smooth the pieces with sandpaper and set them aside while you work on the top and bottom.

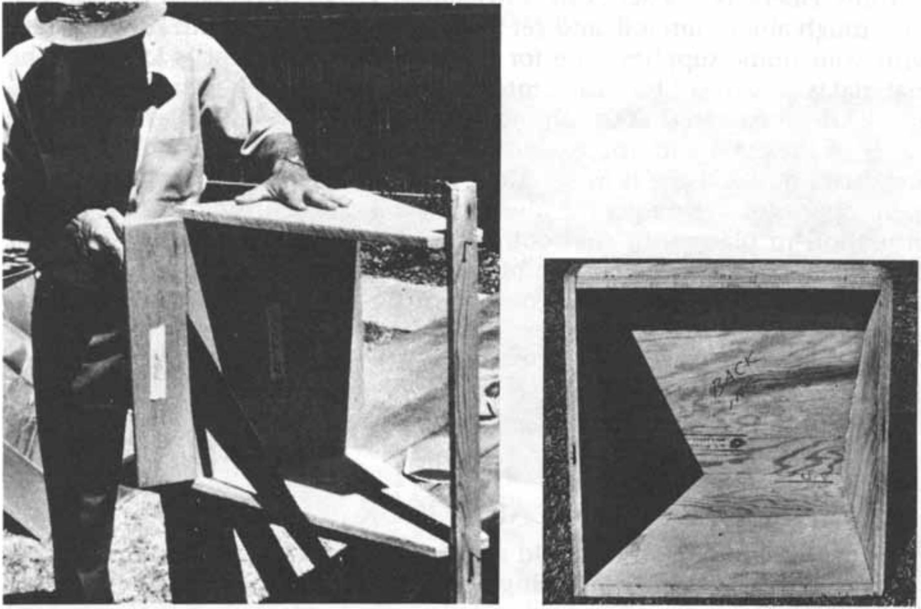
TOP AND BOTTOM—PARTS 3 AND 4

We used a simple method to save work in making the top and bottom pieces from the larger rectangle shown in the plans. Glue and nail the sides to the uncut piece, as shown in the photo. We put glue on one side, stood on the uncut top and bottom piece and held the side piece in place carefully, lining up the edges at the back of the oven. Nail with 2" finishing nails. Then do the same for the other side piece.

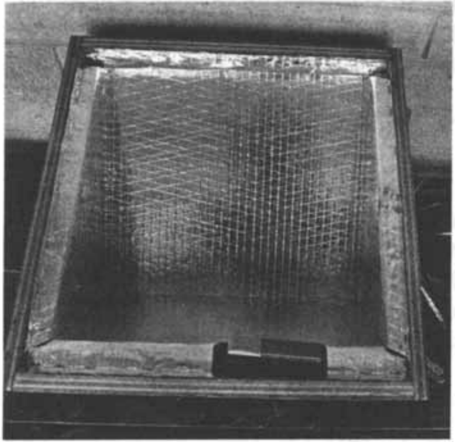
With both sides nailed to the uncut piece (it will stick out as shown in the photo), draw guide lines on both sides. Now saw carefully, frequently checking to see that you are following the guide lines. Take your time and make an accurate cut. The piece you have just cut off should fit neatly between the sides to form the top.

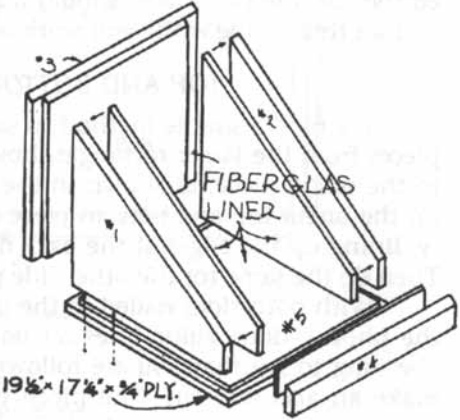
BACK—PART 5

Now you're ready to glue and nail the oven back to the sides. Apply glue and carefully nail the back to the already assembled sides, bottom, and top. Use 2" finishing nails. Keep all edges even so that the oven is square and true; then smooth it with a sandpaper block or sander so that the glass cover will lie flat on the open face of the oven.



Left—The piece cut from the rectangle will become the oven top. Note the strip of wood holding sides together. Right—The completed oven box. Use wood filler where necessary to close up any gaps.





Left—Trim the aluminum part of the insulation after securing it with roofing nails, so that it can be easily stapled to the oven box. Right—Assembly of the oven box and fiberglass liner.

INSULATION

For an oven temperature of 250° F, we could stop right here. Instead, we add fiberglass insulation so that the oven will really heat up. We use Owens Corning/Fiberglas 704 Series rigid insulation 1 1/2" thick, faced on one side with tough aluminum foil, and get temperatures of 350° F and above. Check with your home supplies store for the insulation. The cost is low, and the material is easy to cut for fitting into the oven. Use a knife or saw.

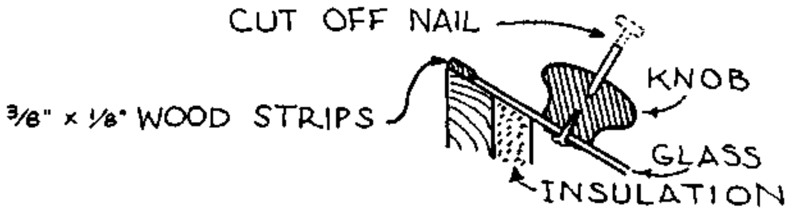
Plan all cuts so that the aluminum side of the insulation will be on the inside of the oven and not up against the plywood walls. Fit the side pieces first. Trim one and use it as a pattern for the other—being careful to make them opposites so you get the aluminum foil on the inside. We tacked the insulation in place with the roofing nails. The fiberglass is soft, so don't drive nails in below the surface of the foil. Fit the top and bottom pieces and nail them in place. Then cut a piece for the back, push it into place, and nail.

Remember our discussion on a good solar energy absorber? Right now the shiny aluminum surface makes a good reflector instead. So paint it dull black. You can brush the paint on, or use a spray can. Be sure to buy paint labeled "non-toxic."

GLASS DOOR

The opening of your oven should measure 18" by 18". The double-strength window glass overlaps this opening 3/8" all around, so the glass must be 18-3/4" square. Have the glass cut at the glass shop unless you are experienced in working with glass. The glass shop can also sand the edges for safety and drill the 3/16" hole. The hole should be 2" from the edge and centered, as shown on the plans.

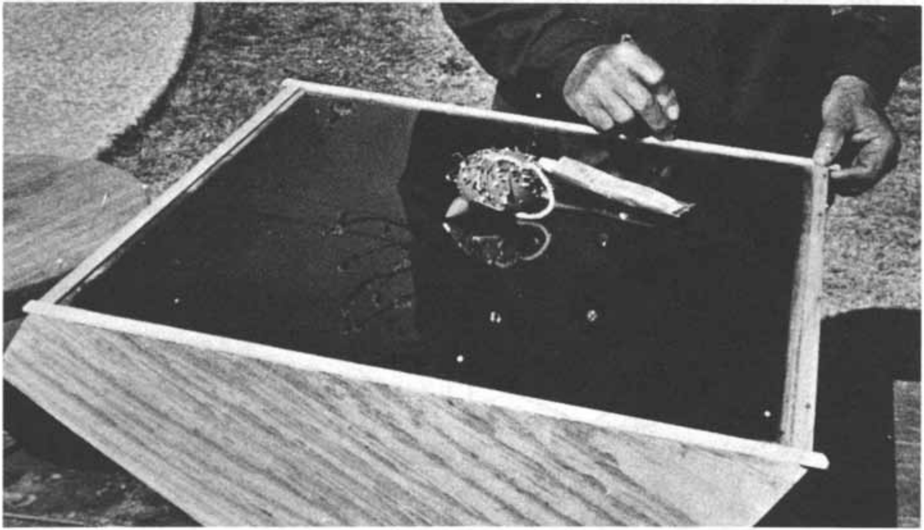
The small hole in the glass is for attaching the wooden drawer knob used for opening and closing the oven door. We bought a 1" wood knob and attaching screw and it worked fine. You may have to cut the end of the screw off with a hacksaw.



Detail of oven door handle.

Also drill a small hole in the front center of the knob, as shown on the drawing. This should be a tight fit for a short length of nail from which the head has been removed. We inserted the nail by squeezing it and the knob in a vise. The nail should protrude from the front of the knob about 3/4". Round off the sharp edge with a file. This is a simple sun-tracking device—no shadow means the oven is pointing directly at the sun! Now attach the knob to the glass, using the fiber washer between the screw and the glass to guard against cracking.

To attach the glass cover on the front of the oven, place the thin wood strips all around, as shown in the plans and photo. To simplify this task, we used 1/8" x 3/8 x 36" balsa wood from a model airplane shop. We bought three pieces and used the cut-offs to piece together the fourth side. You can substitute balsa wood, pine, or other wood strips.



The wood stips are being glued to the oven face. The pins hold the strips in place while the glue dries.

As shown in the photo, block up the oven with the front face level. Lay the glass on it, with an equal distance from the glass edges to the outside of the box. Now apply glue to the strips of wood and carefully pin them in place, so they are not quite touching the glass. Don't let the glue run out from under the wood strips and touch the glass as this may cause you a little extra work getting the glass loose. Use quick-drying glue for this job and tack the wood in place with short brads.

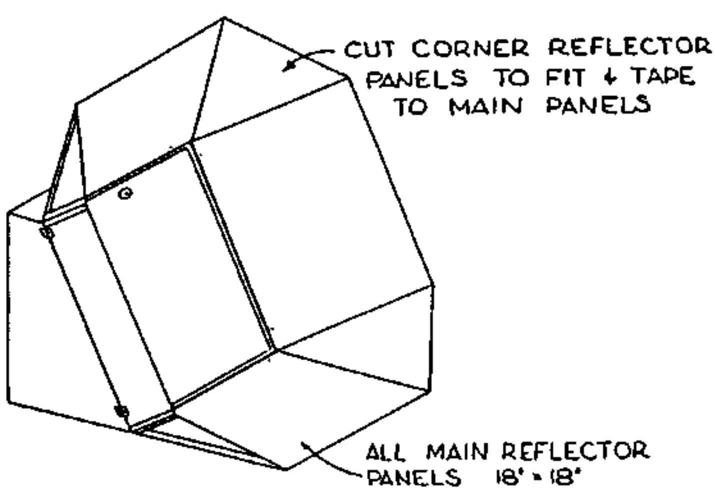
Your solar oven will now work. In fact, this glass-covered box was all that early solar cooks used. On a good bright day the oven may reach above 200° without attached reflector panels. This temperature will do a great deal of cooking, but most times that isn't enough. So now we'll attach the shiny reflectors that bounce more solar energy into the oven.

Since light bounces off a mirror at the same angle at which it strikes it, we can attach a reflector the same size as the opening in our oven and reflect all the light striking it into that opening. But this is so only if we keep the reflector at an angle of 120° from the glass cover, as shown on the plan.

REFLECTORS

The reflector panels can be made from several different materials. Perhaps the simplest method is to cut 18" squares of corrugated cardboard and glue aluminum foil to them. If you do a smooth job, these will work almost as well as glass mirrors, and they are feather-light, cheap, and easily replaced if damaged.

We've had the best results using a double layer of cardboard. This prevents the reflector from warping as it tends to do when it gets damp or warm. (Remember, you'll need eight 18" squares using the double-layer method.) Apply a coating of rubber cement, white glue, or contact cement to the cardboard squares. Then press them together and lay them on a flat surface with a moderate weight holding them together until dry.



Reflector panals attached and taped

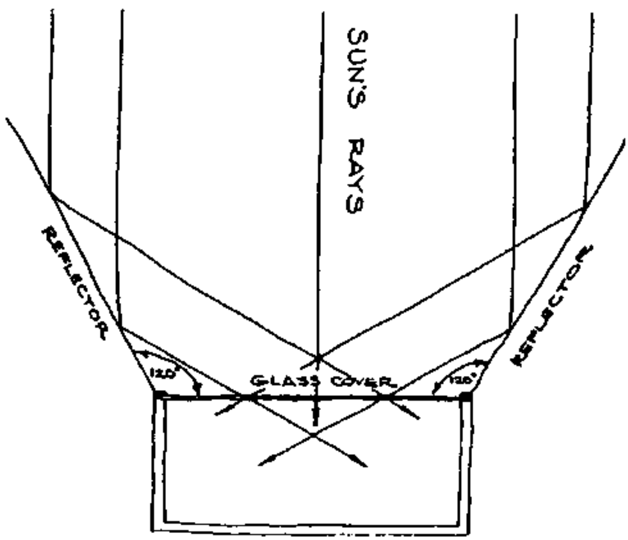
With the cardboard squares dry and flat, you're ready to apply the reflective material. Be sure to use double-strength foil, in an 18" roll. It's possible to use thin foil, but heavy-duty is so much easier to use and keep smooth that it's worth the slight additional cost. We find it easier to apply glue to the cardboard and then place the cardboard on the foil, rather than doing it the other way. There's less chance of wrinkling the foil this way. Weight the cardboard and aluminum foil while they dry. Don't trim the foil until the glue has dried, and use a sharp knife.

We've also had good results making reflectors from 1" urethane foam with aluminum foil backing already attached. This home insulation material is very light and not expensive, and a 4-ft x 8-ft sheet made lots of reflectors. We've also used aluminized Mylar glued to thin masonite or other suitable backing material. Just about anything will work as long as you keep the reflector flat, smooth, and shiny. We buy aluminized Mylar on poster board backing from local art supply stores.

REFLECTOR ATTACHMENT ANGLES

The way the oven box is cut, the top and bottom reflectors require different angles attachments than the sides. So make sure all the angles are bent correctly or you'll be wasting solar energy and not cooking as well as you could.

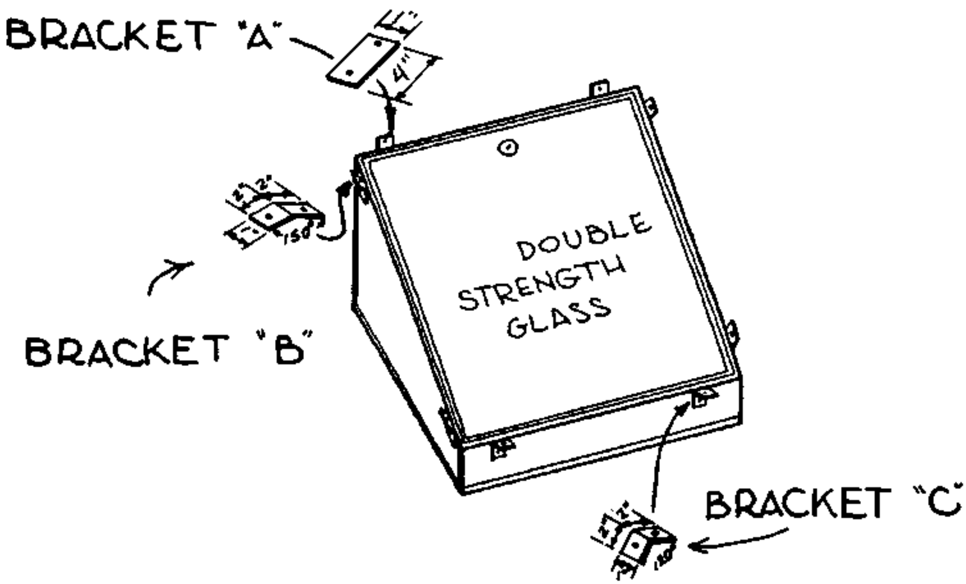
For this reason, we had the angles bent at a sheet metal shop for accuracy and to save time. Aluminum is excellent; it should be 1/16" thick and not soft. If you cannot find aluminum, galvanized or black iron will do. Use 16 gauge metal. The angles are made from blanks 1" x 4" which are bent in the center of the 4" dimension. Because of the shape of the oven box, two fittings are left flat; four are bent to an open angle of 150°, and two are 120°. Make sure that the angles are exact so that each reflector will make the proper angle with the glass cover of your oven.



How the reflectors work.

Drill 3/16" holes in both ends of each attachment angle as shown on the plans. Clean the burrs from these holes with a slightly larger drill held in the hand, or with a knife blade you don't care too much about. Now you can attach the angles to the oven box. Hold an angle in place and line up its free leg with the face of the oven as shown on the plan. Mark through the hole onto the plywood for the location of the screw hole. To speed up the process, go ahead and mark all the holes now and do all the drilling at once.

Center punch the hole locations for accurate drilling. It will also help if you wrap a short piece of tape around the drill so you won't drill completely through the 3/4" plywood. About 5/8" is deep enough. Use #10 roundhead wood screws, 5/8" long. Tighten the angles in place, you are now ready to install the reflector panels.



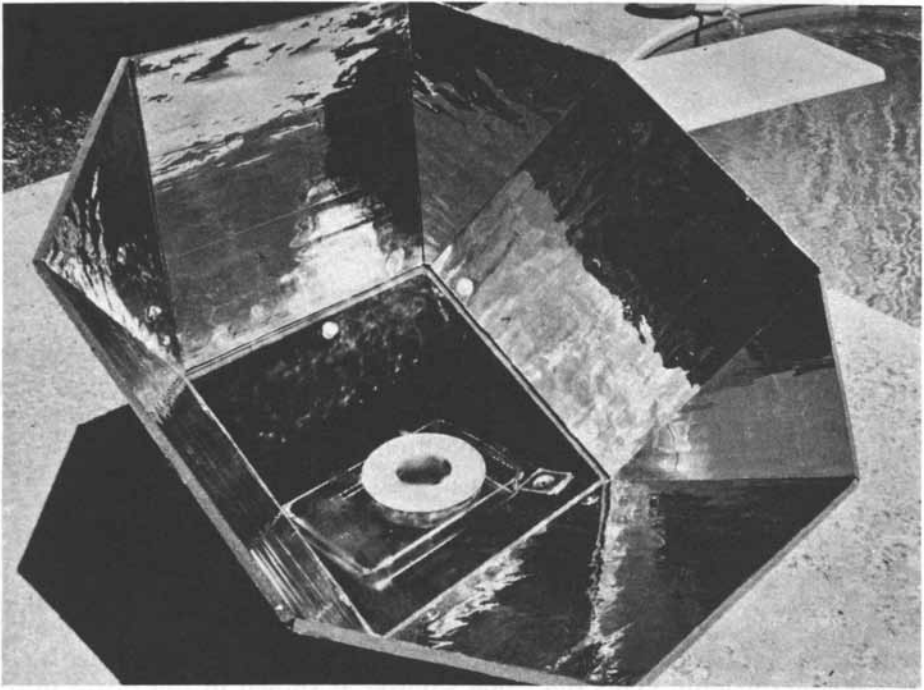
Detail of reflector mounting brackets.

Hold a reflector panel in place (with the aluminum foil toward the glass), just clearing the glass cover. Mark the panel very carefully with a pencil through the hole in the attaching angle. Again, you may want to use the mass production technique and mark all your panels at once.

We found the most accurate way to put the holes in the cardboard was to carefully force a punch or ice pick through the small pencil-marked circles, then run the 3/16" drill through the punched hole. When you have drilled all eight holes you are ready to mount the reflectors to the oven.

The reflectors are attached to the angles with #10 nuts and bolts, with a 1" washer under the bolt head on the reflector side. This large washer keeps the bolt from pulling through the soft cardboard. Attach all four reflectors, tightening the bolts snugly but not too tightly.

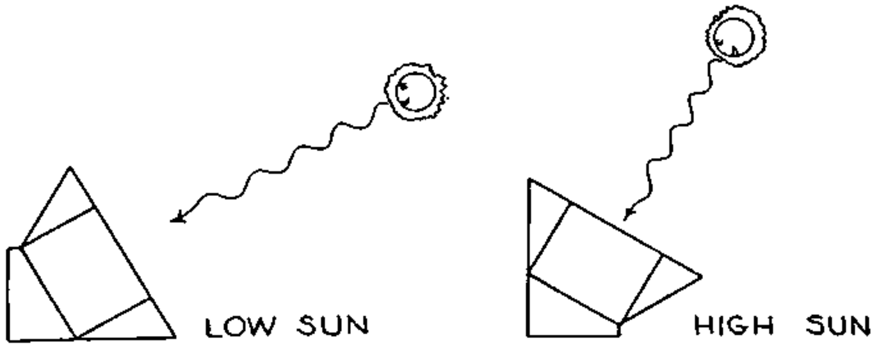
You are now doubling the amount of solar energy going into the oven, and its temperature will really soar. You can add even more heat by filling in the gaps between reflectors as shown in the drawings and photos. Cut four cardboard/foil triangles to fit into the gaps and tape them neatly in place with masking tape, duct tape or Velcro strips. Now your oven should reach between 300° and 350° on good days, enough to cook just about anything you want to cook!



The completed reflector oven with the triangles fitted into the corners.

For storing the oven when not in use, remove the glass cover, turn it over and replace it on the oven with the knob inside so that you can set the reflectors on it. For added convenience, you can hinge the reflectors to the oven with lengths of piano hinge.

Folding up the solar oven for carrying.

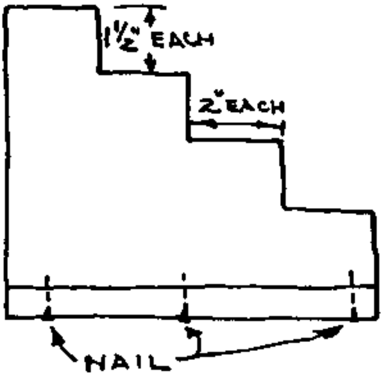


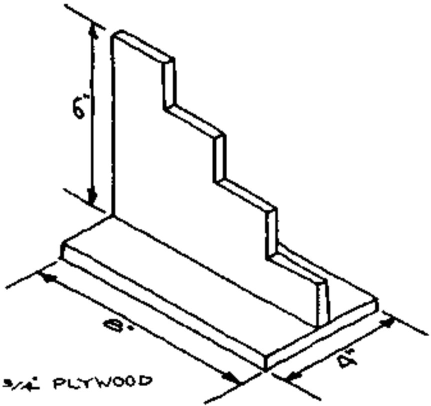
Using the low and high positions of the solar oven.

ANGLE ADJUSTER

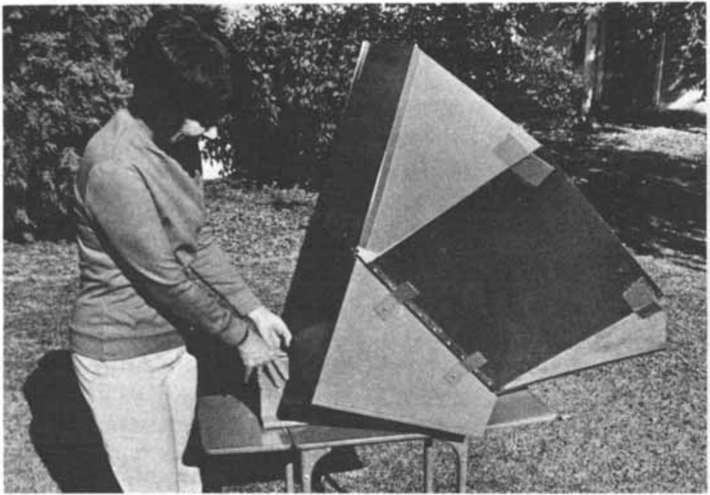
Our solar oven has its glass cover angled at 60° so we can use the oven in two positions and thus point it at the sun more accurately for a longer part of the day. As the sketches show, for early morning and late afternoon cooking you tilt the oven to the lower position. This makes it point closer to where the sun is at those times. This "high sun—low-sun feature" is very helpful.

Even this improvement doesn't guarantee perfect aiming all day long, of course. So for those in-between times we added an "angle adjuster" with which you can easily point the oven at the sun so accurately that the sun's shadow disappears on the tracking knob. This sometimes gives high enough oven temperatures to brown the meringue on a lemon pie or do other high-temperature baking! Make the angle adjuster as shown in the plans, using 3/4" plywood. Then, as shown in the photo, raise the oven with one hand until it is aimed just where you want it. Then slide the stairstep in to hold it there.





Solar oven angle adjuster.



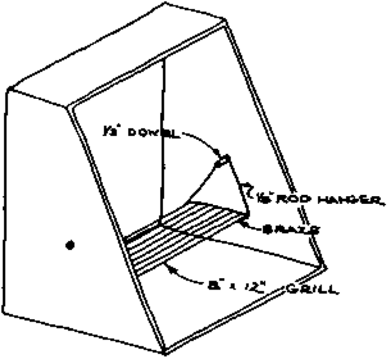
Beth using the angle adjuster to aim the oven at the sun. Note how the reflector panels are taped together.

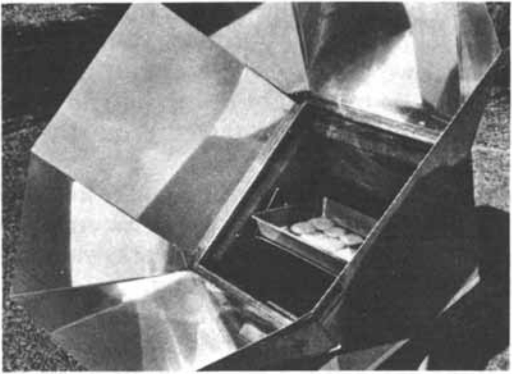
OVEN RACK

We thought we had solved all our problems, until a casserole ran out of its tipped dish. So we added another feature: an oven rack that keeps the pan level no matter how the oven is angled. Starting with a rack bought in the household goods department, we had the sheetmetal man add wire hangers at each end, as shown in the photo and drawing.

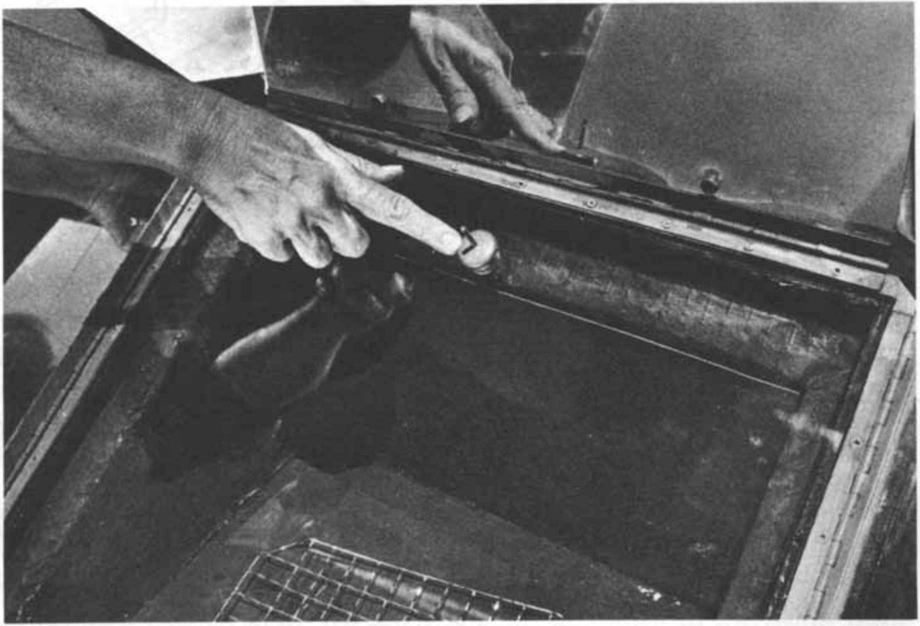
The hangers fit over short length of aluminum tubing glued into holes drilled through the sides of the oven as shown. Using this handy accessory you can be sure a pie won't run out of the pan or a loaf of bread come out looking like it was baked on the side of a hill.

A little paint really dresses up the solar oven. Pick your favorite color and either spray or brush the outside of your creation a gleaming "solar yellow," "fire red," "flame orange," or whatever suits your taste. We painted the angle adjuster too. None of the colors will do anything for the temperature inside the oven but they make the outside more attractive. Ours was originally orange but now sports a brown leatherette trim on the outside.


1/2" DOWEL
ROD HANGER
BRAZE
8" x 12" GRILL



Swinging oven rack.



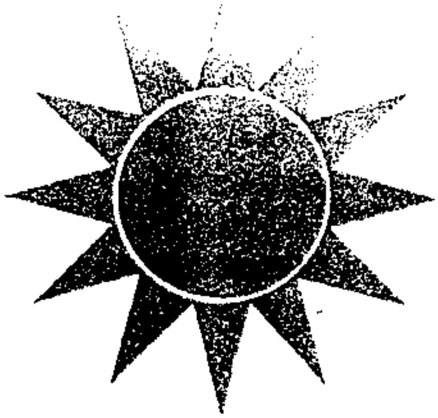
The finger is pointing to the shadow on the knob. Adjust the oven until the shadow disappears; the solar oven will then be pointing directly at the sun.

Putting food in the oven is easy. Just open the glass door, put in the food, and close the door! An inexpensive oven thermometer should be standard equipment. This will let you know the oven temperature accurately—and it really impresses friends who can't believe a solar oven can get so hot!

Of course, you'll get the most solar heat by pointing your oven as directly at the sun as possible. The nail we put into the knob on the glass door is the suntracker that lets you aim the oven right at the sun. So check the shadow until it disappears and you'll be right on target. (You may see several faint shadows, but use the dark one.)

We have even learned how a meal can be cooked while you're away for several hours. The trick is to aim the oven at a point halfway between where the sun is at the start and the finish of cooking. This method works very well for a roast and vegetables. But a cake needs more exact focusing.

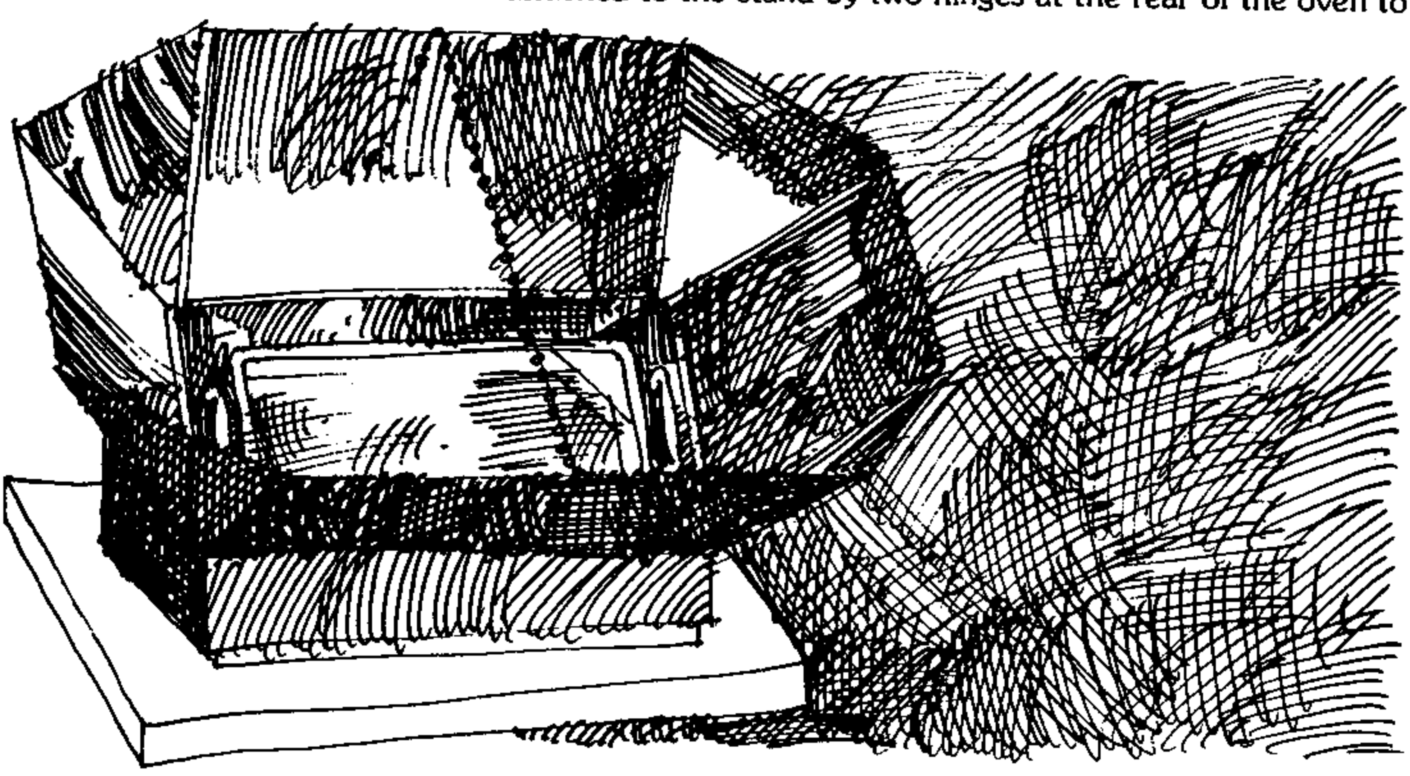
The inside of the oven gets very hot and the black paint may give off fumes and smell for a while. So leave the empty oven in bright sun for several hours until the smell is gone. Wipe any residue from the inside of the oven and the glass cover. When you're satisfied that the fumes and smell have burned off, you're ready to start cooking.



Solar Oven

This solar oven consists of an inner box of stainless steel and an outer box of galvanized iron, separated by 1 inch of industrial fiberglass that helps to retain heat. On the front of the oven is a removable double-glazed "window" that allows light to enter the oven and that traps heat radiating from the blackened interior. Reflective panels on the front of the oven concentrate the sunlight entering the oven. During sunny weather, temperatures of 400°F. are easily achieved.

A stand supports the oven at a convenient height. The oven is attached to the stand by two hinges at the rear of the oven to



allow it to be tilted so that the direct rays from the sun, entering the window of the oven, are always perpendicular to the surface of the glass. Wedges under the oven can be moved in and out to accomplish changes in the inclination of the base of the oven.

The oven that was originally constructed was designed around a secondhand microwave oven door. A window for the oven door could equally well be made using tempered glass from a conventional oven and building a frame around it. The assistance of a skilled sheet-metal worker might well be advised unless you have considerable experience working with sheet metal.

Materials Required

15 square feet of self-adhesive aluminized Mylar (at least 2 feet in one dimension)

10 square feet of light-gauge stainless steel (at least 2 feet in one dimension)

25 square feet of light-gauge galvanized sheet metal (at least 2 feet in one dimension)

1 24-by-30-inch piece of ¾-inch plywood

20 feet of 1½-by-1½-inch softwood

1 recycled microwave oven door or equivalent

4 dozen ⅜-inch sheet metal screws

1 tube of clear silicone sealant

2 2-inch loose-pinned butt hinges

2 metal handles for oven door

2 wooden wedges (see illustration and text)

industrial fiberglass sufficient to insulate structure (This insulation is usually available from heating equipment suppliers.)

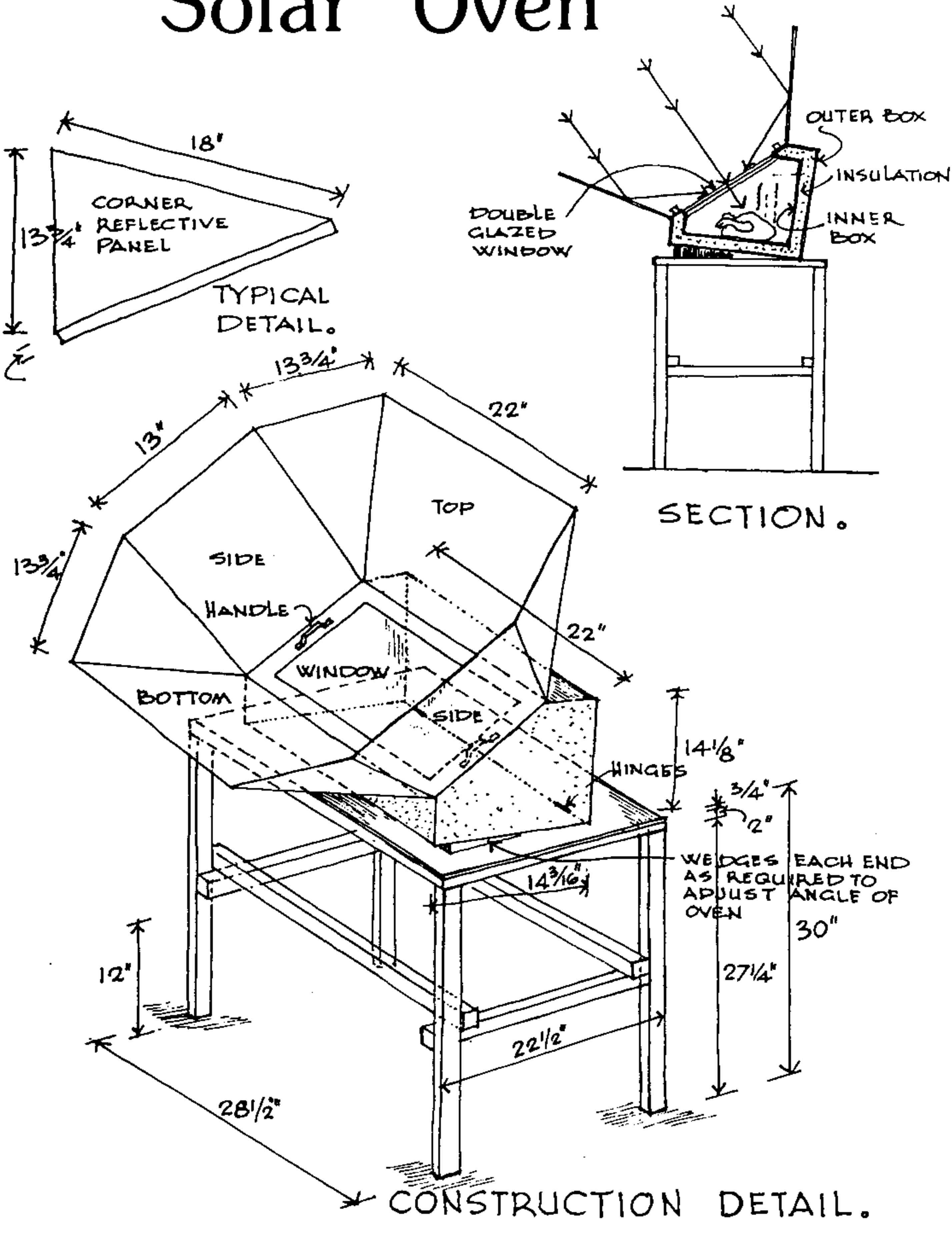
rivets

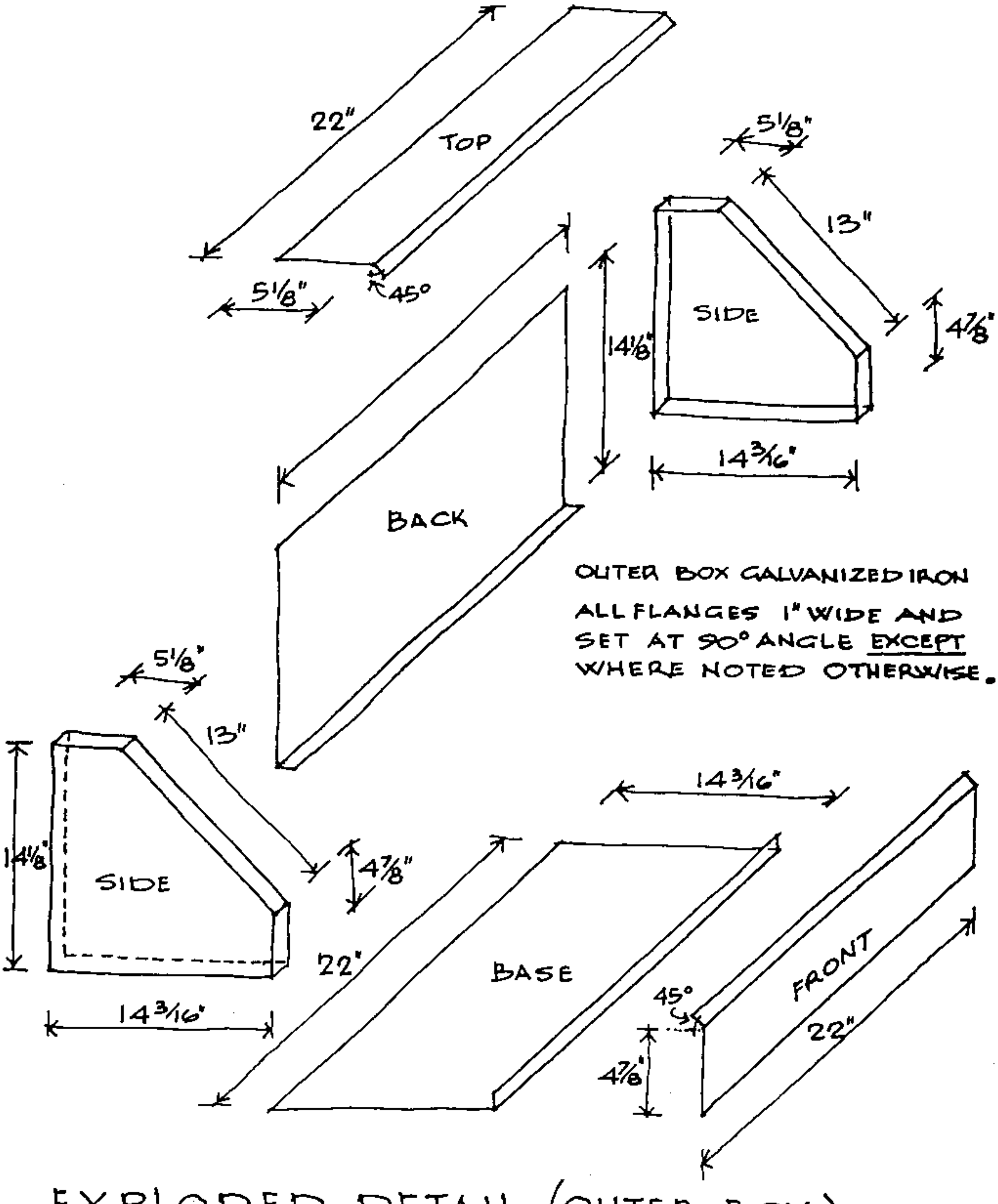
paint

Internal Box

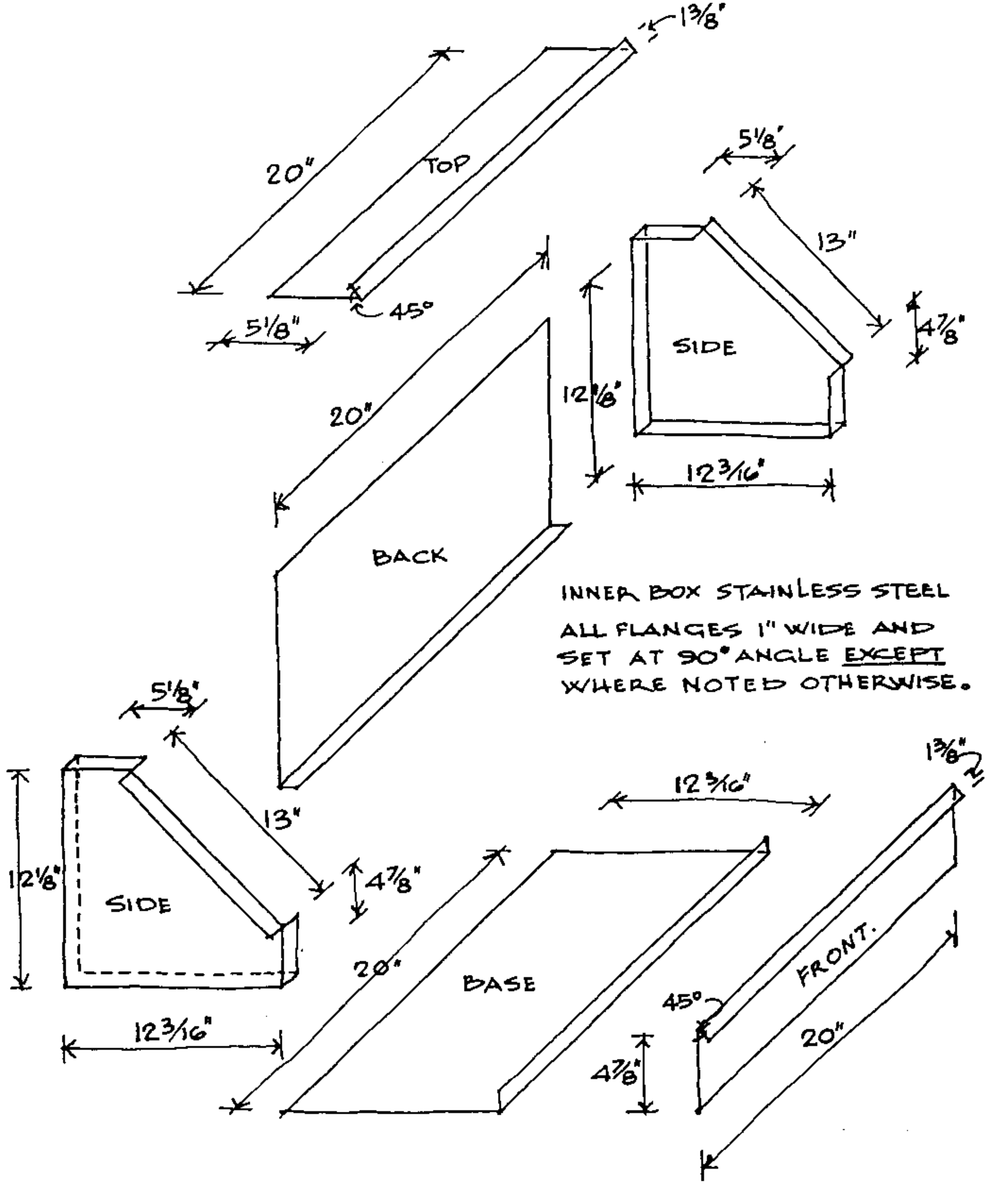
The internal box should be made as follows. The various pieces of light-gauge stainless steel are cut to the dimensions shown in the exploded view of the oven. Each of the protruding flanges is made 1 inch wide and should be bent at 90° except where noted otherwise. All screws should be fixed in position by screwing them from the inside of the box outwards. Using ⅜-inch number 6 sheet metal screws, attach the top to the two sides. Then firmly secure the back in place. Next slide the base into position and screw it to the remainder of the structure already constructed. Finally, attach the front to the internal box.

Solar Oven


18"
13 3/4"
CORNER REFLECTIVE PANEL
TYPICAL DETAIL.
OUTER BOX
INSULATION
INNER BOX
DOUBLE GLAZED WINDOW
SECTION.
13 3/4"
22"
13"
TOP
13 3/4"
SIDE
HANDLE
22"
WINDOW
BOTTOM
SIDE
14 1/8"
HINGES
3/4"
1/2"
WEDGES EACH END AS REQUIRED TO ADJUST ANGLE OF OVEN
14 3/16"
30"
27 1/4"
12"
22 1/2"
28 1/2"
CONSTRUCTION DETAIL.



EXPLODED DETAIL (OUTER BOX).



EXPLODED DETAIL (INNER BOX)

External Box The external box is made of galvanized sheet metal. Follow the illustrations and the order of assembly outlined for the internal box. All screws are screwed from the outside into the interior. Before the front is fixed in place, slide the internal box inside the box you are fabricating. At the same time stuff the cavity with industrial fiberglass. Use screws to secure the two boxes together where they overlap. Cut small metal plates to cover each gap remaining at the corners, then braze into position.

Oven Door Side flanges are screwed to the microwave oven front and handles are placed on either side of it. The front of your oven will have to be made according to the materials available to you. Bear in mind that the glazing must be heat-resistant. Whatever window arrangement you fabricate, make side flanges up to 1 inch in width and the length of the sides of your oven window frame, to hold the frame in place.

Reflective Panels The reflective panels are made of light-gauge sheet metal. The top and bottom reflective panels are cut 18 by 22 inches and the two sidepieces are cut 18 by 13 inches. The four corner reflective panels are cut in a regular triangular shape; two sides 18 inches long and base 13¾ inches. The 18-inch sides have 1-inch extensions on them (see illustration). All the reflective panels are riveted together, and then hinges or sheet metal pieces are used to join the reflector configuration to the front edge of the oven. The interior surface of the panels is lined with self-adhesive reflective Mylar.

Stand The stand is made as follows: cut the top from ¾-inch plywood, 24 by 30 inches. Then cut two pieces of ¾-inch plywood, 2 inches wide and 24 inches long, and two pieces 28½ by 2 inches. Nail the pieces together to complete the top of the stand (as illustrated). Cut four legs 30 inches long out of 1½-by-1½-inch softwood. Glue and screw these legs under the corners of the stand top. Cut two stand crossmembers 22½ inches long; again from 1½-by-1½-inch lumber. Glue and screw into place 12 inches from the bottom of the legs, as shown in the diagram. Then attach two more crossmembers, measuring 28½ by 1½ by 1½ inches, as shown.

Finally, attach hinges to the back of the oven connecting the oven to the stand. Cut two wooden wedges with which to adjust the angle of the oven. The farther the wedges are pushed under the oven the greater the inclination becomes.

If high cooking temperatures are desired, the whole oven may be covered with a removable insulating cover to minimize heat losses.

Bon appétit; the menu is as varied as your creative imagination!

I wanted to design a solar cooker that:

1 Cost as little as possible;
2 Could be made by almost anyone, without regards to building skills;
3 Required no special tools or a workshop to build;
4 Used commonly available materials;
5 Had useful cooking power for a family, but also power that is impressive, to demonstrate to people know that solar cooking is a real alternative;
6 Would not intimidate people, but instead, by its simplicity, let them know that they too could design and build a cooker to fit their needs;
7 Was fun and convenient to use.

The SunStar fulfills all of these design goals. Over the years, this cooker has become a part of my life. The food it can cook so deliciously has kept my family looking forward to those sunny days, when we can let the bright rays of the sun serve us our meals. At this point, it is not the issue of survival that keeps us cooking in this way. It is definitely the taste of the solar cooked meals keeping us looking to the sun. The only way we can share the unique quality of solar cooked meals is to help you build one also. In this chapter, I will teach you as clearly as possible how to make one on your own.

Searching for the Right Boxes

We will be describing how to build a medium size SunStar solar cooker. You can build smaller cookers with this information, or much larger ones as you wish. Medium sized cookers, in most cases, are the most useful in the family setting. They are able to cook nicely sized family meals. Even if you feel that you need more cooking potential than one medium sized cooker, you will probably find that two medium sized solar cookers are more useful than one larger cooker. Though larger cookers can be useful in special circumstances, they are also a little more awkward to use.

The first step in building the SunStar is to go on a treasure hunt. Look for those cardboard boxes you can magically transform into your own cooker. At first, you will be looking for two specific boxes which create the ovenbox. One box ends up being the inner ovenbox, and the other becomes the outer ovenbox. The source of these boxes may be behind any store. Larger stores often recycle their boxes, so you might ask to look in their storage room.

One of the variables in this design is whether you want a rectangular ovenbox (these boxes are easier to find), or a square ovenbox (these boxes are harder to find, but the reflectors fold up more easily). Both shapes are useful; maybe you could build one of each. The smaller, inner ovenbox defines the cooking area. For a medium sized ovenbox, when you multiply the length times the width (width should be at least 9″), the area should equal 120–180 square inches.

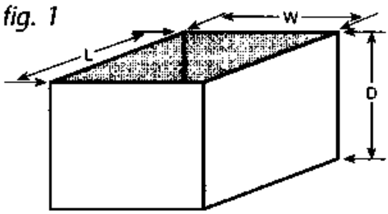
For example, a good inner box might have a width of 10″ and a length of 14″, so 10 x 14 = 140 square inches. Another example is a box that is 12″ wide and 12″ long, so 12 x 12 = 144 square inches.

Another requirement for a good inner box is that it should be at least 8″, better yet 9–12″, deep.

The outer ovenbox should be 2-3″ larger than the inner box in all directions: length, width, and depth. For example, if the inner box is 10″ x 14″ x 10″ (L x W x D), then the outer box could be 12″ x 16″ x 12″ (or slightly larger).

If you can't find the right boxes, you can easily alter the size with some cutting and gluing (see page 108). Your cooker will be stronger if you find the right size of boxes, without this cutting and gluing, so try your best to find good sized boxes.

fig. 1



After finding these two boxes that define the ovenbox of the cooker, gather

5–7 more medium sized cardboard boxes that can be cut up for insulation.

To make the reflectors, you will need to find four flat pieces that are about 2′ x 3′ wide. These pieces are cut from large boxes, such as washing machine or bicycle boxes. It is best that this cardboard is single strength rather than double strength. Double strength cardboard is two layers thick and thus is a lot harder to bend and work with.

Other Materials

Next, gather the other materials you will need.

1 About 8 oz. of white paper glue (like Elmers). Homemade glue can made by mixing 1/2 cup of flour, 1 tablespoon of sugar into one cup of water. This mix must be gently heated while stirring until it thickens. When dried this glue has been shown to be inedible to insects, at least in Arizona, and is as strong (or stronger) than Elmer's white glue.

2 One small roll of 18″ wide aluminum foil, preferably the heavy duty kitchen foil found at grocery stores.

3 A small amount of flat black paint (see "Paint" in previous chapter).

4 One piece of double strength glass, 1/2″ larger than the length and width of the inner ovenbox, so it can sit on the top rim of this box and completely cover it, thus enclosing the cooking area.

5 A baking tin that will fit inside the ovenbox to serve as a rack.

6 Some thick string, maybe a pair of shoelaces.

7 Some strong cotton cloth from recycled clothes.

8 (For a square cooker only) About one yard of elastic. This can be found at sewing stores. It comes as a stretchy ribbon of various widths. Buy the one that is about 3/8″ wide.

Putting the Ovenbox Together

1 First, work with the larger, outer ovenbox. Cut pieces of cardboard (from the extra boxes you collected) and place them in the bottom of the outer ovenbox until the cardboard layers are one inch thick (see figure 2). This will take about seven layers of cardboard. Some layers can be made from pieces of cardboard; they don't all have to be the full size. Place one or two layers of aluminum foil among these cardboard layers to act as heat reflectors (optional).

2 Next, position the outer box's upper flaps. Bend two opposite flaps inward and down. Bend the other two flaps outwards (see figure 3). If you are building a rectangular cooker, bend the two longer flaps outwards.

3 Now position the flaps of the smaller, inner ovenbox. Fold all four of its upper flaps all the way out and down. Place this box inside the outer box (see figure 4).

fig. 2

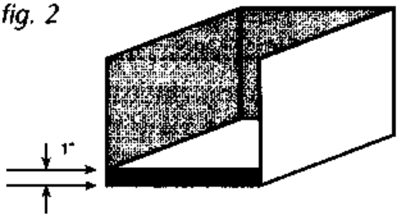


fig. 3

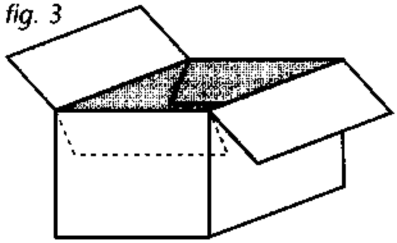


fig. 4

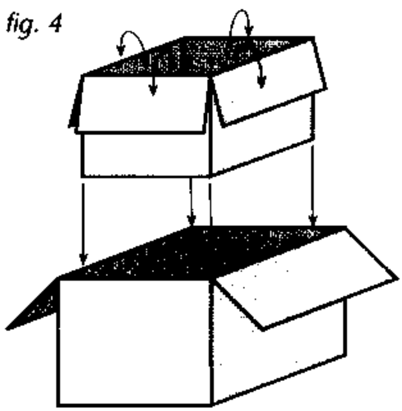
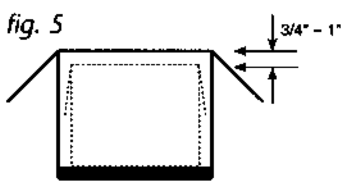


fig. 5



The upper flaps must end up between the two boxes (see figure 5).

4 The top rim of the inner box should be 3/4″–1″ lower than the top rim of the outer box (see figure 5). If it isn't, adjust the number of layers of cardboard in the bottom of the outer box.

5 The next step is to cut other pieces of cardboard (from the extra boxes) and stuff them between the inner and outer ovenbox. These cardboard filler pieces are the insulation for the ovenbox. Designate one of the four side walls to be the upper side wall and one the lower. The upper sidewall is defined as the higher sidewall when the ovenbox is tilted towards the sun. Designate which are the upper and lower side walls of the outer box from the sides with the flaps folded out. When you start placing the filler pieces into the side walls there are a few things you should keep in mind:

A All four side walls should end up with similar thicknesses, about one inch.

B It looks nicer if most of these filler pieces are doubled over, so that the cut edges of cardboard don't show (see figure 6). This is purely an aesthetic step; the filler pieces don't have to be doubled over to work. To bend cardboard where you want, crease a line with a blunt point and bend in on the crease (see figure 7).

fig. 6

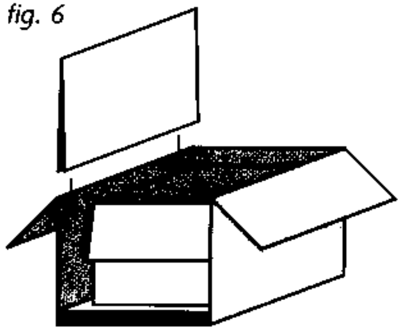
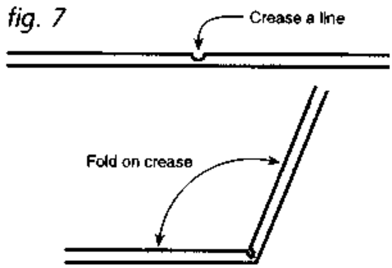
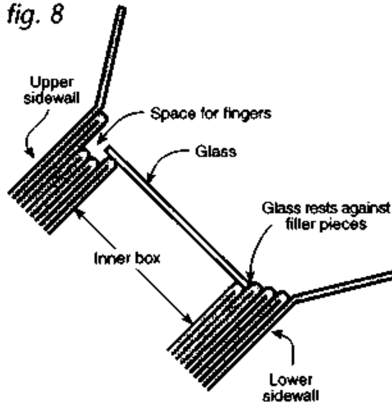


fig. 7



C The tops of the filler pieces on the lower side wall should be arranged so that when the glass is placed on top of the inner box, it will still cover the inner box completely. When the ovenbox, with the glass in place, is tilted towards the sun, the glass will slide down and rest against the card-board filler pieces in the lower sidewall (see figure 8). When the glass is in this tilted position, it must still completely cover the inner ovenbox in order to trap the hot air.

fig. 8



D The filler pieces in the other three side walls should be arranged so the pieces next to the inner box are slightly lower than the top rim of the inner box. This is to allow the glass to rest on the top rim of the inner box with no interference from the filler pieces (see figure 8).

E The filler pieces near the outer box should be slightly higher than the top rim of the inner box (see figure 8).

F When the glass is placed on the top rim of the inner box, you should be able to slip a finger under one side to remove the glass.

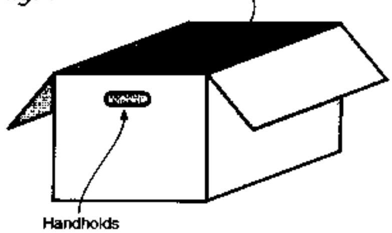
G Place one or two layers of aluminum foil into the four side walls to act as heat reflectors (optional).

H Continue putting these filler pieces into the side walls until the inner box is held tightly in place. Later, after the oven box is used for a while, the inner box will shrink slightly and will loosen up. The side walls should be repacked at this point, and at any time it becomes loose again.

6 Paint the inner ovenbox flat black (see figure 9). Because the bottom of the inner box heats up the most, it

will show a little wear in a year or so. To protect this surface you can cut another piece of cardboard to fit in the bottom. Paint it black (optional). When this added piece wears out, you can just replace it with another piece.

fig. 9



7 Cut handholds out of the outer ovenbox so that the oven will be easier to carry (optional, see figure 9). Just cut through one layer of cardboard and squirt some glue up under the cut to keep it from tearing out.

Building the Reflectors

1 Draw the reflector dimensions onto the four flat pieces of cardboard (see figure 10).

A The reflectors are based on the size of the glass. A square ovenbox will have four reflectors of equal size. A rectangular cooker will have two sets of equal size reflectors based on the length and width of the glass.

fig. 10

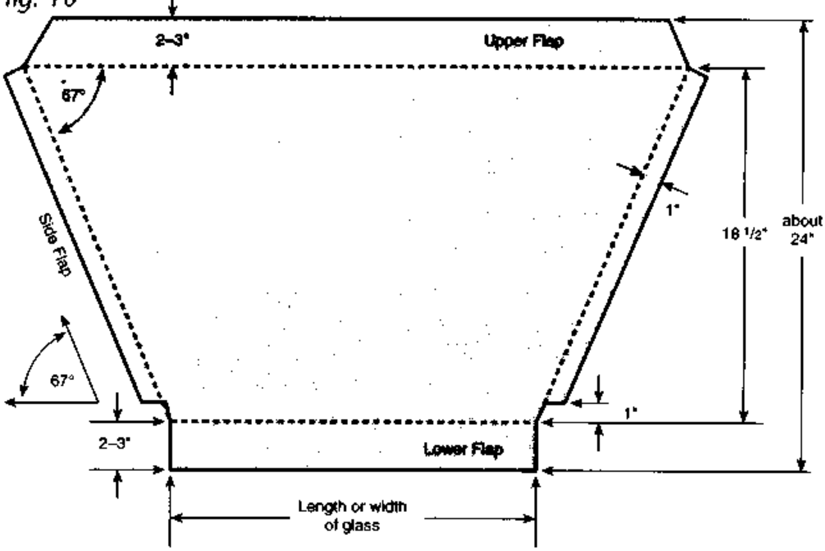
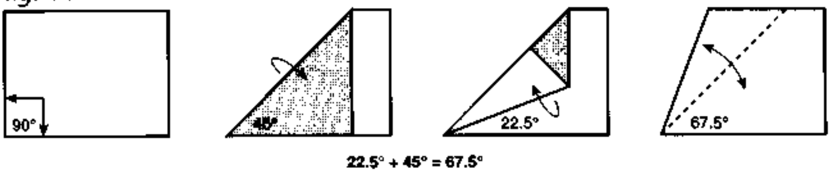


fig. 11



B The SunStar's reflectors are based on a 67 degree angle. To find this angle, use a protractor. You can also find this angle by folding a piece of paper a couple of times (see figure 11). Take a square corner (90 degrees) of a piece of paper and fold it in half so you have a 45 degree angle. Now fold one of the 45's in half, and you have two 22.5 degree wedges. Unfold the paper and add one of the 22.5 degrees to the 45 degree angle (22.5+45=67.5). Now you will have an angle close enough to 67 degrees.

C To keep the reflectors fairly durable, the design includes flaps that can be folded over and glued on to the top and bottom edges of each reflector. These flaps should be about two to three inches wide.

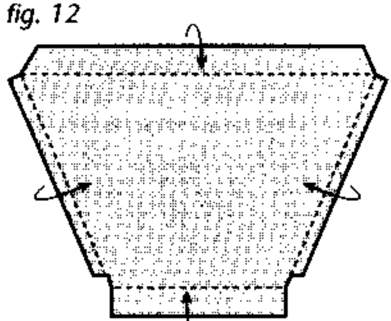
D To connect the reflectors together, you need to leave one inch flaps on both sides of each reflector. They should start one inch from the bottom side.

E The distance between the upper and lower sides, not including the flaps, should be a little more than 18", say 18.5". This is based on the common size of a roll of aluminum foil.

2 Once you have the dimensions drawn, cut out the reflectors. Use a razor blade knife or a mat knife.

3 Next, crease a line between the upper flap and the rest of the reflector, and bend in on this crease. Follow the same step for the lower flap and the side flaps. They should all bend towards the same direction (see figure 12).

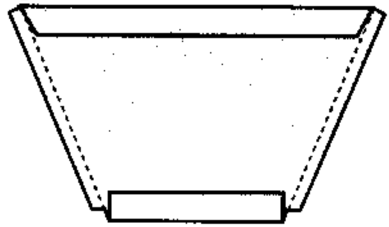
fig. 12



Crease and fold flaps in

4 Bend the upper and lower flaps all the way back and glue them to the back side of the reflector (see figure 13). When you glue these flaps, press them with weights until they are dried. Now, you have four separate reflectors.

fig. 13

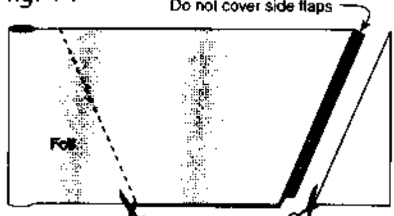


Fold upper and lower flaps and glue

Gluing the Foil on the Cardboard Reflectors

1 For this step, you need a flat working surface. Do a careful job because it will make your cooker look nicer and work better. Lay a reflector on the work surface with the upper and lower flaps down. This allows the clear side, to which you are going to apply the foil, to be facing upwards. Take the roll of foil out of its box and unroll it so that it completely covers the reflector. Rub your finger over the creases in the side flaps. This slightly creases the foil and will show you where to cut it. Cut the foil so that it does not quite reach the side flaps, leaving about 1/4" clearance (see figure 14). This will make it easier to center the foil onto the reflector when applying. The foil must not end up covering the side flaps.

fig. 14



Cut out foil

2 Remove the cardboard reflector from the working surface. Lay the cut piece of foil on the working surface, dull side up. Next, make up some of the glue mixture you will use, either the flour paste or the white paper glue. If you are using a white paper glue like Elmer's, take about 5 tablespoons of glue and add 10 tablespoons of water and stir it up. Now dribble 2-3 tablespoons of this glue on to the dull side of the foil (see figure 15). Take a small piece of clean cloth and smear this glue mix over the whole surface of the foil. Be care-

ful around the edges, so that the glue doesn't get on the shiny side. It should smear easily. If not, add more water to your mix.

If you are using the homemade flour paste, apply a thin layer to the dull side of the foil. Again, if it is not easy to spread, add a little more water.

3 Next, line up the lower side of the cardboard reflector with the lower side of the foil. Gently lower the reflector onto the foil (see figure 16). Press lightly and turn it over, the foil should stick to the cardboard. If it is not centered very well, gently try to center it with a little pressure from your fingers. If this does not work, peel the foil off at this point. Let the glue dry, put some more on, and try again.

fig. 15

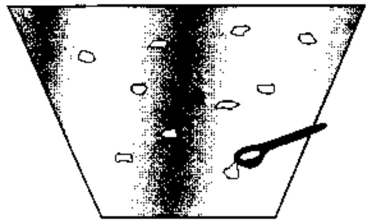
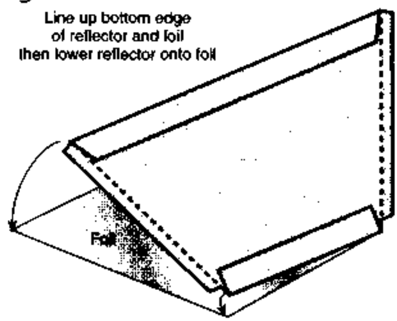
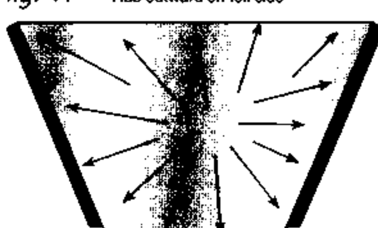


fig. 16



4 Press on the edges of the foil with your finger and pull out any large wrinkles. Small wrinkles are alright. Take another piece of clean cloth and rub the foil onto the reflector from the center outwards (see figure 17). Again, be careful around the edges, so that the glue doesn't get on the shiny side. If some does, let it dry and then rub it off. If a small air bubble is created that you can't rub out, take a pin and prick it and then rub again. Later, if any corner is not glued down well, take some more of the glue and stick it down.

fig. 17



Judge your work now. Does it look nice? If not, peel it off before the glue dries, and try again. Remember, it doesn't have to look perfect.

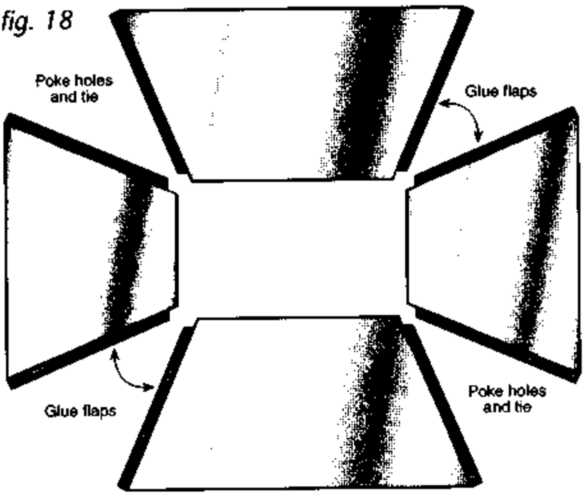
5 Repeat the process until all four reflectors are done.

Connecting the Reflectors Together

For a rectangular cooker:

1 Arrange the reflectors as they will fit on the ovenbox and set them out on the ground (see figure 18).

fig. 18



2 Glue two diagonal sets of corner flaps together. You then end up with two sets of two reflectors. When you glue these flaps together, press them with weights until dried.

3 Connect the side flaps that are not glued together. In each of the remaining flaps, poke four sets of corresponding holes. These two corners are tied together with a thick cotton string. Punch the holes near the bend between the reflector and the side flap (see figure 18).

For a Square Cooker:

1 Glue two sets of side flaps together so that you end up with two sets of two reflectors (see figure 19). Press the glued side flaps with weights until they are dry.

2 Lay the reflectors out on the ground as they will be arranged on the ovenbox.

3 Cut off one of the side flaps from each set of reflectors in only one of the corners (see figure 20).

fig. 19

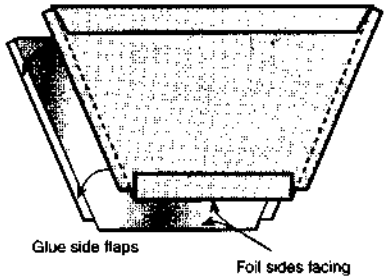
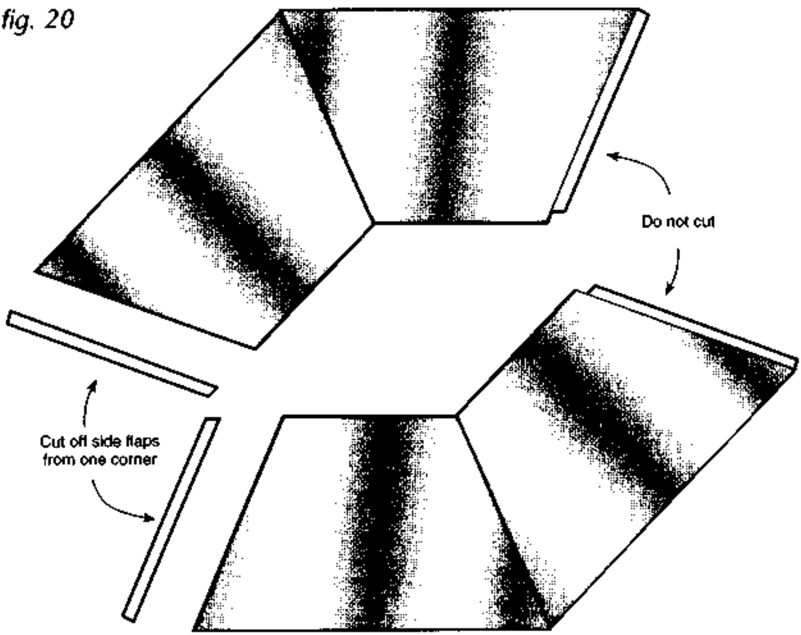
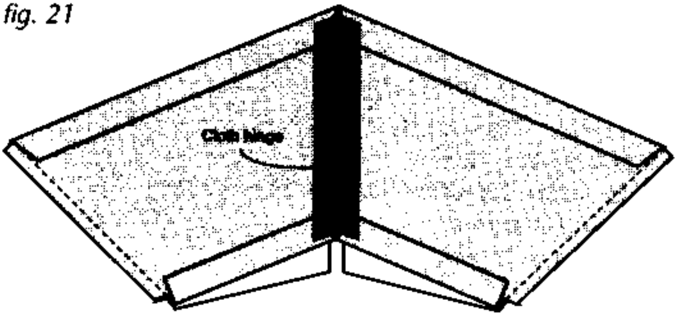


fig. 20



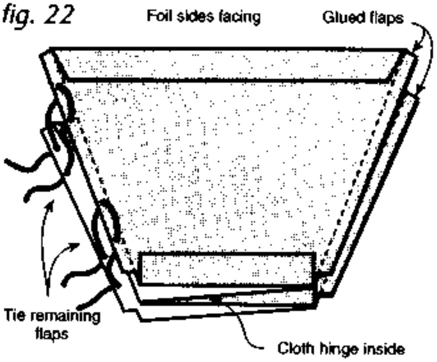
4 Arrange the reflectors so that the two reflectors with the side flaps cut off are lined up with their reflective sides down. Cut a piece of cotton cloth, 4" by 18". You will use this cloth to glue this corner together. Apply glue to the cloth and then lay the glued surface down onto the cardboard side of the seam between the reflectors (see figure 21). This will make a cloth hinge in one corner of your reflector assembly.

fig. 21



5 When the glue on the cloth hinge has dried, arrange the reflectors so that they are all together in one pile. The cloth hinge should be folded in on itself in the middle (see figure 22), and the two side flaps that are not connected should be lined up on the outside. Poke four sets of corresponding holes in the side flaps that still need to be connected. Poke the holes near the crease. Take the elastic material you got at the sewing store and tie these flaps tightly together (see figure 22). It probably would be easier if you tie two sets of holes near the lower side together and the two sets near the upper side of the reflectors together. Unfold the reflectors and see what you have created.

fig. 22



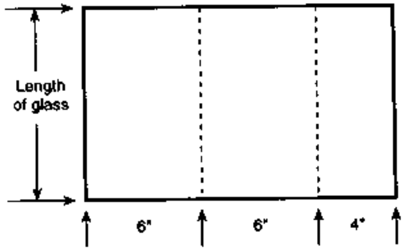
When I wrote the last version of this book, the reflectors were attached to the ovenbox by poking two sets of corresponding holes in both the upper flap of the ovenbox and in the upper reflector. Then I used a string and tied the reflector to the top flap of the ovenbox. This works fine. I have also found that I could create a slip-in piece to easily attach the reflectors to the ovenbox. By inserting the slip-in piece between the insulating layers of cardboard in the upper side wall, the reflectors can be secured to the ovenbox. I still tie the reflectors to the upper flap of the ovenbox, but only when it's windy.

Creating the Slip-in Piece

1 Cut a piece of cardboard 16″ wide and the same length as the glass. For example, if the glass is 14″ long, then this cardboard piece should be cut 16″ by 14″.

2 Crease two lines, on the same side of the cardboard, to split the 16″ into three sections with widths of 6″, 6″, and 4″ (see figure 23). Bend in on these creases.

fig. 23



3 Cut a piece of cotton cloth 6″ wide and the same length as the glass. Put glue on 3 inches of this cloth and lay this glued cloth onto the first 6″ section of cardboard. This leaves 3″ of the cloth without glue not on the cardboard. Next, put a little glue down each of the two creases in the cardboard and again on the 3″ of cloth. Smear the glue around a little. Fold the 4″ section over onto the adjoining 6″ section (see figure 24). Then fold these two sections over onto the 6″ section with the cloth leaving a 3″ strip of cloth exposed (see figure 25). Press the slip-in piece with weights until it is dry.

fig. 24

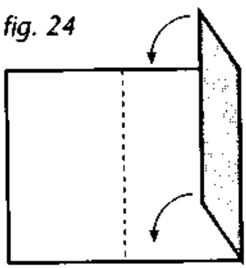
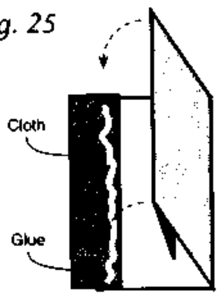


fig. 25



When you use your cooker you will understand why I fold the slip-in piece this way. You will be pushing down on the slip-in piece to insert it between the insulating layers of cardboard in the upper side wall of the ovenbox. The slip-in piece will last longer if you are pushing down on a doubled over piece of cardboard.

Attaching the Slip-in Piece to the Reflectors.

1 For the rectangular cooker, just glue the 3" width of cloth, sticking out of the slip-in piece, to the lower side of the upper reflector (see figure 26).

2 For the square ovenbox, glue the 3" width of cloth, sticking out of the slip-in piece, to the lower side of the reflector to the right of the reflector's cloth hinge (see figure 27).

fig. 26

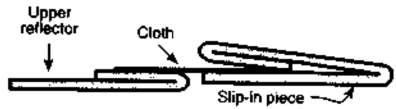
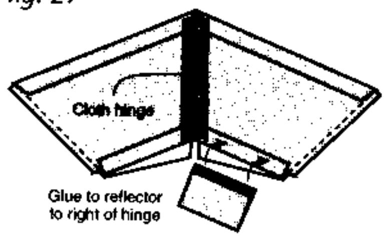


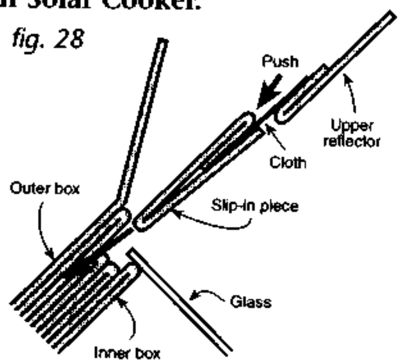
fig. 27



Finishing and Setting up your Solar Cooker.

Push the slip-in piece, with reflectors attached, between the insulating cardboard spacers on the upper side of the cooker. The reflectors should hang in place off of the cloth hinge attached to the slip-in piece (see figure 28).

fig. 28



The Rack

A dark baking tin is used as a rack to hold the cooking vessels and to catch any boil over. The rack is propped level against the bottom and the lower sidewall of the ovenbox.

It's nice if the rack puts a slight pressure on the oven's left and right sidewalls to add stability. If the baking tin has handholds, they can be bent downwards to make it fit better.

For example, let's assume that the inner ovenbox is 14 inches long. A baking pan that is slightly larger than 14 inches, when you include the hand holds, would be a perfect size. You can slightly bend the handholds down until the pan is just barely more than 14 inches long and then slip the pan into the ovenbox. It will now put a slight pressure on the sidewalls for stability.

Any baking tin that fits in the cooker can work. If the pan does not put a little pressure on the oven's walls, you will have to be a little more careful in arranging the cooking vessels so that they don't spill. You might have to set-up a propping system inside the ovenbox at some cooking angles.

You can build your own rack out of wood or bent metal. Paint the rack black.

When I build a cooker now, I start with the size of a traditional baking tin and find the necessary boxes for the oven to fit the pan. At first, though, it's more important you find any boxes that will work to get you started. In the future, you might keep your eyes open to find boxes that will fit a particular baking tin that you'd like to use.

The Glass

Place the glass on the top rim of the inner ovenbox. If any of the cardboard filler pieces are interfering with the seal between the glass and the rim of the inner box, correct them. Next, lightly push down on the four corners of the glass when it is in place on the top rim of the inner box. If the glass rocks, it means two of the corners are high. Press down on the high corners until the glass no longer rocks.

Take a close look at the fit between the glass and the cardboard rim. Sometimes there is a high or low spot. Correct this by pushing down on higher spots on the top rim of the inner cardboard box. Just try to get as good a fit as can be easily achieved. Over time, as the cooker is used, steam will naturally make the glass seal better.

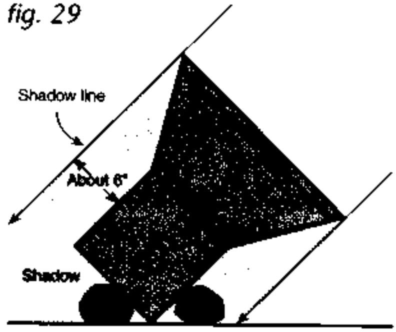
It should be easy to slip a finger under one side of the glass when it is lying on the ovenbox. This will allow you to easily remove it to access the food. You may have to cut some of the filler pieces to make it easier to slip your finger under one corner.

When the glass is hot, you should still be able to still handle it, if you only hold it by the edges. If it is still too hot for you, use a cloth to protect your hands. Some people tape the edges to make the hot glass easier to handle. You can do this, but if you learn to handle the edges only, with the palms of your hands, the tape will not be necessary.

Propping the Cooker

Use rocks or other objects (blocks of wood, shoes, rolled-up clothes, etc.) to tilt your cooker towards the sun. You must prop it both in front and in the back (see figure 29). If you only prop up the back, wind can easily tip it over and make an unnecessary mess in your cooker.

fig. 29



Prop in front and back

Aiming the Cooker

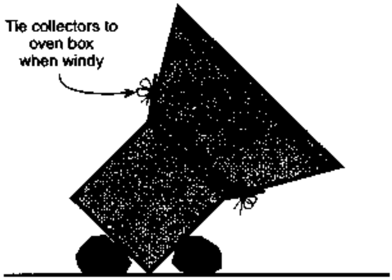
Never look at the sun to aim your cooker! Always use the shadows created by the cooker. For the east-west motion of the sun, use the shadows on the sides of the cooker.

For the vertical motion of the sun, stand behind the cooker and touch the ovenbox. Watch the shadow line that crosses your arm. A focused cooker will have the shadow line cross your arm about 6" from the ovenbox (see figure 29). By watching how the shadows move over time, you will learn how to aim the cooker ahead in the path of the sun.

Wind

For windy days, poke two corresponding sets of holes in the flaps of the ovenbox and in the upper and lower reflectors. Tie each of the reflectors to a flap with string (see figure 30). Shoe strings work well. Also don't forget to prop your cooker securely, in front as well as in back.

fig. 30



Curing the oven

The first couple of times you use this cooker it will smoke slightly, but after a few times this will stop.

Inner Box Shrinkage

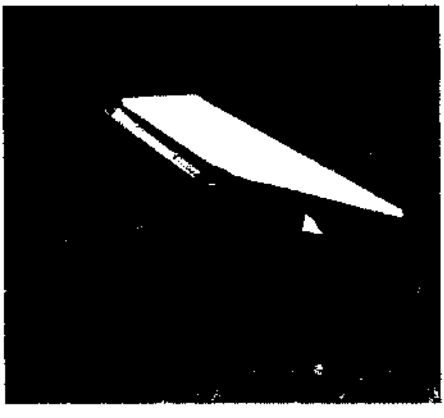
After cooking a few meals, the inner box will naturally shrink a bit. The reflectors' slip-in piece will no longer fit tight enough to hold the reflectors to the ovenbox. Cut some more filler pieces and repack the walls of the oven. Usually after another month or so, the ovenbox will again have to be repacked with more cardboard pieces, but this will probably be the last time.

Important Habit

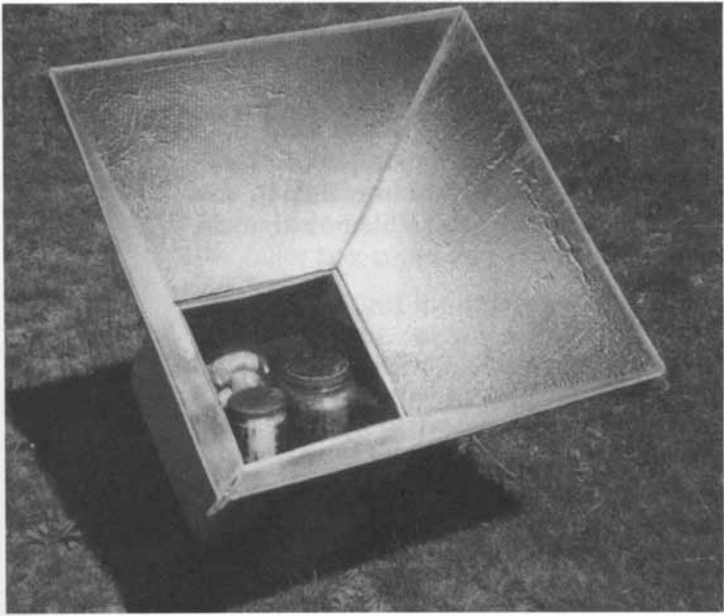
Your cooker is essentially made from paper, so you don't want to leave the cooker out in the rain or out at night in the heavy dew. You can close the reflectors down onto the cooker after the food is cooked, and carry the cooker into the kitchen. This keeps the food hot and in the kitchen and the cooker out of the weather.

Another Good Habit

Reflectors, when new, will bow due to changes in humidity. Don't worry about this. After a while, when the reflectors get older, they will lose this ability to bow. Also, when storing your ovenbox for extended periods of time, set the ovenbox on top of the reflectors. The weight will keep the reflectors flat.



Above: Folded down, the reflectors insulate the food until ready to eat.

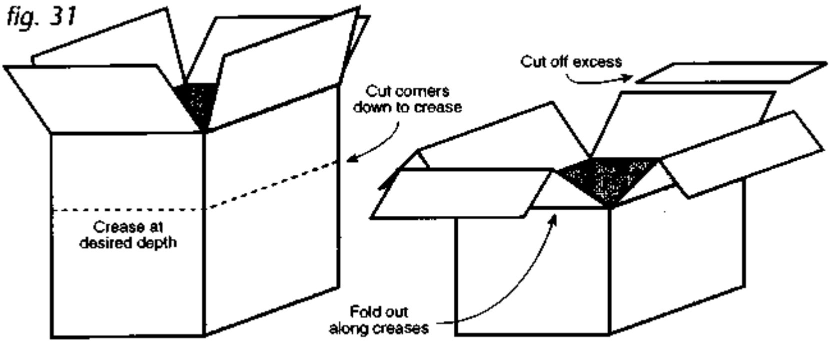


Altering the Size of Cardboard Boxes

If you cannot find the right boxes for the inner or outer ovenbox, remember that cardboard boxes can easily be altered. Here are a few examples:

1 Correct length and width, but too deep (see figure 31): Measure desired depth up from bottom. Draw a line around the box at this desired depth. Use a blunt point and crease along this line. Cut corners down to this line and bend sides out. Cut the excess off.

fig. 31



2 Correct length and width, but too shallow (see figures 32 & 33): Measure desired depth up from the bottom of the box to somewhere on the upper flaps and draw a line. Cut the cardboard off above this line. Turn the box over, break the seal, and fold the flaps out and down.

fig. 32

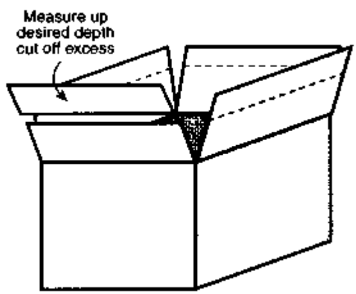
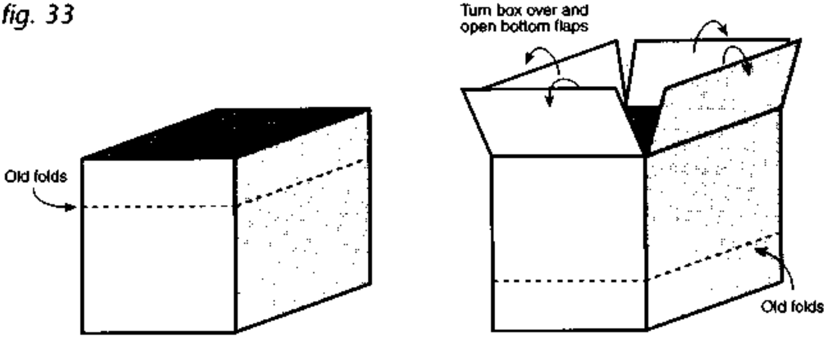


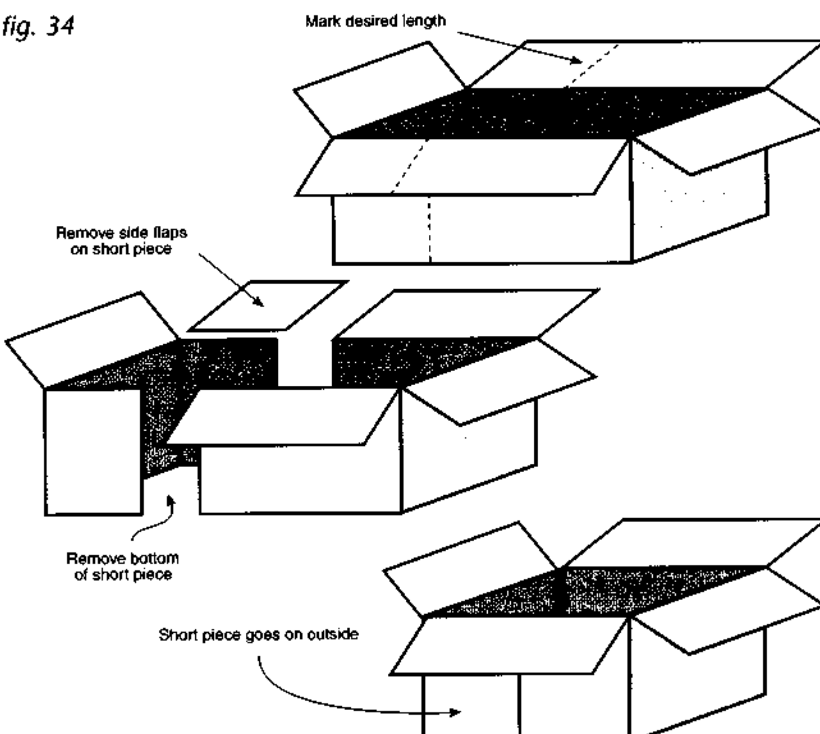
fig. 33



Insert this box into the outer box. To keep the cut flaps in place at the bottom of the inner box, cut another piece of cardboard that will fit snugly into the bottom.

3 Correct depth and width but too long (see figure 34): Cut box at the desired length. Take the short end, and cut off the bottom and the two upper side flaps. Also,

fig. 34



cut a little off the side walls. Now, put the box back together. The sides of the short end will enclose the long end of the box. Make sure that the top rim of the box is at the same level. Glue in place.

To Increase Power

Other than making a larger cooker, there are two ways to increase the power of a SunStar cooker.

1 Use a thermal pane consisting of two pieces of glass separated by about 3/8″ of air. In the last chapter, I told you how to build one. You can expect about a 50° F rise in temperature.

2 On the inner side walls of the ovenbox, glue a layer of aluminum foil. This will add 10–15% more power. The foil on the sidewalls reflects the light onto the cooking pots.

These increases in power may also increase the potential of glass breakage due to heat. If you decide to try these methods to increase the power, and the the glass does breaks, it will break in a squiggly line. This usually happens when the cooker is heated with no food in it, or when a cold wind blows across the hot glass.

Usually, I don't use either of these methods on my personal solar cookers. They are usually hot enough without them, and I have never broken the glass. But there are times these methods of increasing power could be useful and necessary.

The Rainbow Cooker

While finishing this book, I built a larger cooker that I'd been thinking about for a while. It worked out so well that I need to share it with you before this book is published. This cooker does not really break any new ground from what has already been presented, but it does illustrate how you can build a specific cooker to fill a specific need.

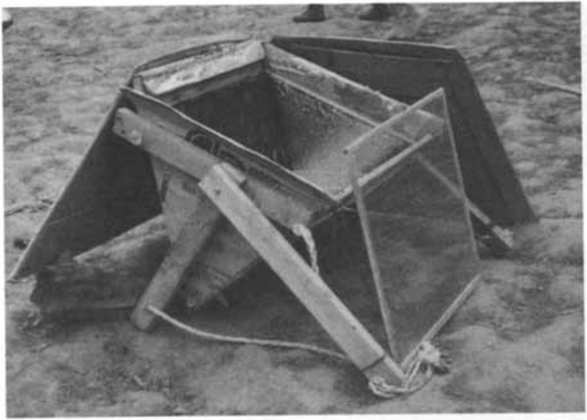
I have been sharing my SunStar solar cooker at the National Rainbow Gatherings over the last few years. The SunStar, is a fairly small family-size cooker and was not able cook a large enough quantity of food to share. Instead, I told people to build their own, learn to use it, and bring it to the gathering the following year.

Knowing how much people are lead by their stomachs, I started to wish that I had a larger design that could feed more people. This large-sized cooker needed to fill certain design goals to function at a gathering. We usually hike a couple of miles to a gathering site, so it needed to be easy to transport. It also needed to be a fairly powerful oven to impress the folks with the amount and quality of food it could cook. And, like the SunStar, it needed to be built out of inexpensive, recyclable materials. I also wanted it to be very easy to use by one person.

The cooker I came up with succeeded in all of these goals. I was able to cook 250 bread rolls a day. It also produced pizzas, cornbread, cakes, cookies and corn on the cob during my stay at the gathering. The cooker can be set up or taken apart in 5 minutes using only 4 wingnuts and a few shoestrings. When disassembled, this cooker folds completely flat for easy transport and storage. The cooker was built using basic materials: cardboard, glass, foil, a little wood, and some silicone. The total cost to put this one together was twelve dollars. Six of those went to the dump and six were spent on foil. Some of the materials, like the white paper glue, I already had on hand.

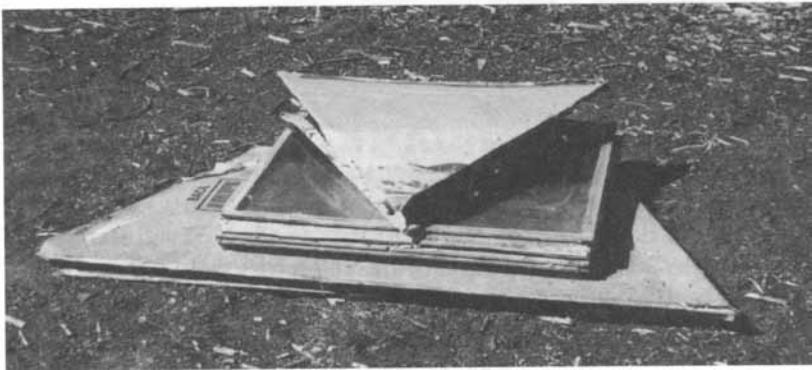
This cooker's design started with the recycled glass which I found at the dump. This was important because the glass, if bought new, would have been very expensive. At the dump, I found a screen door with two pieces of safety glass of the same size. This allowed me to build a thermal pane, with some wood strips and silicone. Safety glass is much stronger than regular glass, so the likelihood of breaking it is lessened. I left a small gap in the thermal pane seal to let any trapped moisture escape.

Below: The "Rainbow" cooker (left) next to a "SunStar."



Left:
The "Rainbow" opened for access to food.

Below:
Collapsed for portability.



Next, I focused on the ovenbox. As you see from the pictures, I based it on a triangle shape which is very stable and strong. The two side triangle wedges are able to separate using the four wingnuts, which allows the ovenbox to fold flat for packing away. The oven walls used some wood and one inch of layered cardboard and foil for its insulation.

The rack is a cut down oven rack with a chain, as described earlier in the book. The stand uses some 2x4's, rope, and a bolt pivot point. Both are fairly primitive methods, but they work and that is the goal.

The reflectors use two refrigerator boxes and are built just like a larger version of the SunStar's square cardboard reflectors. They are 3 feet in depth, and use two strips of 18″ wide aluminum foil. When applying the foil to these larger surfaces, I found it easier to wet the cardboard and the dull side of the foil with the glue/water mix. Then I applied a flat weight to the reflectors so they stayed flat as they dried. The weak points of the reflectors were strengthened with glued cotton cloth and sewed with shoe strings.

The glass used for this cooker was not square, but slightly rectangular, at 27″ x 32″. I wanted to use the square version of my reflector style because I really wanted them to fold up together without having to separate two corners. To accomplish this, I lengthened the side triangular pieces until they were 32″ wide and based the reflectors on a 32″ square.

I don't want to get into a more detailed description of this cooker because it is just a prototype. The next time I build one, it will probably be built slightly different. I just needed to share it with you before this book was published because it shows adapting designs to meet different needs.

At the gathering, I arrived about a month early when there were just a few people. When I came on site and set up I was the first bakery. At this point, I significantly added to the food supply and everyone was talking about the solar


WILL
EVER

bread. As the numbers of people increased, this cooker became more of a neighborhood cooker.

During the gathering, our numbers swelled to over twenty thousand hippies in the woods. Wood fires are traditionally the main cooking source when dealing with high numbers of people that need to eat. I started to perceive that there could be a place for solar when dealing with this many people. Wood fires can bring food quickly up to cooking temperature, but holding the food at a simmer is difficult, causing smoky fires and kitchens, and often scorched foods. While solar takes a longer time to bring food up to boiling, it is perfect for keeping food at a simmering temperature, with no smoke or scorching. Using a combination of wood and solar could work well.

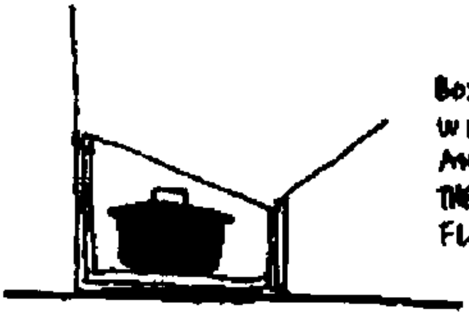
I envision using an efficient wood-burning rocket stove to bring a series of 4 or 5 large pots of food up to a boil early in the morning. The rocket stove uses an 8″ thin walled pipe which is rocked and mudded into a easy to use stove. Small sticks can then be burned with high efficiency and no smoke. When it is burning correctly, it makes a slight roaring noise, hence the name rocket stove.

When each pot reaches boiling from the wood fire, it can be added to a large slant faced solar cooker to keep it simmering throughout the day. The solar cooker could use a thermal pane sliding glass door as its glazing. This glass would be built into an insulated box at a 30 degree angle. The oven box could have a series of 4 or 5 doors in back to put the boiling pots inside. This cooker could have two simple adjustable reflectors connected to the long side of the window of the ovenbox. For ease, it would be nice to have wheels on this cooker, set up like a little red wagon. I believe this could put out a large quantity of high quality food. If clouds build up, you could close down the reflectors and insulate the glass so that the food would continue to cook in the insulated box as it slowly lost temperature.

The Sun Star Solar Cooker

A solar cooker is an insulated box to trap the heat of the sun for cooking food. Sunlight penetrates the glass cover of the box, and is absorbed by the black surfaces inside the box. The light's energy is converted to heat, which is released into the box as warm air and thermal radiation. Glass has an advantageous property--it permits the solar radiation to pass through, but retards the passage of thermal radiation [light rays can go in, but heat rays can't get out. Ed.]. The collectors added to the box have a reflective surface which concentrates more of the solar radiation into the cooker. Maximum temperature without the collectors is approximately 150 F (65 C). With the collectors, temperatures is increased to approximately 325 F (162 C).

These drawings are not plans, but a design--a concept. This particular cooker is to be made of cardboard, but cookers can be made of plywood, sheet metal, possibly even plastic. They can be insulated with several layers of dead air space, crushed newspaper, sawdust, etc. [the dead air spaces provided by multiple layers of cardboard work very well. Ed.].



Use of Cooker

- use a dark cookie sheet or other baking pan to hold food and catch boil over.
- Cook in dark pots or painted glass jars and lids. Poke a small hole in the lid to relieve steam pressure.
- These ovens cook in winter and summer.
- Bright sun works best. Hazy days are okay.
- Start cooking early in the day.
- Set the oven ahead of the sun approximately 1 hour.
- More food takes more time, less food, less time.
- USE HOT PADS, oven gets HOT!

Food

- Grains and legumes: Use typical water ratio. Soak hard beans overnight.
- Bread: Pre-heat oven 1 to 2 hours. Use large rock or brick to absorb heat while preheating. Place bread on top of rock or brick.
- Vegetables: Cook without water.
- Pizza: Pre-cook crust. Add toppings and cheese to melt.

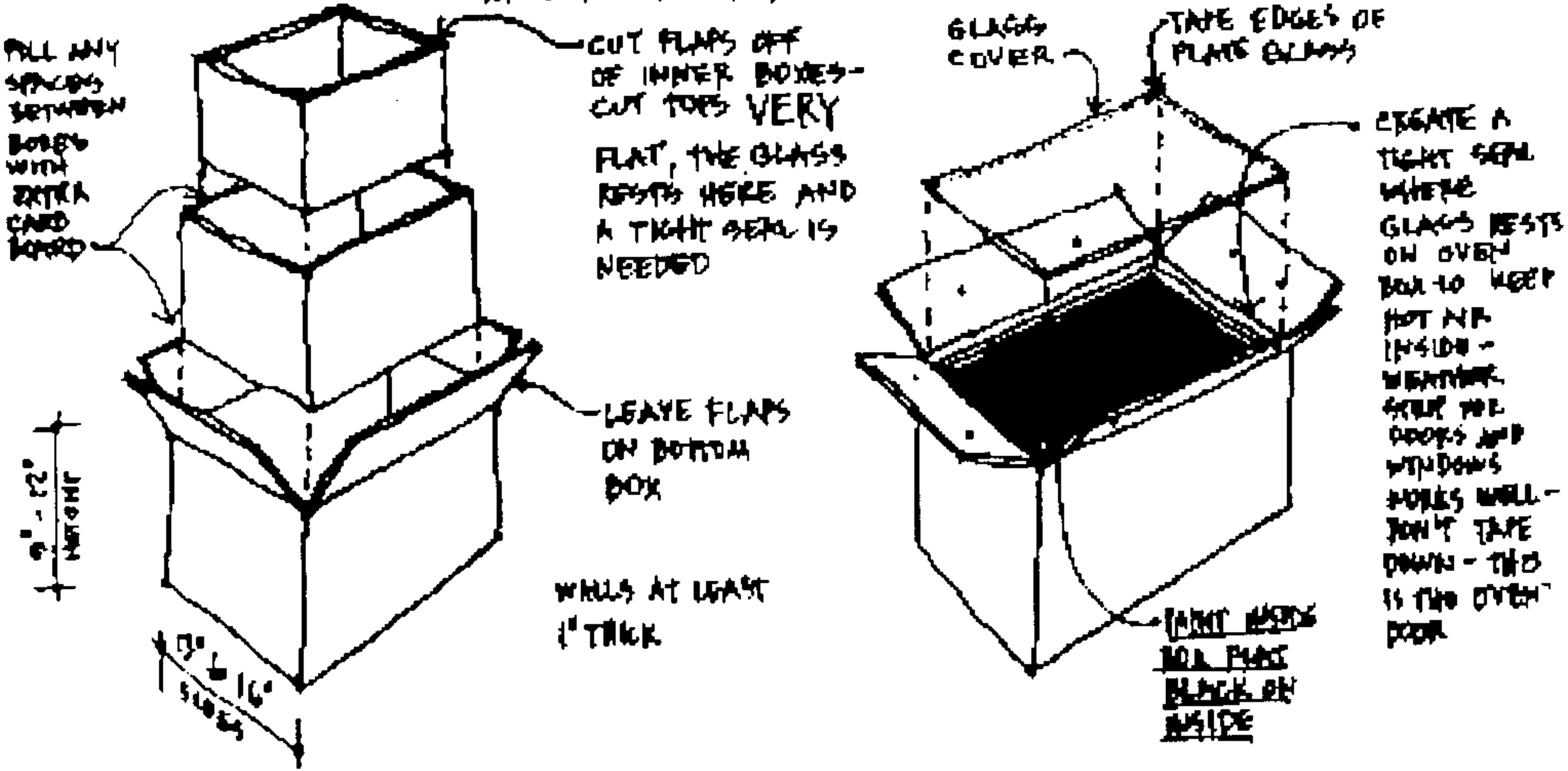
For more detailed information on this and other solar cookers, refer to Heaven's Flame: A Guide to Solar Cooking by Joseph Radabaugh. Available for $10.00 through:

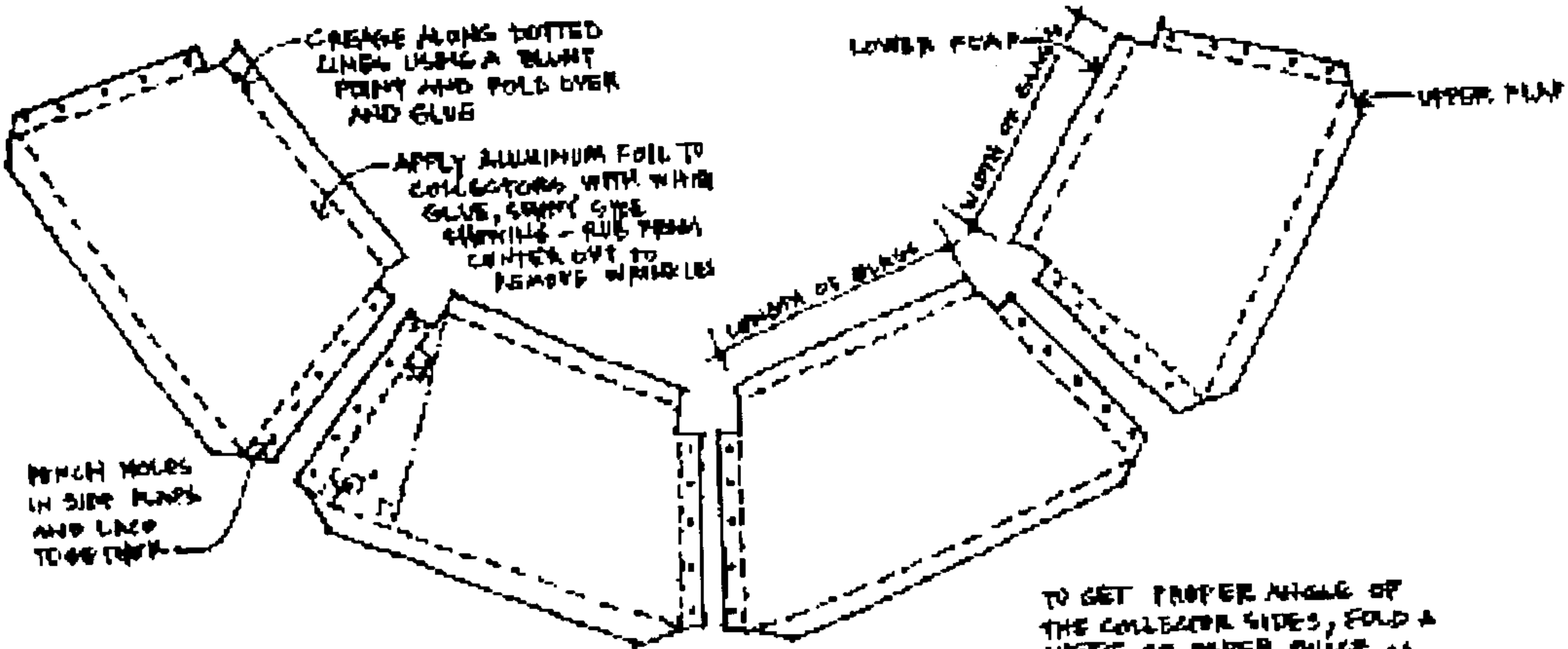
Home Power Inc.
P.O. Box 275
Ashland, CA 97520

(916) 475-3179

OVENBOX

: USE 2 TO 3 CARDBOARD BOXES THAT NEST WITHIN EACHOTHER

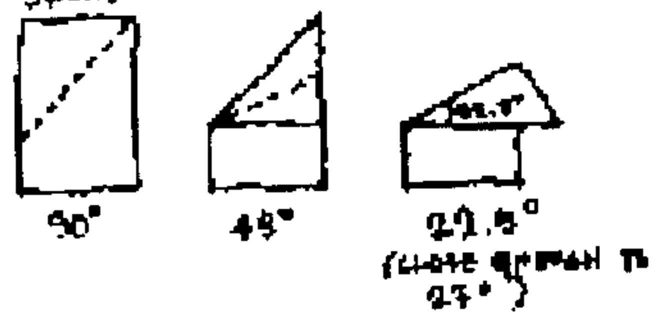


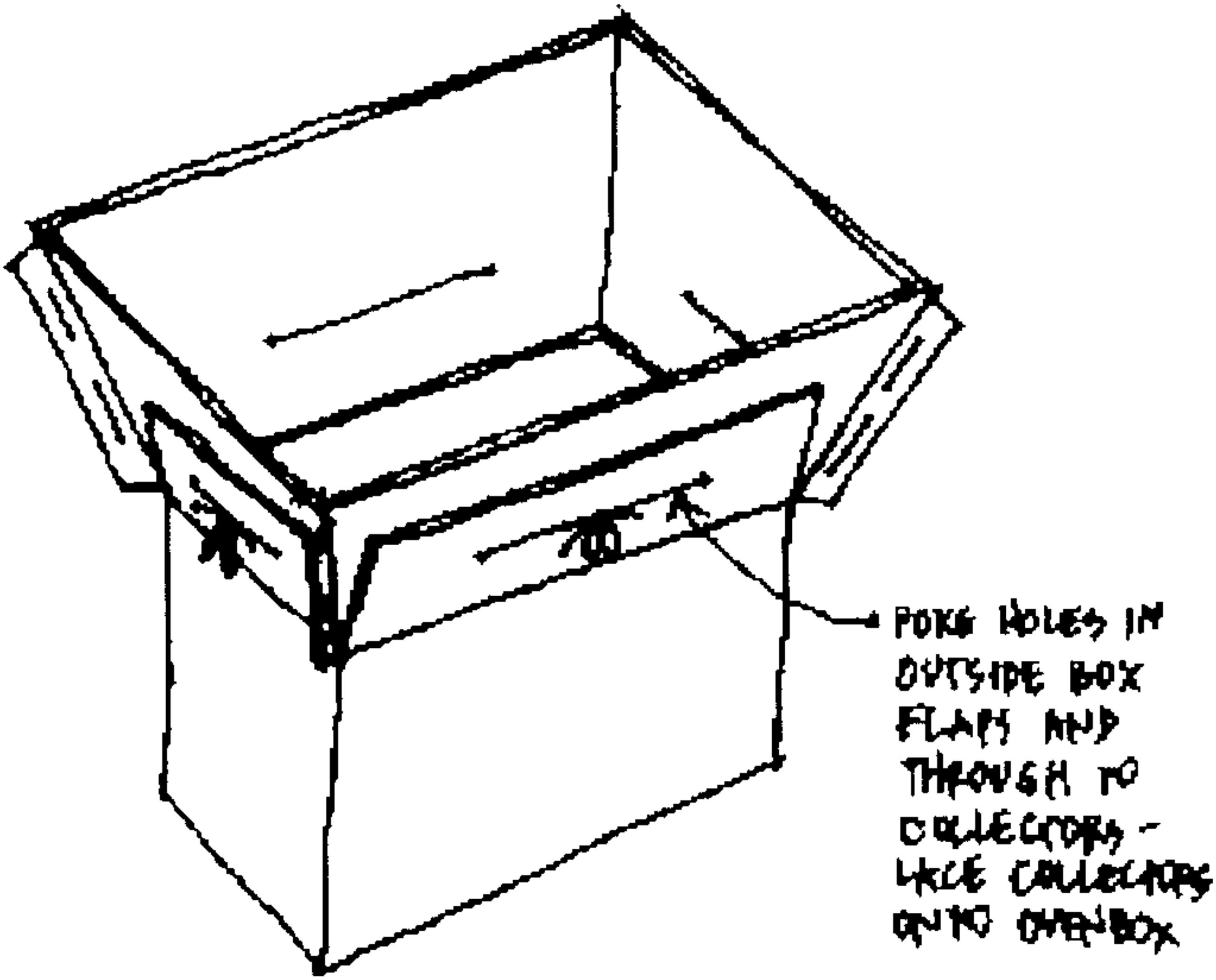


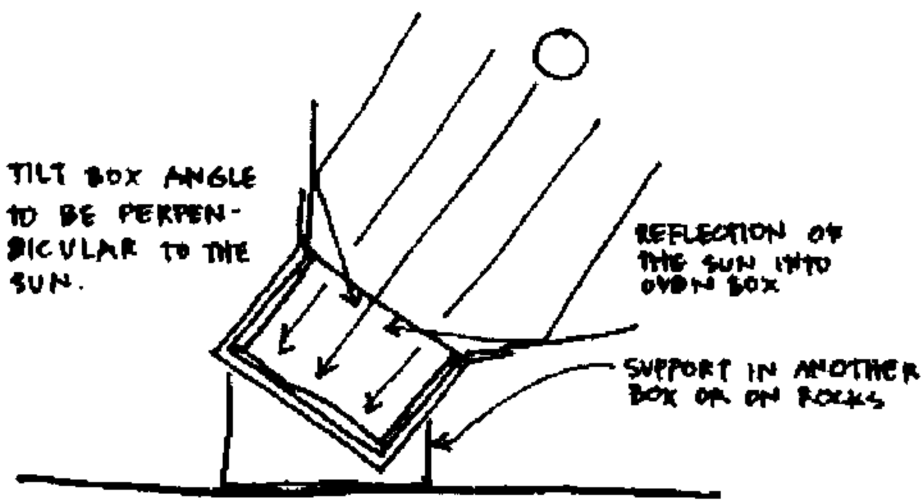
COLLECTORS

REFLECT EXTRA SUNLIGHT INTO BOX COOKER, INCREASING OVEN TEMPERATURE.

TO GET PROPER ANGLE OF THE COLLECTOR SIDES, FOLD A SHEET OF PAPER TWICE, AS SHOWN BELOW.







Drawings are based on a design of Joseph Radabaugh and drawn by Caleb Crawford. For more information contact

Main Solar Energy Association
RFD Box 751
Addison, ME 04606

Simple solar projects

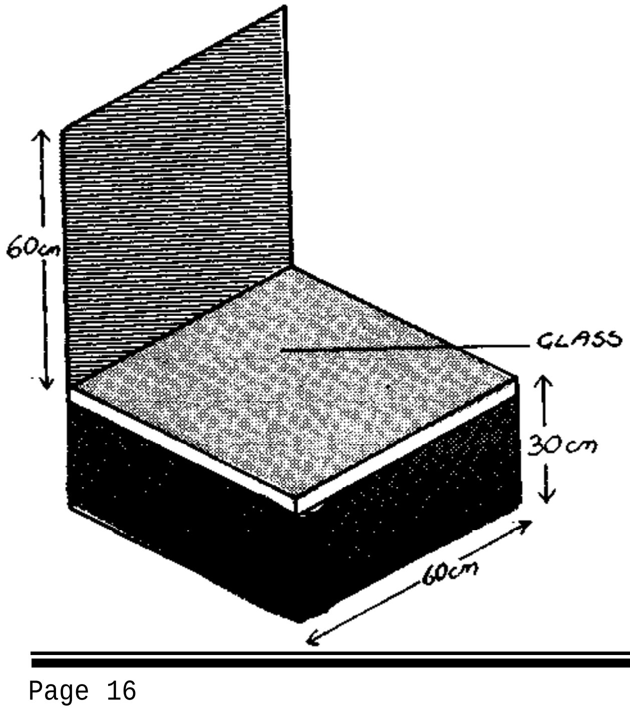
Over the years a massive number of simple solar experiments and construction projects have been printed in a large number of different books and publications. In this regular column we will be looking at the many practical ideas that are around from many sources. We will give the sources of these so people can get hold of the original source material.

Solar Oven

Solar ovens are used in India, which is situated in the tropical region, to cook the mid-day meal. Although they are not as effective in our more temperate climate, you should be able to cook snacks on clear sunny days.

You will need :

o a strong corrugated cardboard box (or wooden box)



* a roll of aluminium foil
* 2 sheets of window glass
* polystyrene foam or newspaper
* a piece of corrugated cardboard or plywood.

Method of Construction

1. The box should be about the size shown in the diagram. It can be made from plywood or cut from a corrugated cardboard box and put together with adhesive tape.

2. Cut polystyrene foam or newspaper to fit snugly around the sides and bottom of the box. These materials keep in the heat - that is they insulate. The insulation should be 5 cm thick.

3. Cut a square of cardboard or plywood to be used to reflect the sun's rays into the box as shown in the diagram.

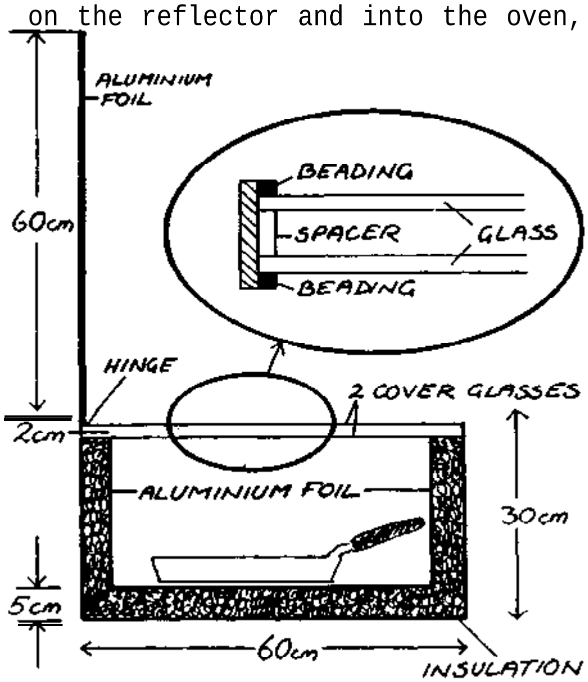
4. Cover the insulation and the reflector with aluminium foil. Make sure that it is smooth.

5. Fit the reflector edge to edge on one side of the box using hinges or pieces of strong adhesive tape to act as hinges. The reflector can be adjusted to an angle to reflect the sun's rays into the box.

6. To make a glass lid prepare a frame from a strip of wood or corrugated cardboard 3cm wide. The frame should be the same dimensions as the box. Around one inside edge of the frame fix a narrow ledge about ½cm. high for the glass to sit. Now place above the glass a 2cm. high strip on which to sit the top piece of glass. Now fix a ½cm. wide strip above the top glass sheet. The lid can now be hinged to the box.

7. Fit the reflector edge to edge on one side of the glass lid using hinges or pieces of strong adhesive tape to act as hinges. The reflector can be adjusted to reflect the rays of the sun into the box by using a stick as a prop.

8. Place the oven in the sun so that as much sunlight as possible falls on the reflector and into the oven,



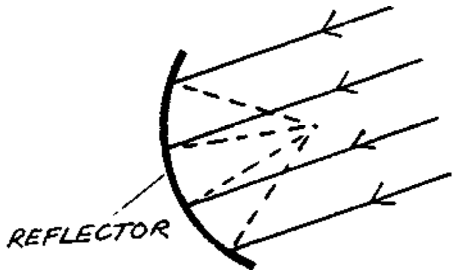
Place the frying pan in the box and put in it what you want to cook, perhaps an egg or a sausage.

Reflective Cooker

A reflector cooker is more difficult to make, but they use the sun% rays more efficiently than the solar oven.

The sun's rays hit the curved surface and are reflected back to a small area where the cooking vessel is placed. Because the sunlight has been concentrated you must be careful not to let it fall directly on your eyes.

You will need:
* 2 large sheets of stiff cardboard.



* a large sheet of flexible cardboard
* string and pencil
* aluminium foil
* a Stanley knife

Method of Construction

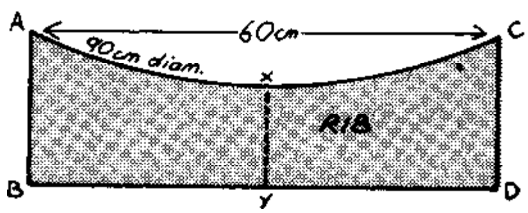
1. Using the string and pencil as a compass, draw an arc of a circle with a radius 45cm.
2. Cut this out in the shape of a 'rib' which has a base of 60cm. Repeat this process another 7 times but cut these other 7 ribs in half along the line xy as shown in the diagram.

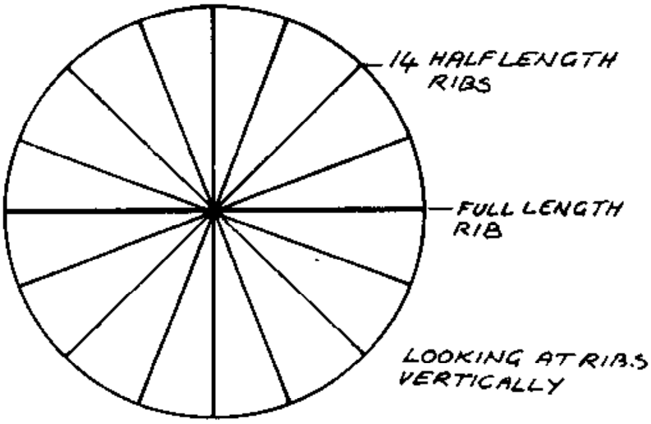
3. Cut one piece of stiff cardboard into a 60cm. diameter circle.

4. Glue the complete rib and the 14 half ribs on to the base circle. First place the complete rib vertically along a diameter and then the 14 half ribs vertically along radii, space at about 22½ degrees around the circle as shown in the diagram.

5. By this time you will have the shell of your reflector. But the ribs will need to be filled in with more flexible cardboard so that you will have a surface on which to glue your aluminium.

6. Carefully measure 16 pieces of flexible cardboard (like sections of a pie) to fit across the ribs. Curve the cardboard to fit the ribs by rolling the cardboard in the direction shown by the arrows in

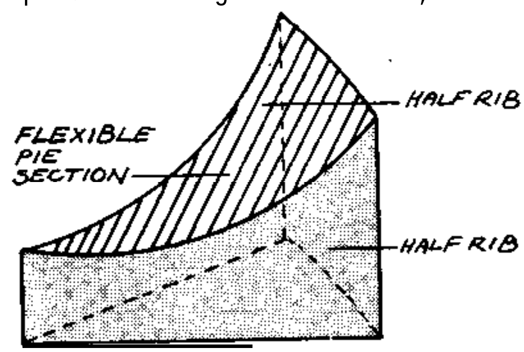




the diagram and then releasing it. Now cut and give a strip of card-board around the vertical edges of the ribs to strengthen the shell.

7. When the glue is dry cover the whole dish with aluminium foil. Make sure that it is very smooth.

8. Make a wooden stand to support the reflector. For cooking, place the reflector so as to catch as much sunlight as possible. You will need a post with an arm on which to hang a black billy-can to hold water or suspend a wire grill to cook,



This information came from the "Energy Resources Kit" produced by the Environment Action Centre. Copies available from F.O.E. and the Environment Centre, Victoria.

ULOG Solar Ovens in Basel and Worldwide

Solar Energy For All !

This is the motto of the ULOG group, an informal group of about 20 volunteers in Switzerland committed to making solar energy available to the people of the world. The ULOG group was founded by Ulrich Oehler in 1980 to realize this objective. During the past twenty years, the group has successfully developed standard and family-sized solar oven cookers for tropical as well as non-tropical conditions. It has also developed SHCK, the Solar Hybrid Community Kitchen, which serves more than 40 people.

Success in Basel

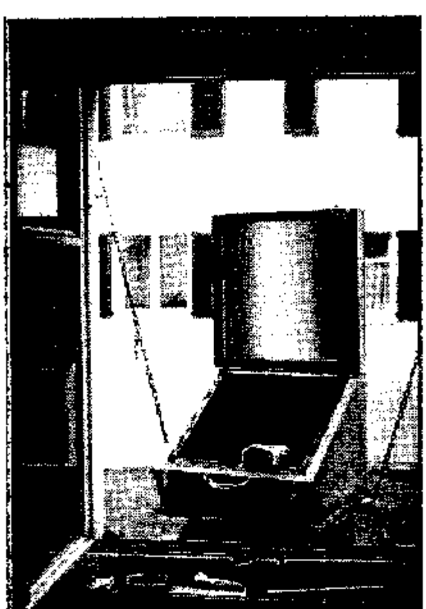
Presently, more than 6000 Swiss households own a solar oven! Switzerland has probably the highest density of solar cookers of all of the countries of the world. The one cooker per 1000 inhabitants saves as much energy as all of the PV-installations in the country. In Basel, the solar cooker can be used on 100 to 150 days per year. On average, one can prepare about 250 cooked meals in that time, which saves about 500 kWh per year.

Assembly Instructions - Recipe Books

To make the cookers acceptable to communities, the group produced a simple design that can be manufactured and disseminated locally. The cooker costs little, is easy to use, and can reproduce local cuisine. It comes with an installation instruction booklet, and people can see an instructional video film in several languages to help them build a solar oven. The assembly instructions also give information about what a solar cooker can do and cannot do, how long the cooking hours are, how the oven should be cleaned, how the oven works, etc. They include detailed recipe books for local foods as well.

Workshops

The ULOG group offers ready-to-use and partly assembled models in two sizes with instruction and accessories. In Switzerland, they hold one- or two-day courses in which people can learn how to assemble the solar ovens. A wide variety of interested groups has organized courses where even those who are inexperienced in handcrafts can build their own ovens. For groups of at least six participants, the ULOG group furnishes an instructor, who can also present a slide show covering many additional aspects of solar energy and the oven.



Success all over the World

The solar ovens' biggest successes are in Senegal, Kenya, and Sudan. Several thousands of solar cookers have been built in these countries by the ULOG and other project groups as well. At the end of the year there will be about 20 SHCKs, Solar Hybrid Community Kitchens, in India, Sudan, Kenya, Peru and Europe. SHCKs are used for, e.g., monasteries, hospitals, schools, and refugee camps. Many projects were subsidized by private sponsors from Switzerland and by a specialized NGO called VKSE. The mobile SHCK is often used for 'solar happenings' in Switzerland and Germany.

No Patent Protection

The products are not protected by patents. The ULOG groups encourage everybody to build their own equipment.

More information from Ulrich Oehler, development engineer, 18 Morgartenring, CH-4054 Basel, Switzerland. Ph: +41-61-3016622.

Solar cooker in Basel Switzerland. If the flat does not have a sunny balcony, the solar cooker can be placed on a plate outside the window.

2.2 'Developing' Countries

Every year, more and more people from all over the world write to us to get information about and plans for our solar products, especially for the solar cooker. Upon request by grass-root organizations, missions and NGOs, members of our staff go for a few months to the corresponding country to train carpenters and other workmen how to construct durable solar cookers. At the same time, the women are taught how to cook with them. In most of the poor countries however, even locally produced cookers using cheap material are too expensive for a majority of the population. That is why we try to find sponsors to subsidize the cookers and to install simple credit systems. In Switzerland we have a specialized NGO, the "Verein zur Forderung Kleintechnologischer Nutzung von Sonnenenergie als Entwicklungshilfe" (VKSE), which supports many of our projects in tropical countries, as well as those of others.

2.2.1 Solar Cookers

Our most successful solar cooker projects at the moment are in Senegal in Western Africa, in Kenya and in Sudan in Eastern Africa. Several thousands of solar cookers have been built in these countries, not only by us but by other project groups as well.

In the north of Senegal, where the desertification is very bad, a project was begun at the end of 1990. In a village there, a group of six carpenters made about 1OO solar cookers completely by hand. They sold them in the village and to others in the neighbourhood for a highly subsidized price. One of the women in the village, who gained a lot of solar cooking experience, was made responsible for teaching the new customers how to cook with their solar ovens.

The demand for solar ovens there is increasing daily. It was especially surprising to see how quickly the women were able to adapt their cooking habits. They were naturally also pleased at the time and effort they were saving, that would usually have gone into collecting wood. Because the villagers are managing the project themselves very well, some-one from our group need only travel there now and then.

In Kenya, there are three places that now make solar ovens on their own. The 'Institute for Cultural Affairs' has also brought out a recipe booklet in Kiswahili.

2.2.3 Solar Hybrid Community Kitchens

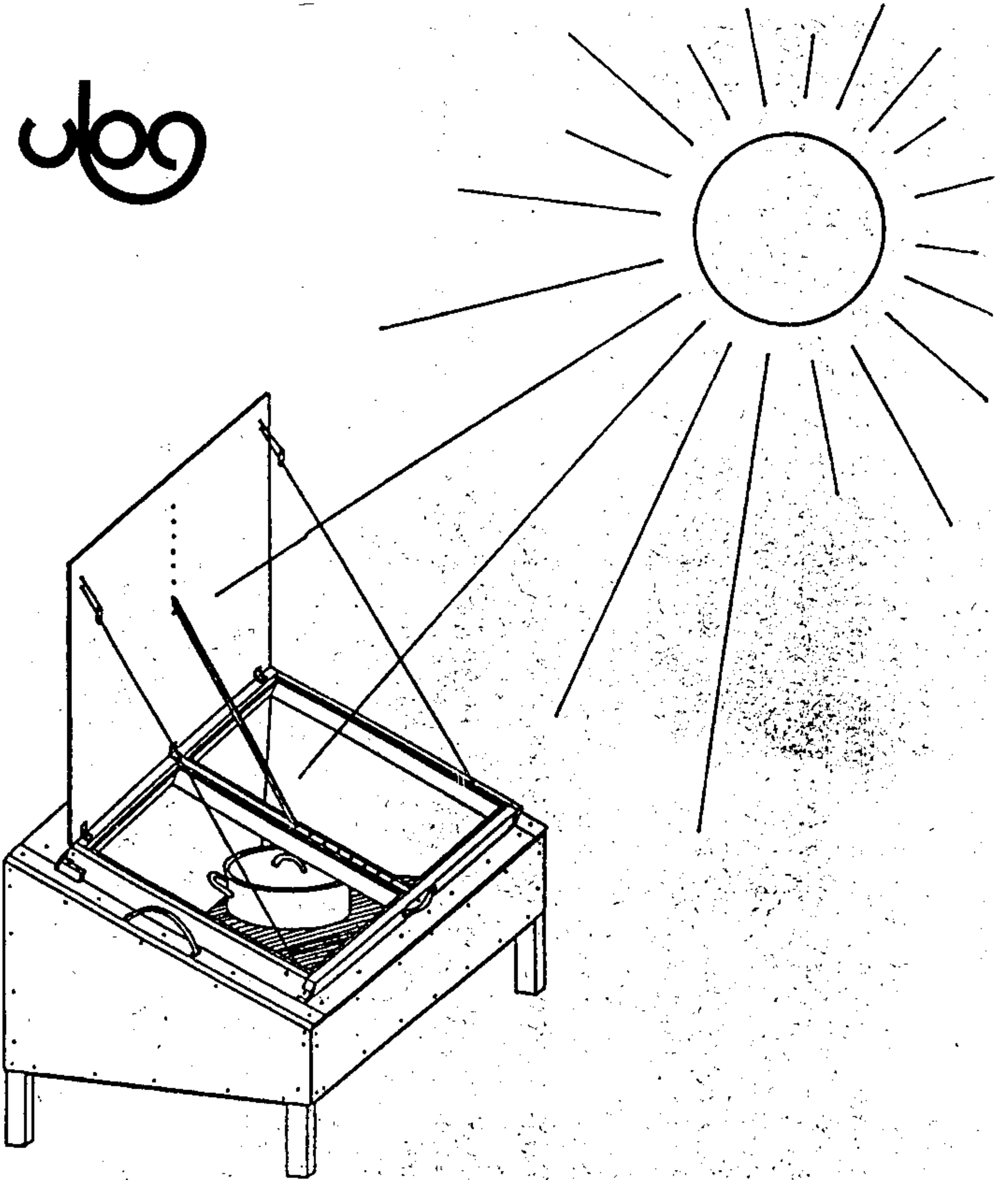
A solar cooker may be good for a family but for communities of up to several hundred people, like boarding hostels, hospitals, prisons, monastries etc., something else was needed. That is why we developed the "Solar Hybrid Community Kitchens" (SHCK).

Each cooking place has a parabolic fix focus reflector of 7m2 with 47 flat mirror elements covered with a reflecting plastic film. It concentrates the solar rays onto a window in the wall of the kitchen building, where a cooking pot of 80 to 1OO litres capacity is standing. This pot is surrounded by an insulated wrap and can be rolled aside onto a fireplace when there is no sunshine for cooking. As the rotating axis of the reflector is parallel to the earths' axis, the daily tracking of the reflector can be done by a mechanical clock. The seasonal adjustment only has to be done once a week. To store solar energy for the following morning, one of the reflectors (normally) is used to heat a water tank of about 200 litres. To date, several SHCK have been constructed in India, where a local enterprise is commercialising them without our further assistance; and in Kenya. One SHCK has been built in Sudan. The technology of the SHCK is naturally much more complicated than that of the solar ovens, but it is nevertheless something which can be mastered by well trained technicians in any country and it can also be produced anywhere where there is welding equipment to be found. The only special part which has to be imported is the reflecting plastic film.

With the same fix-focus technology, we have also made a mobile SHCK, with a cooking capacity of 30 litres. The alternative heating source here for overcast days is propane. The mobile SHCK is often used for 'solar happenings' in Switzerland and Germany. Some relief organisations, like the Red Cross, are interested in such kitchens for refugee camps and for their relief activities during natural catastrophes etc.

2.2.3 Solar driers

Besides the solar cookers, we are also developing and promoting solar driers for food-stuff preservation in Europe, as well as in tropical countries.



ULOG SOLAR OVEN COOKER

FOR NON TROPICAL AREAS

Installation Instructions

SOLAR ENERGY FOR ALL

This is the motto of the ULOG Group ; a loose association of people in Switzerland committed to making solar energy available to the people of the world, and in particular to those less fortunate in the so called "third world". There, the most widely used fuel for cooking and baking is wood and in many places is becoming less and less plentiful. This over exploitation of natural resources must be stopped in all our interests as it leads to soil erosion and finally to the encroachment of desert conditions. The solar oven cooker is a useful and well proven alternative to wood fuels! It is an extremely simple piece of equipment ; capable of being put together almost anywhere ; and it requires no other fuelling than direct sunlight. Most dishes can be prepared with it, and without additional expenditure ; quite the opposite! Cooking with the solar oven requires practically no supervision, as there is no need to stir the pan.

The solar oven cooker functions on the basis of the "greenhouse effect", i.e. the light rays from the sun penetrate through the window panes; they become absorbed by the black surfaces of the interior and are thereby transformed into heat. Since the interior space of the cooker oven is hermetically sealed, and as glass for all intents and purposes hinders the passage of heat waves, the inside temperature rises until the radiation loss and the influx of energy balance themselves out. In order to prevent loss of heat, the window is double pane glazed and the oven cooker insulated all round against heat loss. In this manner temperatures of well over 100° C are generated ; sufficient to cook and even to bake. As only a small amount of warmth can be stored, the influx of direct sunlight is requisite during the greater period of the cooking time.

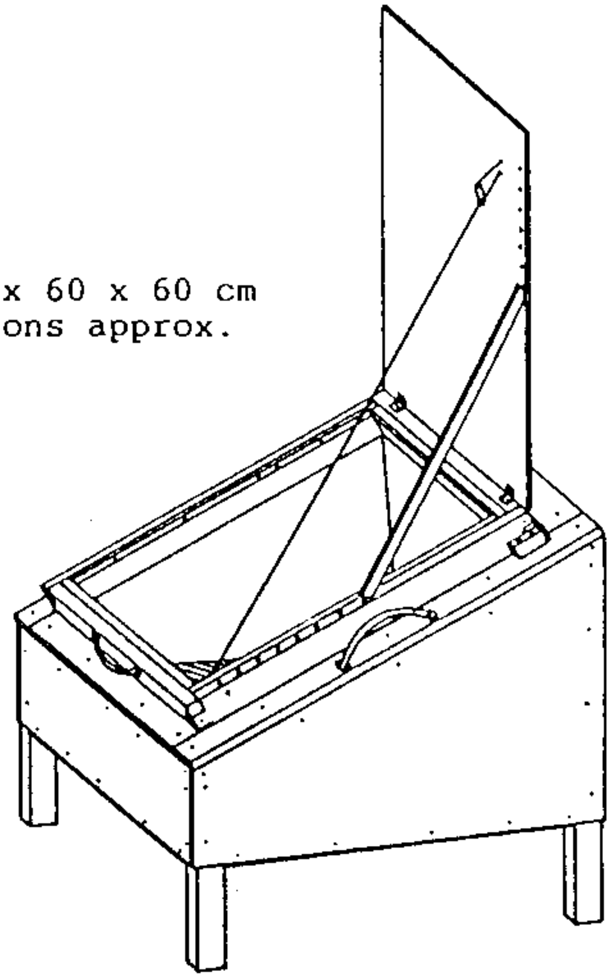
The following erection instructions should enable a layman with some knowledge of woodworking to set up a solid and permanent solar oven cooker. The materials involved are easily obtainable and cheap at the price. The basic dimensions can be altered according to requirements ; e.g. a different window size or a deeper oven space. The model described in this brochure is in two sizes and is suitable for non tropical areas, i.e. for all regions 25° to around 50° N or S of the Equator. For areas further away from the Equator, the window inclination angle would have to be appropriately increased. For Equatorial regions, there are special models having horizontal windows instead of inclined and are therefore easier to construct. For those on the move wishing to use their solar oven cooker whilst journeying, there are compact portable models, also in two sizes. Assembly instructions for all these other models are available from the ULOG Group, even in several languages. Constructional kits and ready to use solar oven cookers are suppliable in all models.

Apart from solar oven cookers, we also publish instructions for the construction of solar dryers for foodstuffs and simple water warmers. For larger communities, such as schools, hospitals, convents and monasteries, we have developed a solar kitchen with which cooking can be carried out for several hundred persons, based on fix focus mirror technology ; and should sunlight not be apparent, then conventional fuels can be employed by energy conserving means. We would be pleased to provide more details of what we have to offer!

If requested to do so, our men and women associates will travel to regions where a solar oven project is to be introduced, even to third world countries. Training will be given to local craftsmen in the construction, in the first instance, and to women for operating the equipment. Financial support is also available at the same time, from among others the "VKSE Society for the Furtherance of Small Scale Technological Exploitation of Solar Energy" P.O.Box, CH-4011 Basle, Switzerland.
New members will be gladly welcomed!

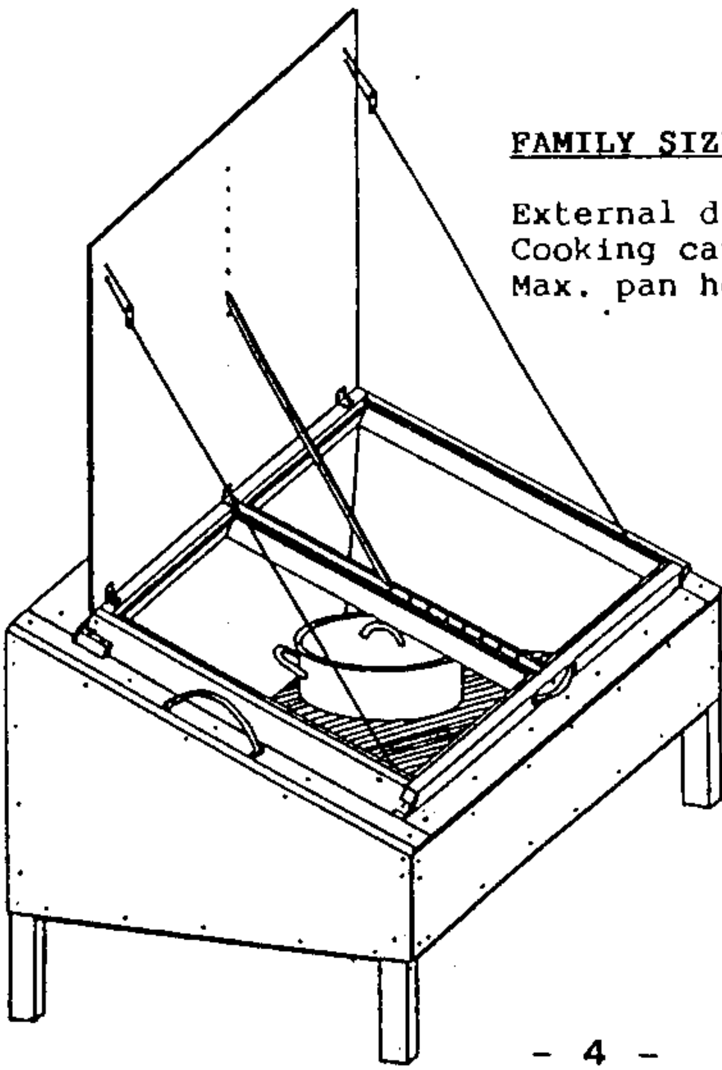
STANDARD SIZE S

External dimensions: 67 x 60 x 60 cm
Cooking capacity: 6 persons approx.
Max. pan height: 19 cm



FAMILY SIZE F

External dimensions: 120 x 60 x 60 cm
Cooking capacity: 12 persons approx.
Max. pan height: 19 cm



PARTS LIST FOR STANDARD (S) AND FAMILY (F) SIZES

Pos.	Amount S	Amount F	Description	Dimensions (cm)	Materials
1	2	4	Glass window pane	50 x 50 x 0.3	Window glass
2	4	2	Glass frame	54.9 x 6 x 2.2	Wood
3	-	2	Glass frame	107.6 x 6 x 2.2	Wood
4	-	1	Cross bar	50.5 x 6 x 2.2	Wood
5	8	16	Glass securing batten	49.5 x 1.4 x 1	Wood
6	4	8	Glass distancing batten	49.5 x 2.4 x 1	Wood
7	1	-	Reflector cover	55 x 55 x 0.5	Bakelized plywood
8	-	1	Reflector cover	108 x 55 x 0.5	Bakelized plywood
9	1	-	Reflector foil	55 x 55 x 0.01	Aluminium foil
10	-	1	Reflector foil	108 x 55 x 0.01	Aluminium foil
11	2	3	Hinge	3 x 3	Galvanized steel
12	1	1	Reflector support	50 x 1.5 x 1.5	Wood
13	1	2	Bracing line	0.2 x 100 approx.	Nylon
14	1	2	Line brace	3.5 x 1.5 x 0.5	Bakelized plywood
15	2	2	Window retaining batten	25 x 2.5 x 1	Hardwood
16	2	2	Stop block	5 x 2 x 2	Hardwood
17	2	2	Panel batten	66.5 x 6.3 x 1.5	Wood
18	1	-	Panel batten	55 x 4.3 x 1.5	Wood
19	-	1	Panel batten	107.8 x 4.3 x 1.5	Wood
20	1	-	Panel batten	55 x 7.4 x 1.5	Wood
21	-	1	Panel batten	107.8 x 7.4 x 1.5	Wood
22	3	3	Bow handle	16.5	Chromed steel
23	1	-	Oven bin	99.5 x 84.7 x 0.03	Offset plating
24	-	1	Oven bin	152.4 x 84.7 x 0.03	Offset plating
25	2	2	Oven framework	50.5 x 8 x 2.2	Wood
26	1	-	Oven framework	66.5 x 7 x 2.2	Wood
27	-	1	Oven framework	119.5 x 7 x 2.2	Wood
28	1	-	Oven framework	66.5 x 9 x 2.2	Wood
29	-	1	Oven framework	119.5 x 9 x 2.2	Wood
30	4	4	Connecting piece	15 x 7.5 x 0.8	Plywood
31	2	2	Side panel	60.5 x 43 x 0.5	Plywood
32	1	-	Front panel	66.5 x 15 x 0.5	Plywood
33	-	1	Front panel	119.5 x 15 x 0.5	Plywood
34	1	-	Rear panel	66.5 x 43 x 0.5	Plywood
35	-	1	Rear panel	119.5 x 43 x 0.5	Plywood
36	2	2	Front leg	30 x 4 x 4	Wood
37	2	2	Rear leg	56 x 4 x 4	Wood
38	2	2	Reinforcing batten	51.5 x 2.5 x 1.5	Wood
39	2	-	Reinforcing batten	58.5 x 2.5 x 1.5	Wood
40	-	2	Reinforcing batten	111.5 x 2.5 x 1.5	Wood
41	1	-	Bottom panel	67.5 x 60.5 x 0.5	Plywood
42	-	1	Bottom panel	120.5 x 60.5 x 0.5	Plywood
43	22	32	Countersunk wood screw	0.3 x 2	Steel
44	38	70	Countersunk wood screw	0.3 x 2.5	Steel
45	4	4	Countersunk wood screw	0.35 x 2	Steel
46	12	12	Countersunk wood screw	0.35 x 3.5	Steel
47	-	4	Countersunk wood screw	0.35 x 5	Steel
48	4	6	Flat round rivet	0.3 x 0.8	Aluminium
49	120	156	Flat headed nail	0.14 x 2	Steel
50	18	24	Countersunk nail	0.14 x 3	Steel
51	14	14	Countersunk nail	0.2 x 5	Steel
52			Wood glue		
53			Paint		Mat black
54			Insulating material	Strength 8 cm	Mineral wool matting
55			Weather-proofing		e.g. Linseed oil

ALTERNATIVES TO ITEMS IN THE PARTS LIST

Pos.	Alternatives:
1	Alternative glass thickness: min. 2mm and max. 5 mm, involving possible adjustment in the width of Pos. 5. For greater breakage security: hardened glass quality. Such so called Temperite or Security Glass is at least 3.5 mm thick and about double the price of normal window pane glass. It should be ordered for the correct measurements as it cannot be subsequently cut again. Such glass is not readily available. It is only worth the increased expenditure for a larger number of units.
2/3/4	Poor timber quality will require thicker battens and stay, up to 2.5 cm section approx. The length will then have to be appropriately adjusted so that measurements remain the same in the interior of the framework. Adjustments will also be necessary in Positions 17, 18, 19, 20 and 21.
5/6	In case of poor timber quality, thicker section battens should be considered up to 1.3 cm approx., together with an appropriate adjustment of the lengths.
7/8	Normal plywood of 8 mm to 10 mm gauge. When employing plywood of 4 mm to 5 mm gauge, the cover will have to be strengthened all round with a bracing frame. In the "F" version, an additional bracing batten will have to be provided, sited over the centre window stay. Battens of the dimensions as Pos. 38, for example. By the using of aluminium sheeting of 0.4 mm to 0.5 mm gauge in place of plywood, the reflector Pos. 9 and 10 will become superfluous.
9/10	Offset plating or aluminium sheeting. See 7/8.
11	Hinge straps of strong textile material or leather in 10 x 5 cm. Four pieces for the "S" version and 7 pieces for the "F" version. These should be attached to the upper face of the cover and on the glass framework with a plywood batten. Width 4.5 cm ; length for "S" version 54 cm and for "F" version 107 cm. Nails as in Pos. 49
22	Bow handle of bent branch timber or sawn from hardwood.
23/24	Aluminium sheeting from 0.2 mm to 0.5 mm gauge or galvanized corrugated sheeting (e.g. beaten flat corrugated sheeting) of max. 0.2 mm gauge.
25/26/27 28/29	Larger wood section should be employed in cases of poor timber quality, up to 3 cm approx. Appropriate adjustments will then become necessary to the distances between the top edges of the front and rear panels of Pos. 32 and 33 and/or 34 and 25 respectively and the top edges of the legs, Pos. 36 and 37 ; see drawing on page 16.

Pos.	Alternatives:
31/32/33 34/35/41 42	Plywood gauge 4 mm. In place of plywood, aluminium sheeting from 0.2 mm to 0.5 mm gauge or galvanized iron sheeting of max. 0.2 mm gauge may be employed. For reasons of stability however, the framework of the oven, oven frame, legs and bracing battens, should first be rigidly jointed together before the metal sheeting side and bottom panels be attached to the framework. It is recommended to allow the panels to overlap the oven framework by 1 cm approx. and to bend these overlaps round the corners before applying the panel battens.
36/37	In cases of poor timber quality, larger wood sections should be preferred which may also be square. Appropriate adjustments will then become necessary to the distances between the top edges of the front and rear panels of Pos. 32 and 33 and/or 34 and 25 respectively and the top edges of the legs, Pos. 36 and 37 ; see drawing on page 16. Longer leg lengths may be selected in order that the solar oven cooker has more ground clearance.
48	If the reflector cover, Pos. 7 and 8, has been fitted with a frame, the hinges should be fastened to the cover with countersunk wood screws as in Pos. 43. This is however also possible without a frame, by anchoring these with a batten applied to the upper face of Pos. 7 and 8.
53	Blackboard paint or a self mixed paint according to the following recipe : mix soot or iron manganese powder with a semi oil preparation. This comprises part turpentine ~~or white spirit~~ and boiled linseed oil. Let the mixture stand over night. A small sample should be applied with a brush to the interior of the solar oven and should be allowed to set at a temperature of at least 130°C. If the result is too thin, add more powder or soot to the mixture. If the painted surface is too gloss, reduce the linseed oil content of the mixture.
54	Organic materials, such as hay, rice straw, coconut fibre, ground nut shells, wood wool, wood chips, kapok, raw cotton, twists of newsprint. <u>NO</u> styropore, as this is not heat resistant.
55	Weather-proof coloured paint or varnish. When employing metal sheeting for the panels, cover and bottom, only the exterior wooden parts should be painted.

ASSEMBLY INSTRUCTIONS

1. GENERAL:

- The assembly instructions refer to those items in the parts list. Alternatives to the various parts are listed on pages 5 and 6.
- When finishing the various parts and assembling these, it is recommended to work with absolute precision. Inaccuracies can have a negative influence on the functionability of the solar oven cooker. Much time will then be wasted on the subsequent locating, correcting and adjusting of errors.
- Except where expressly otherwise stated, all woodwork is to be joined together with wood glue.
- The symbols "S" and "F" stand for the "Standard" and "Family" versions. During assembly work, only those instructions should be followed which are preceded by the appropriate symbol.
- The position numbers and those of the various constructional parts appear in square brackets throughout, e.g. [15].
- The illustrated drawings are given only for the "S" version, but can also be taken as guidance for the "F" version, with the appropriate adjustments for size.

2. Window

1. S,F: Cut tongue and groove joints on each end of the glass frame pieces [2] and [3], as indicated in the drawing under no. 2 on page 14, using a saw and chisel. Joint the 4 pieces together to form a rigid unwarped rectangular framework. Secure all tongue and groove jointings with a nail [51].

F: Attach the cross bar [4] in the centre of the rectangular framework with 4 screws [47], two at each end.

2. S: Attach 4 glass securing battens [5] on the inside of the glass frame abutting the outer edging, without a break in the 4 corners with 4 screws each [44] and without wood glue, to permit the replacement of damaged glass panes as required. The battens should be drilled in advance to 3 mm diam. The first glass window pane [1] should now be sited. This is to be secured all round with the 4 glass distancing battens [6]. Ensure that in the corners the ends of the various glass securing and distancing battens do not overlay each other but are staggered. This renders the window more airtight. 4 nails [49] are required to affix each batten. Before siting the second glass window pane, both glass panes should be thoroughly cleaned. To prevent condensation forming on the inner side of the glass panes when operating the solar oven cooker, these surfaces should be treated with glycerine or an anti-misting cloth. The glass should be rubbed with these several times up, down and across. Polish the glass panes with a dry cloth to remove anti-misting residue. Attach the second glass window pane in the same manner with the 4 remaining battens [5].

F: Follow the same instructions as for "S" for the two adjacent glass pane windows.

3. S,F: Draw the reflector foil [9] or [10] over the reflector cover [7] or [8]. If the foil is not self adhesive, apply with contact adhesive or waterproof household glue.

4. S,F: Attach the hinges [11] to the reflector cover on the mirror side with the rivets [48] (holes 3 mm diam., see drawing on page 15). The cover can now be attached to the glass frame with the screws [43]. In order that the cover fits tightly when closed, a chisel may be used on the frame, where the hinges are sited, to chip off wood corresponding to the thickness of the folded hinges.

5. S,F: Hammer a nail [51] into both ends of the reflector support [12] leaving 1 cm approx. showing. If hardwood is employed, pre-drill to avoid splitting the wood. Nip off the heads and file the ends off round. Bend both nails to approx. 45° in the same direction. Chip off both edge ends of the support to an angle of 45° under the bent nail until a surface of 1 cm approx. is formed (see drawing on page 15).

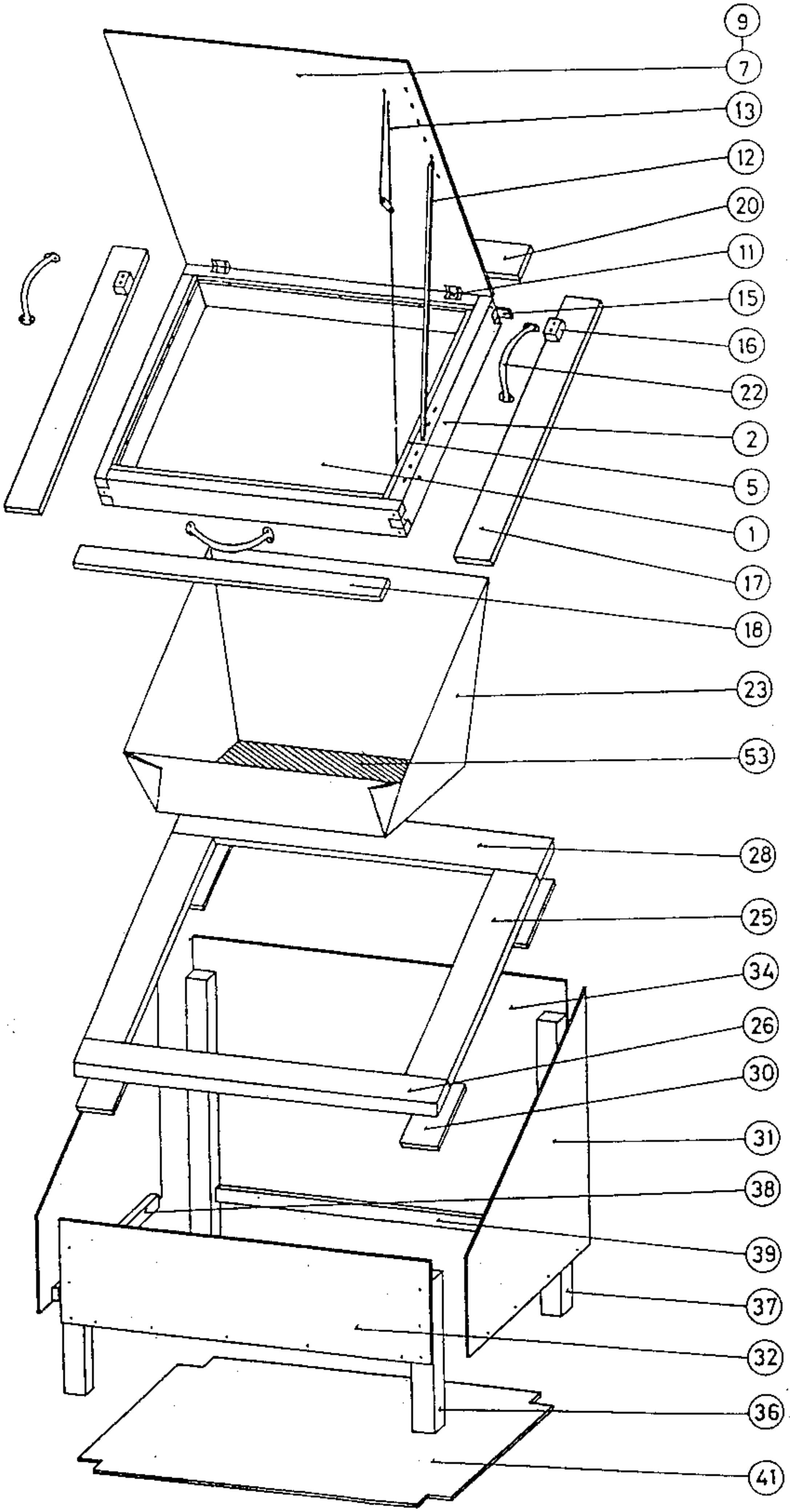
6. S: On the right hand side of the closed reflector cover drill 5 mm diam. holes for the reflector support through the reflector cover about 1 cm. into the glass frame thereunder, as well as drill 2 holes on the same side of the reflector cover 3 mm diam. for the bracing line, as in the drawing on page 15.
The bracing line [13] is attached to the glass frame by drawing it through a drilled side aperture 3 mm diam. (see drawing on page 15). First countersink the hole conically from the outside and tie a stop knot on the end of the bracing line. Draw the bracing line through until the knot rests in the countersunk hole and secure it with a nail [49]. The end of the line brace [14] should be rounded off and a 3 mm diam. hole drilled through each end. The other end of the bracing line is drawn through one of the holes in the end of the line brace and then threaded through both holes in the reflector cover. Draw the end of the bracing line through the second hole in the line brace and apply a stop knot.

F: The holes for the reflector support are to be drilled in the centre of the reflector cover and in the cross bar. Bracing lines are to be fitted to both ends of the window.

3. Oven

1. S,F: Form a rectangular shape with the 4 parts of the oven framework [25], [26] and [28] for "S" and [25], [27] and [29] for "F" and joint them together with the 4 connecting pieces [30] and 8 nails each. In the "S" version, this forms a square of 66.5 x 66.5 cm and in the "F" version, a rectangle of 66.5 x 119.5 cm.
The exterior edgings of [26] and [28] and/or [27] and [29] respectively, should now be planed off at 25° angles (see drawing on page 14).

2. S,F: Attach both the front legs [36] with 3 nails [49] each to the front panel [32] and/or [33] respectively, as well as the reinforcing battens [39 with 5 nails [49] and/or [40] with 9 nails [49], as the case may be. In the same manner attach the rear legs [37] to the rear panel [34] and/or [35] respectively with 5 nails [49] each, as well as the reinforcing battens [39] and/or [40] as the case may be. Affix the reinforcing battens [38] to both side panels [31] with 4 nails [49] each, in such a way as to provide a finished left-hand and right-hand panel.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3. S,F: Assemble and attach the four panels, one after the other, with nails [49] to the oven framework and connect them together at the legs to form a rigid box form.

4. S,F: For forming the oven bin [23] and/or [24] respectively, transfer the drawing on page 17 to a sufficiently large offset plate and cut out the collapsed shape along the boundary lines (e.g. 2 or three cuts with a Stanley cutter and ruler and then break off by bending over). Should insufficiently large offset plates or aluminium sheeting be available, 2 or 3 smaller pieces may be employed, in joining them up severally by folding the edges together as shown at the bottom of the drawing on page 17. Ensure that such joints are made at the bottom and in the middle portions of the collapsed oven bin. The oven bin is now shaped in the following manner: first bend up the 4 side walls along the dotted lines by pressing a sharp edged piece of hardwood or metal against the edges of the bin bottom. Bring together each of the 2 points A, B, C and D at the four corners and then press the thereby formed triangular tips together in the middle. These tips must be bent over in such a way that they lay flat against a side panel (see drawing on pages 10 and 11). Finally bend the upper edge outwards, with advantage over the edge of a table. Before introducing the finished oven bin into its position in the oven framework, first attach it with its bent over upper edge to the inside edge of the rear of the oven framework [28] with 4 nails [49] and/or [29] with 7 nails [49] respectively, from the underside. The oven bin is now still standing vertically in an upwards position. The oven bin is now pulled down so that the bent over edge with the attaching nails is now no longer visible and the upper edge of the oven bin is flush with the upper edge of the oven framework. The remaining three sides can now be attached with 4 and/or 7 nails [49] each to the inner edge of the oven framework. In order to create a flush finish between the oven bin and the oven framework, thin battens can be applied along the front and side edges (e.g. of 5 mm gauge bakelized plywood in 1.5 cm width) flush with the upper edge of the oven framework to cover the join, directly with nails [49] without the necessity of previously attaching the metalwork to the oven frame.
Should the oven bin be too pliable because of employing very thin metal sheeting, the bottom of the oven bin can be made rigid by applying 1 or 2 battens of the size [38] from below. The battens are then fixed at right-angles to the front and rear panels with nails, e.g. [50]. Paint the bottom of the oven bin with mat black stove flue paint [53].

5. S,F: Fill the cavity between the side panels and the oven bin and between the oven bin bottom and the bottom panel with insulating material [54]. Should loose material be employed, ensure that sufficient is compressed into the cavities so that no air pockets remain as well avoid shrinkage with time. On the other hand, not too much should be compressed into the cavities as optimum insulation is obtained with sufficient air present among the fibres of the material. Apart from this the solar oven cooker would become unnecessarily heavy.

6\. S,F: Before the <u>bottom panel</u> [41] and/or [42] respectively can be attached, cut outs will have to be made in all 4 corners to accommodate the legs. The bottom panel is affixed with 18 screws [43] for the "S" version and with 26 screws [43] for the "F" version respectively, but without glue so that it can be easily removed subsequently to renew the insulation material.

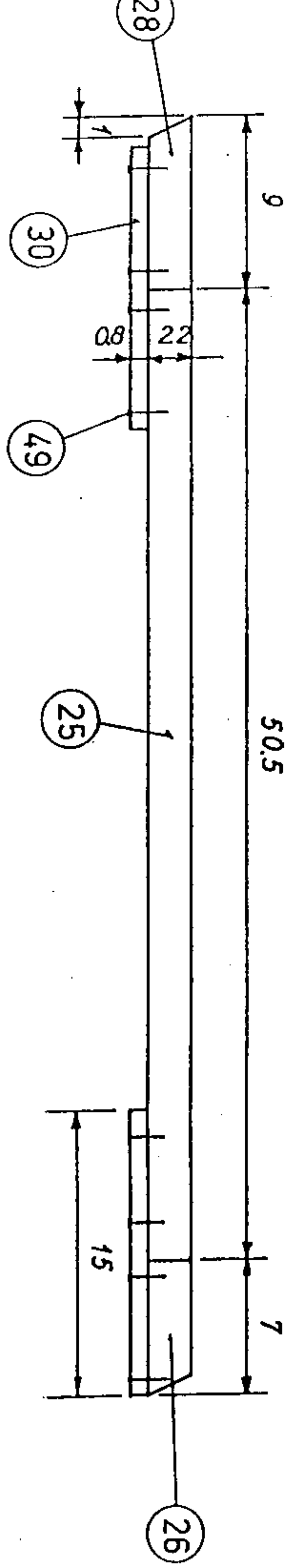
7\. S,F: To attach the <u>panel battens</u> [17], [18] and [20] and/or [17], [19] and [21] respectively, the window should first be laid in its correct position on the glass frame. Site the appropriate 4 battens closely abutting the glass frame ; [17] at the sides, [18] and/or [19] and [20] and/or [21] respectively front and back and attach these with a total of 18 nails [50] and/or 24 nails [50] respectively.

8\. S,F: Attach the <u>bow handle</u> [22] with 4 screws [45] in the front centre of the glass frame in such a manner that the fingers can be comfortably introduced between the bow handle and the framework to open the window. To carry the solar oven cooker, affix 2 other bow handles at the side extremes on the panel batten [17] with 4 screws [46].

9\. S,F: In order that the window cannot slip down on opening, an arrester facility is envisaged (see drawing on pages 4 and 10/11). This comprises 2 <u>window retaining battens</u> [15] on the one hand, which are attached to the rear part of the glass frame with 3 screws [44] each, in such a manner as to protrude by 2 cm, and on the other hand by 2 <u>stop blocks</u> [16], which are attached to the panel battens [17] with 2 screws [46] each and abutting the glass frame and the window retaining battens.

10\. S,F: The whole solar oven cooker should be treated with weather-proofing [55] except in those parts of bakelized woodwork which is already weather-proof.

50,9
66,5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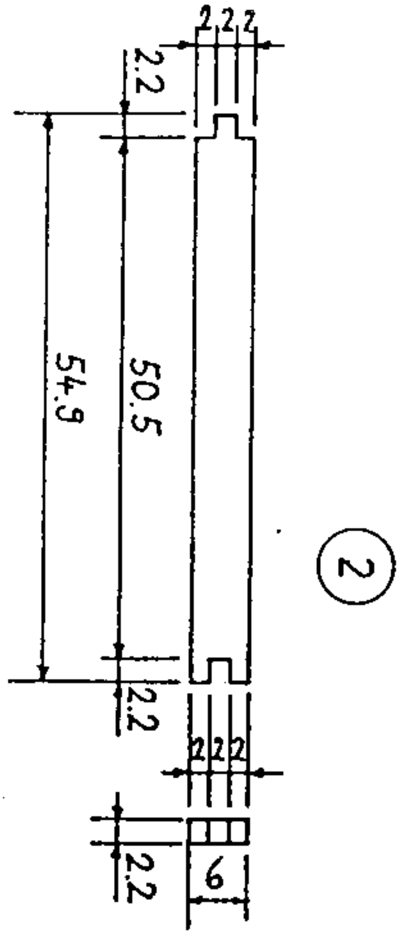
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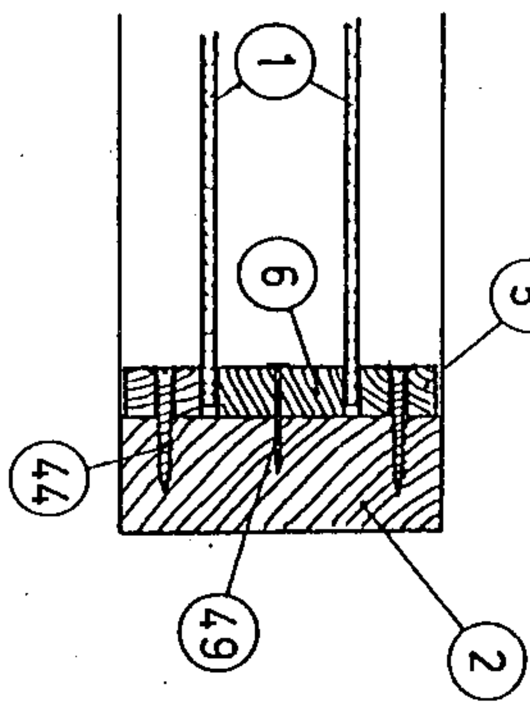
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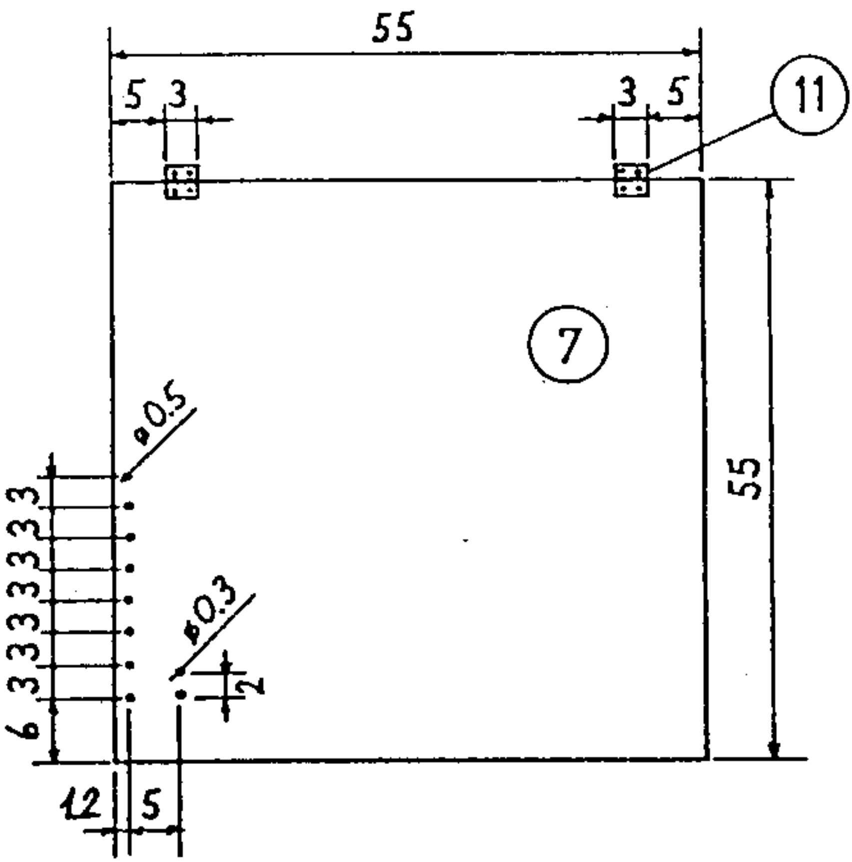

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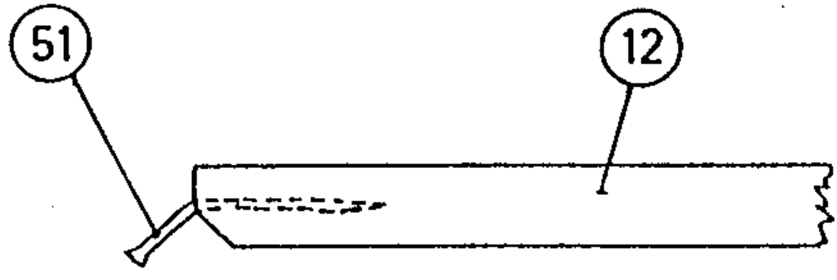

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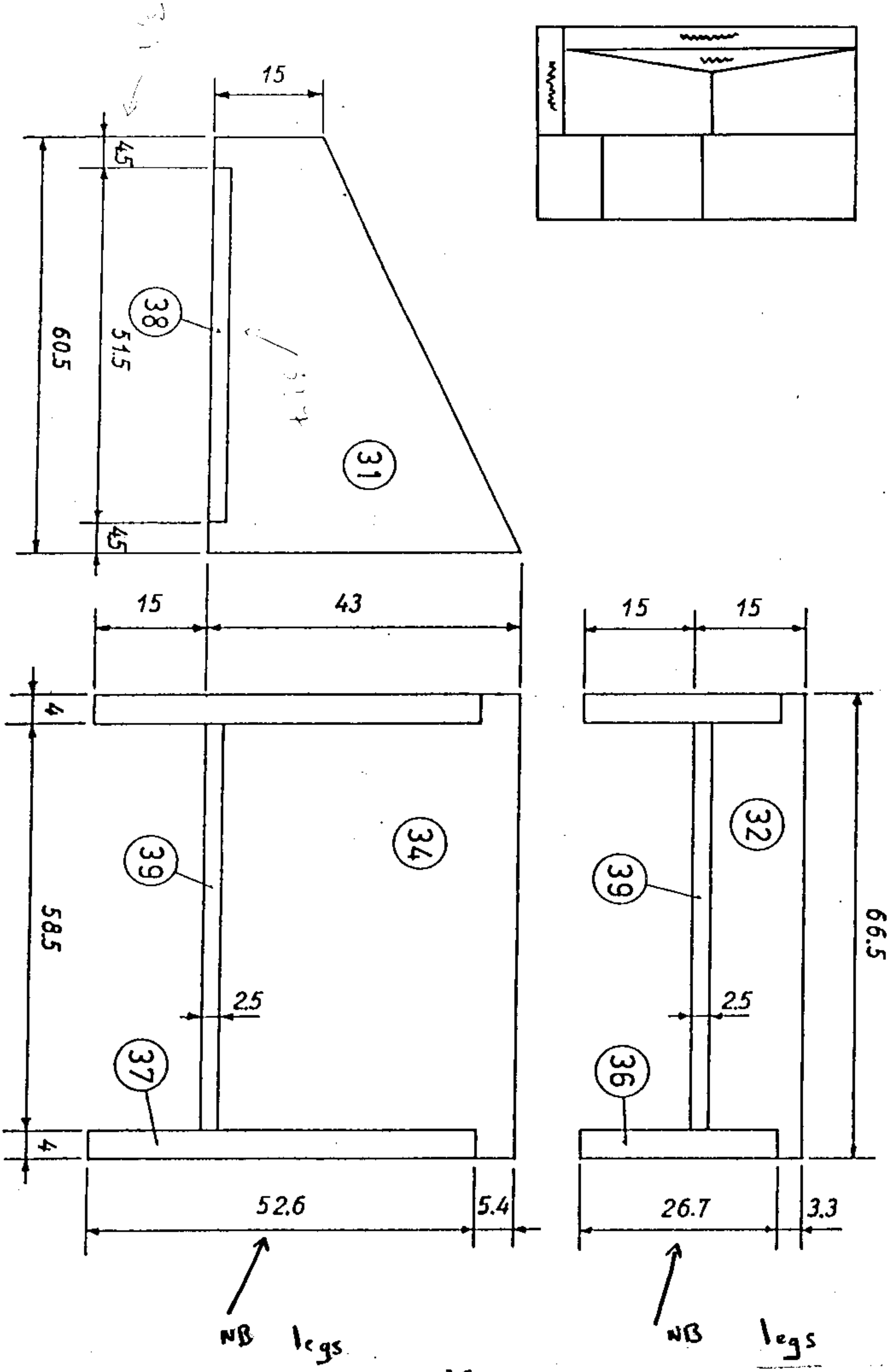
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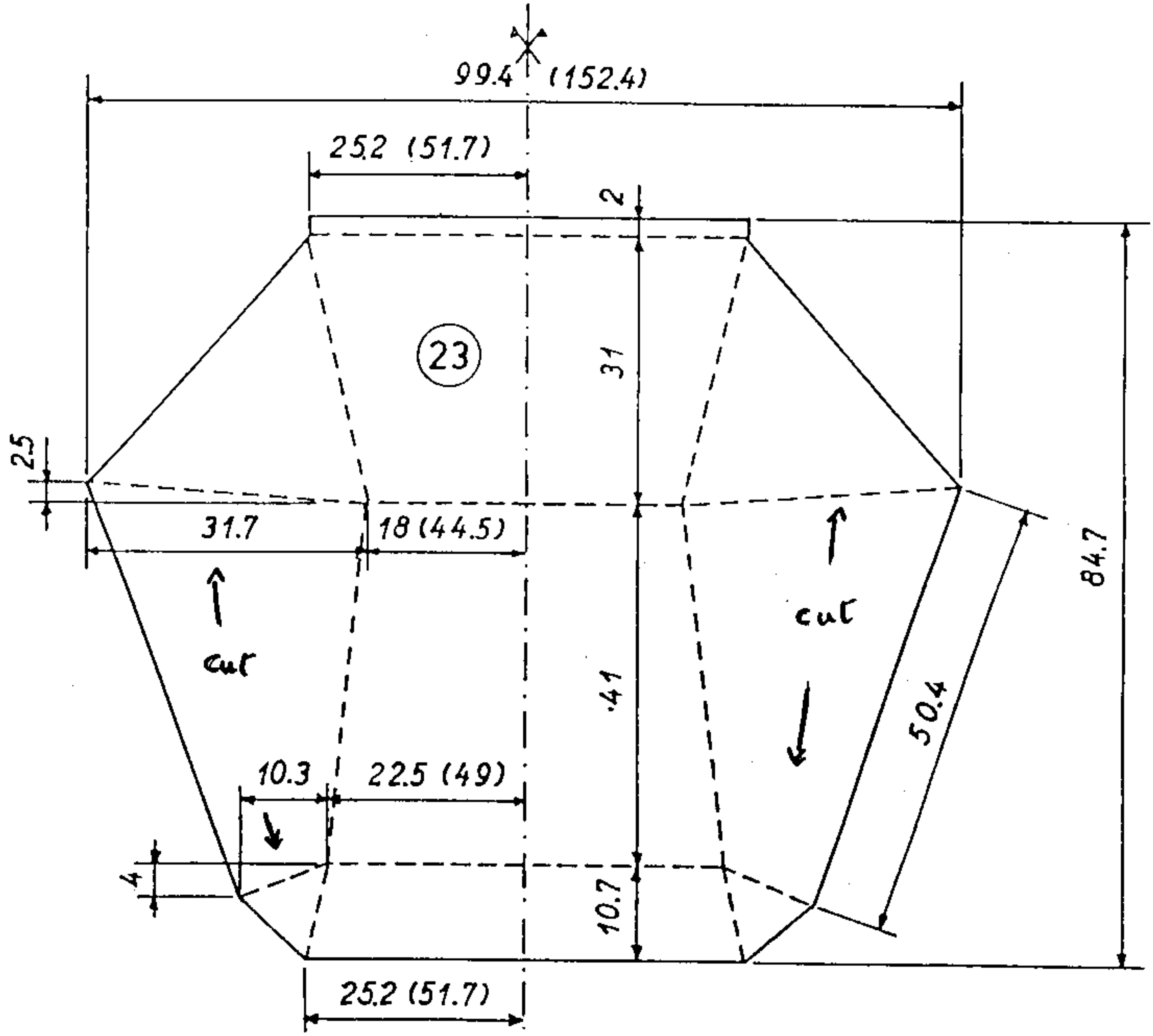
NB legs
NB legs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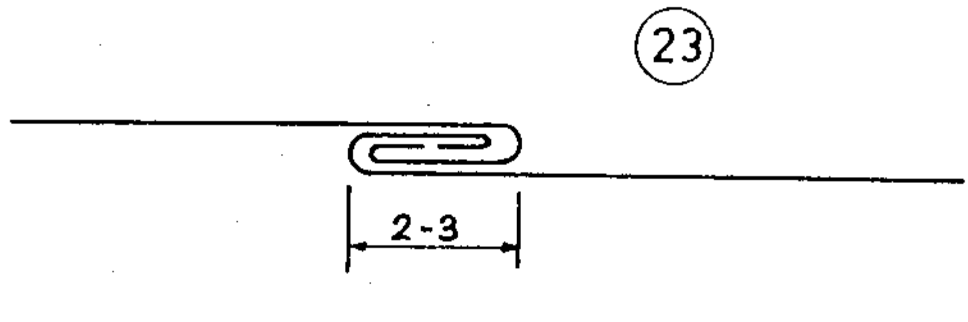
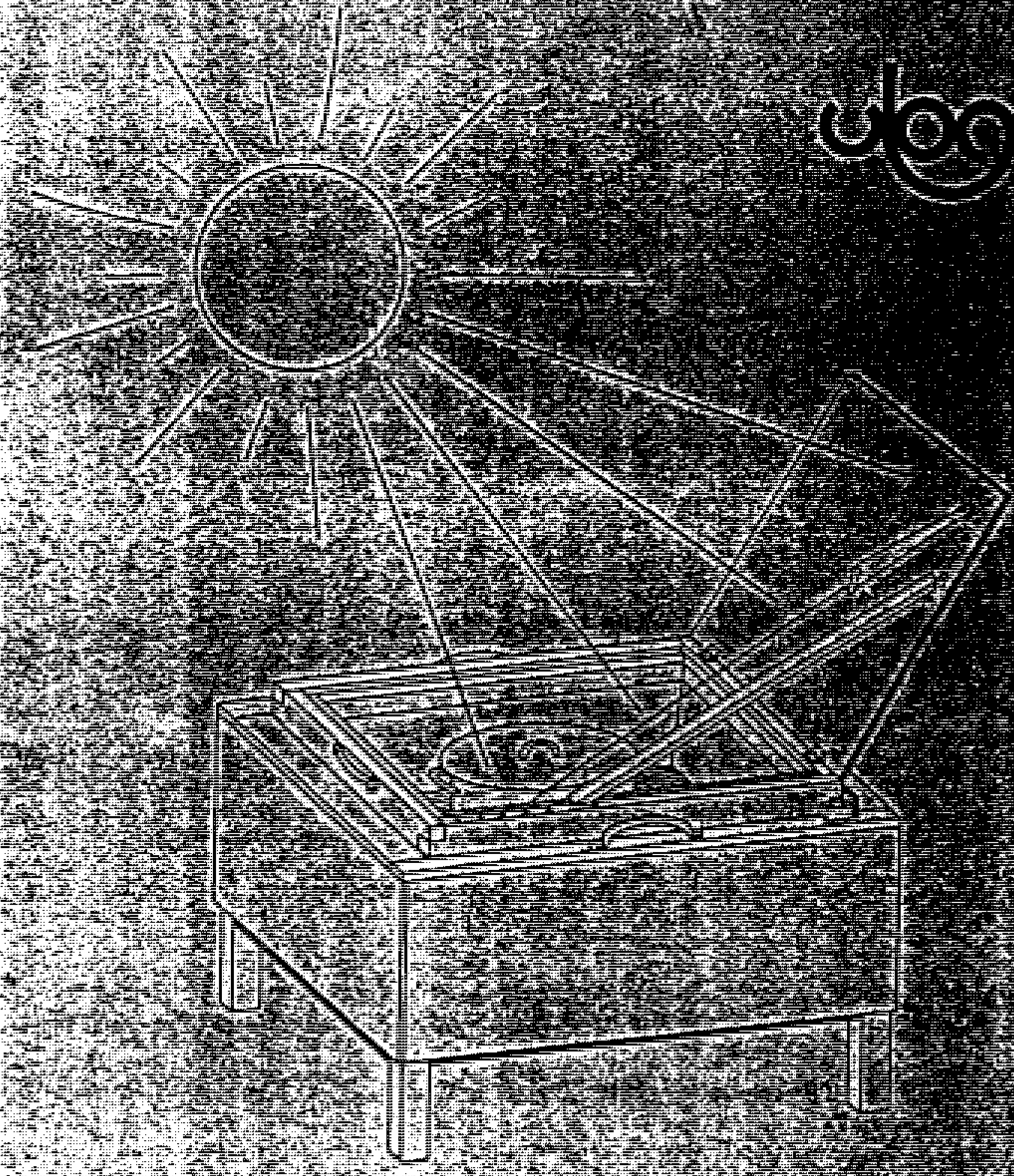

23
2-3

SOME IMPORTANT TIPS FOR USING THE SOLAR OVEN COOKER (SO)

- Do not attempt to cook food on the first occasion or to use it so long as the black paint emits unpleasant odorous fumes.
- The SO only functions in direct sunlight. Clouds, hazy sky or dust in the atmosphere reduce the sun's radiation and correspondingly prolong the cooking time. The air temperature has however little influence!
- Place the SO out of the wind where no shadows are likely to be cast during the cooking time.
- In order to exploit the greatest possible radiated energy, the SO should be correctly directed towards the sun. The reflector serves to amplify the captured light rays. The optimum position of the SO towards the sun can be checked as follows: the shadow of the reflector support should fall upon the woodwork of the glass frame below it. Ideally, the reflection of the sun from the reflector should fall on the centre of the oven bin. The reflection is better recognisable by moving the equipment to and fro. Set the reflector in the correct position with the reflector support and fix with the bracing line. Repeated readjustments are unnecessary. If the SO is positioned just in front of the passage of the sun at the beginning of the cooking time, there is no need for any readjustment. Cooking can continue with the SO in the absence of the cook!
- In order only to lose as little heat as possible, open the SO as infrequently as possible, and then only very briefly. All condiments, apart from salt, should be with advantage added to the food at the beginning. Stirring is unnecessary as nothing can burn to the bottom of the pan or boil over.
- The cooking and/or baking time is 2 to 4 hours, depending on the meal, amount and sunshine. As food in the SO can hardly become overdone, it may also be left in the oven cooker longer than really necessary. Normally, temperatures are generated in the oven cooker of between 120°C and 150°C. Frying and crispy baking are therefore not possible. The best dishes are those cooked in water, such as cereals, beans and vegetables, whereby the conventional amount of water used should be reduced by approx. 1/3. Cereals and beans are more quickly done, when salt is added towards the end of the cooking time. The SO is well suited to the braising of meat and for the baking of bread or cakes. Other applications might be, among others, the roasting of nuts, boiling of water for drinking purposes and the dry sterilisation of medical instruments.
- In order to keep cooked food warm, e.g. until sunset, simply close the reflector cover. A dark plate of stone (e.g. soapstone or slate) or iron in the cooker will accumulate and store heat. On such a preheated plate grilling, baking and roasting is possible.
- In order to exploit the generation of heat best, the exterior of cooking utensils should be coloured dark, and preferably black. The consistency of the cooking utensils is on the other hand not of importance. So as to obtain shorter cooking times, thin metal aluminium utensils should be employed and the food distributed over several smaller pots. An improved heat exchange is obtained if these do not stand directly on the bottom of the oven bin but on a raised grill or simply on two thin battens.
- Apart from the cleaning of dirty window panes, maintenance of the SO is scarcely necessary. Even when provided with weather protection, ensure that the equipment is protected from damp. Renew weather protection materials from time to time. Care of the SO will repay itself as it will provide good service for many years.
- "Practice makes perfect", is the motto in cooking with the SO. Only through trial and error, will successful cooking be acquired and the greater the proficiency, the greater the fun obtained from using the SO!



SOLAR-OVEN ULOG

FOR COOKING AND BAKING IN TROPICAL AREAS

SELF-CONSTRUCTION DIRECTIONS

SOLAR ENERGY FOR ALL !

This is the motto of the group ULOG, a loose alliance of active people in Switzerland who stands for the idea to make the energy of the sun available for the majority of the world population, also for the poor of the so called third world. There the most widly spread form of energy for cooking and baking, the wood, is more and more getting scarce in many places. This over-use of natural ressources, that leads to soil erosion and finally to devastation, must be stopped in the interest of us all. The solar cooker is a useful and manifoldly proved alternative to burning wood. It is an extremly simple, nearly everywhere producible cookr which relies exclusively on the direct radiation of the sun. Most of t dishes may be cooked in it, and this without additional work, quite the contrary! Cooking in the solar cooker/oven does not need supervision because stirring in the pan is not necessary.

The solar cooker functions according to the greenhouse effect, i.e. the light rays from the sun (not heat-rays) penetrate the window and are absorbed by the dark surfaces in the inside and so changed into heat. As the hearth-room is tight and as glass is largely impermeable to heat radiation, the temperature inside rises so long until the losses by radiation are equal to the energy that falls in, until they balance. To reduce the losses of heat on the one hand the window is double glassed and on the other hand the hearth is insulated allround. Thereby temperatures far over 100° centigrades are obtained, enough for cooking and even for baking. As only little warmth can be stored, we need for that the direct sun radiation during most of the cooking time.

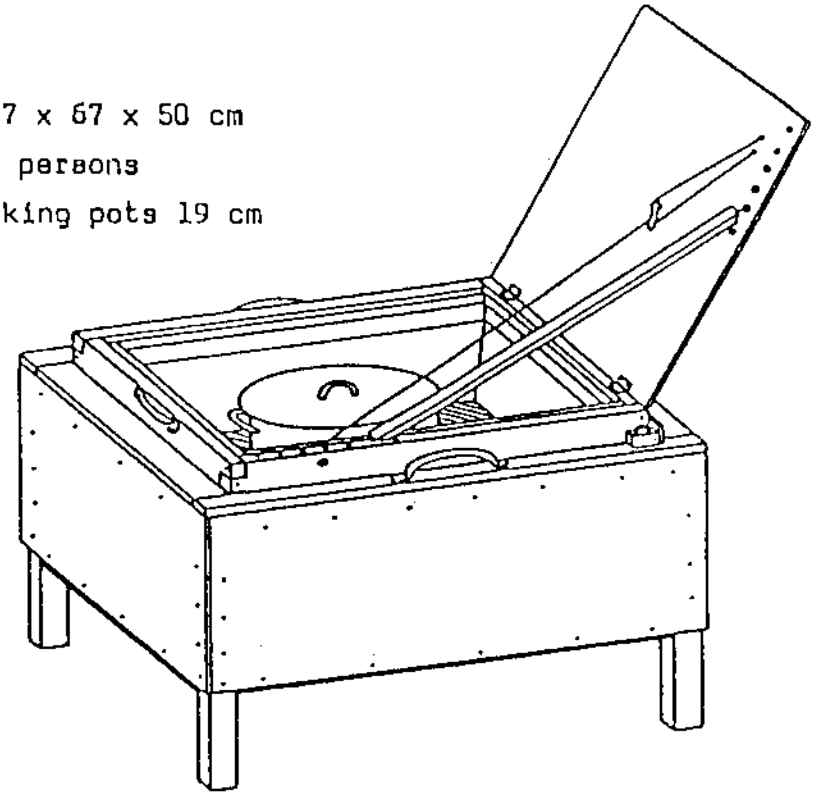
The following directions for self-construction should enable even an amateur with some knowledge of working with wood to build a solid and lasting solar cooker. The necessary material is easy to get and not expensive. The basic measurements may be adapted according to given facts (e.g. different size of the glass,longer legs). The model in question is in two sizes and is suitable for tropical regions, i.e. for all regions near the equator (about 23° N to 23° S). For non tropical zones there are special models which have an inclined window instead of a horizontal one. For travellers who want to use their solar cooker on the way, there are compact trunk models also in two sizes. You may get self-construction instructions for all these other models from the group ULOG in Basel/Switzerland. Kits for construction and ready-made solar ovens of all models can be delivered.

In addition to the solar cookers we have also instructions how to build solar dryers for the conservation of food and simple solar water heaters. For big communities such as schools, hospitals and monasteries we developed a solar-hybrid-community-kitchen SHCK. It suits for cooking and baking for several hundreds of persons with solar energy by fix-focus mirror technic or if the sun-shine fails with a conventional fuel in an economic way. We are glad to give more information on request.

When invited our assistants travel also to areas of the 3rd world where a solar cooker project is built up. First of all local artisans shall be instructed and traind for the construction and women for the use of the equipment. In doing so they may get financial support amongst others from the "Verein zur Förderung kleintechnologischer Nutzung von Sonnenenergie" VKSE Postfach CH-4011 Basel. New members are highly welcome! (VKSE means "Association for the promotion of the small scale use of solar energy").

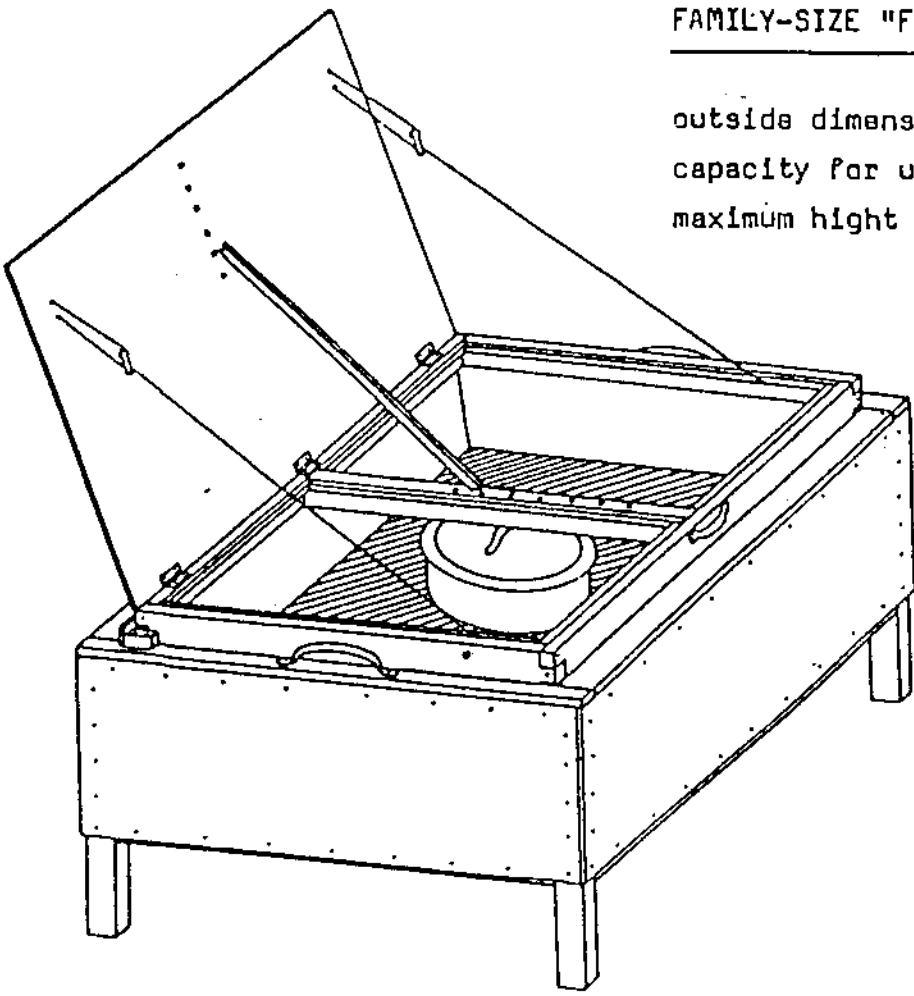
STANDARD-SIZE "S"

outside dimensions 67 x 67 x 50 cm
capacity for up to 6 persons
maximum hight of cooking pots 19 cm



FAMILY-SIZE "F"

outside dimensions 120 x 67 x 50 cm
capacity for up to 12 persons
maximum hight of cooking pots 19 cm



List of parts for STANDARD- "S" and FAMILY-SIZE "F" Solar-Cooker

item	number S	number F	description	dimensions (cm)	material
1	2	4	sheet of glass	50 x 50 x 0,3	window glass
2	4	2	frame for glass	54,9 x 6 x 2,2	wood
3	-	2	"	107.6 x 6 x 2.2	wood
4	-	1	cross bar	50.5 x 6 x 2.2	wood
5	8	16	retaining fillet	49,5 x 1,4 x 1	wood
6	4	8	spacer fillet	49.5 x 2.4 x 1	wood
7	1	-	reflector lid	55 x 55 x 0.5	plywood bakelised
8	-	1	"	108 x 55 x 0.5	" "
9	1	-	reflector foil	55 x 55 x 0.01	alufoil, tinfoil
10	-	1	" "	108 x 55 x 0.01	" "
11	2	3	hinge	3 x 3	steel, galvanized
12	1	1	prop for reflector	50 x 1.5 x 1.5	wood
13	1	2	cord	Ø 0.3 x 100	nylon
14	1	2	cord tightener	3.5 x 1.5 x 0.5	plywood bakelised
15	2	2	window holding ledge	25 x 2.5 x 1	hardwood
16	2	2	buffer block	5 x 2 x 2	"
17	2	2	revetment	67.5 x 6.3 x 1.5	wood
18	2	-	"	55 x 6.3 x 1.5	wood
19	-	2	"	107.8 x 6.3 x 1.5	wood
20	3	3	handle	16.5	steel chromium plated
21	1	-	stove bottom (trough)	78 x 78 x 0.03	offset plate, alu sh.
22	-	1	" " "	131 x 78 x 0.03	" " "
23	2	2	frame f.stove bottom	50.5 x 8 x 2.2	wood
24	2	-	" " "	66.5 x 8 x 2.2	wood
25	-	2	" " "	119.5 x 8 x 2.2	wood
26	4	4	frame joint	15 x 7.5 x 0.8	plywood
27	4	2	side wall	67 x 27 x 0.5	"
28	-	2	" "	120 x 27 x 0.5	"
29	4	4	log	40 x 4 x 4	wood
30	4	2	reinforcing strip	58.5 x 2.5 x 1.5	wood
31	-	2	" "	111.5 x 2.5 x 1.5	wood
32	1	-	floor	67.5 x 67.5 x 0.5	plywood
33	-	1	"	120.5 x 67.5 x 0.5	"
34	30	40	wood screw countersunk	Ø 0.3 x 2	steel
35	24	40	" " "	Ø 0.3 x 2.5	"
36	4	4	" " "	Ø 0.35 x 2	"
37	12	12	" " "	Ø 0.35 x 3.5	"
38	-	4	" " "	Ø 0.35 x 5	"
39	4	6	button head rivet	Ø 0.3 x 1	aluminium
40	131	152	nail flat-headed	Ø 0.14 x 2	steel
41	18	24	nail sunk-headed	Ø 0.14 x 3	"
42	14	14	nail " "	Ø 0.2 x 5	"
43			glue for wood		
44			paint		black, mat, dull
45			insulation material	8 cm thick	mineral wool mats
46			weather protection		e.g. linseed-oil

Variations for some parts of the list.

Item:	Variations, other possibilities:
1	Different thickness of glass: 2 mm or more than 3 mm, if necessary adaption of the width of item 5. Use tempered glass plates for greater crash-proofness. This so-called safety-glass is at least 3.5 mm thick and costs double the price of ordinary window-glass. It has to be ordered in the right measurements and cannot be cut later. Also it is noch everywhere available. The additional expenditure is only worth-while with greater number of pieces.
2 / 3 4	If the quality of the wood is bad, we need thicker wood, up to about 2,5 cm. According to that, the length has to be adapted so that the measurements of the inside of the frame remain unchanged. Adapt the width of items 17, 18 and 19 too.
5 / 6	If the quality of the wood is poor a greater thickness (up to 1.3 cm) is necessary with according adaption of the lengths.
7 / 8	Ordinary plywood (not bakelised) 8 to 10 mm thick. If one uses plywood of 4 to 5 mm thickness only, then the lid must be strengthened all round on the upper side by a frame (ledges or reinforcing strips with a profile as e.g. items 30 and 31.
9 /10	Offset plate or polished aluminium sheet.
11	Straps of strong textile, fabric, leather or skin, about 10 x 5 cm (for "S" 4 pieces, for "F" 7 pieces). Fix them on the upper side of the lid and on the glass frame each with a ledge of plywood 4,5 x 54 cm or 4.5 x 107 cm respectively and with nails as item 40.
20	Handle cut out of curved branches or out of hardwood.
21/22	Aluminium sheet 0.2 - 0.3 mm thick or galvanised sheet metal (e.g. flattened corrugated iron) of max. 0.2 mm thickness.
23/24 25	If the quality of wood is poor you need thicker wood up to about 3 cm. Accordingly the distance between the upper edge of the sidewall 27, 28 and the upper edge of the leg 29 has to be adapted.
27/28 32/33	Plywood 4 mm thick.
29	With wood of poor quality we need a stronger profile which may also be rectangular. To lift the solar cooker higher from the ground, the legs may be longer.
39	Wood screw countersunk Ø 0,3 x 2 cm. To fix and anchor it, a piece of wood (ledge) must be fixed on the upper side of item 7, 8.
44	Blackboard-paint or a dye mixed according the following recipe: Mix soot or black ferrous-manganese powder with "half-oil". "Half-oil" consists of one part of turpentine and one part of cooked linseed-oil. Let stand the mixture over night. Then paint a sample with a brush and bake it in the solar cooker at a temperature of at least 130° Centigrades. If the result is not covering enough, you must add more powder. If the coat shines too much, reduce the part of linseed-oil.
45	Insulation material: Organic stuffs such as hay, straw, coir, peanut shells, wood wool, kapok, raw cotton, balls of newspaper scraps, but no styrofoam because it does not resist the heat.
46	Weatherproof varnish, enamel paint or lacquer.

Construction directions

1. General informations:

- The guidance refers to the parts mentioned in the parts list. Variations to single parts are listed separately on page 6
- Making the parts and fitting them together you have to work exactly. Lack of precision may reduce the efficiency of the solar oven. Corrections need a lot of working time.
- All joints of wooden parts are done with glue, except specially mentioned cases.
- S and F are the symbols for the Standard- and the Family-size model. For the construction only the instructions with the respective symbol are valid.
- Drawings are only displayed for S, but they are valid also for F with suitable adaptions.

2. Window:

S/F Make on the four glass-frame battens 2 and 3 a tenon at one end and two tenons at the other end with saw and chisel according to drawing page 12. Put the four parts together to a rectangular and distortion free square. Secure all 12 tenons with a nail 42 each.

F Fix the cross bar 4 in the middle of the rectangle with two screws 38 on both ends.

S Fix four retaining fillets 5 on the inner side of the glass fraim exactly parallel to the outer edge and without steps in the corners. Use three screws 35 for each fillet but no glue, so that they can be removed easily in order to replace a broken pane later on. The fillets should be bored beforehand (Ø 3 mm). Put now one glass pane 1 in. This is fastened roundabout with four spacer fillets 6. You need three nails 40 for each fillet. Before putting in the second glass pane both must be cleaned thoroughly. To avoid the covering with moisture when the solar oven is used, we treat the inner surface of the glass panes either with a clarifying cloth or with transparent soap. The glass pane that must be protected is coated several times criss cross with the soap. Then you rub the soap lines with a dry cloth until the glass is clear again. The four remaining fillets 5 are used to fasten the second glass pane analogous to the first one.

F The same procedure as for model S for the two window-parts side by side.

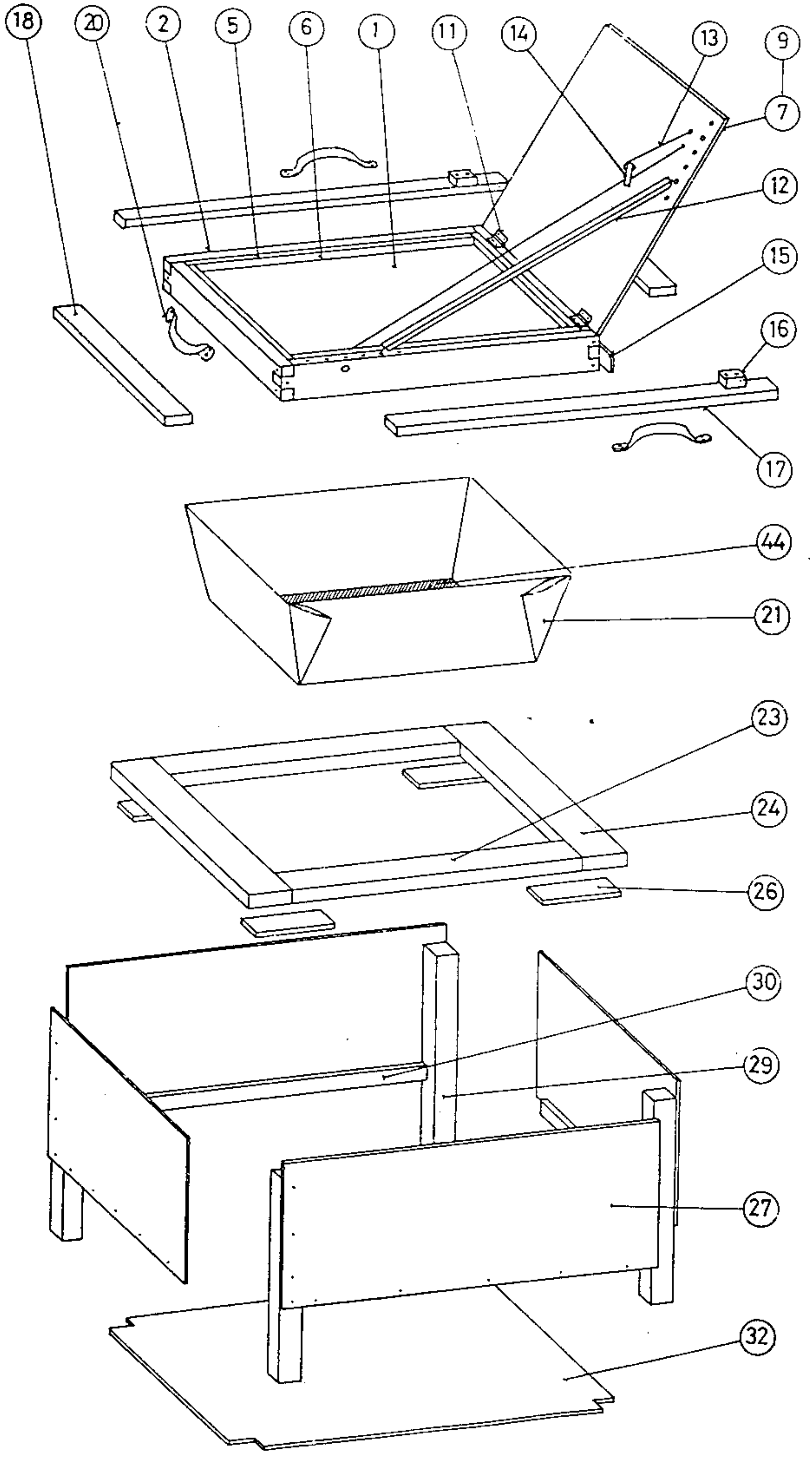
3. Reflector:

S/F Mount the reflector foil 9, 10 on the reflector lid 7, 8. If you do not have a self-adhesive foil use contact-glue or cobbler's glue. Fasten the hinges 11 on the reflector lid on the reflecting side with the rivets 39. Now you can fix the lid with screws 34 on the glass frame.

Hammer into both ends of the reflector prop 12 a nail 42 each until one cm is left protruding. (With harder wood drill first a hole Ø 1.5 mm into the centre of the end of the prop, otherwise it might split). Big heads of nails must be cut off and the ends filded round. Bend both spikes about 45° to the same side. Now rasp on both ends of the prop the edge as shown on page 13.

S Drill on the right side of the shut lid holes Ø 5 mm through the lid about 1 cm into the glass frame and on the same side only in the lid two holes Ø 3 mm for the cord, as drawn on page 13.

The cord 13 is pulled through a lateral borehole Ø 3 mm in the frame. Sink the hole first conically from outside and make a knot into the cord at the outer end. Pull the knot into the countersink and secure it there with a nail 40. The cord-tightener 14 is fitted with two



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holes Ø 3 mm and rounded off on both ends. The other end of the cord is now pulled through the one hole of the tightener and then through the two holes in the lid. Push the end of the cord from below through the second hole of the tightener and knot it as shown.

F The holes for the prop are made in the middle of the reflector lid, respectively in the cross bar 4. There are two tightening cords, one on each side of the window.

4. Frame for stove bottom:

S/F Build with the four parts 23 and 24 respectively 23 and 25 a rectangular fraim. Join them together with four fraim joints 26 useing eight nails 40 apiece. For S results a square of 66.5 x 66.5 cm, for F a rectangle of 66.5 x 119.5 cm.

5. Stove body:

S/F Fasten on each sidewall 27, 28 every time at the same side one leg 29, each with three nails 40 as well as one reinforcing strip 30, 31 with five nails 40 each for 30 respectively with nine nails for 31 according to the drawing on page 11.

S/F Fit up the four sidewalls one after the other with six nails 40 each for 27 respectively with eleven nails 40 for 28 to the frame for stove bottom and join them together at the legs, so that a stiff and gigid body results.

6. Stove bottom (trough):

S/F Transfer the drawing page 14 for the stove bottom 21, 22 on an offsetplate that is big enough and cut along the drawn out lines (e.g. with a carpet knife and a ruler, slit it two to three times and break it by bending). If you can't get offsetplates or aluminium sheets which are big enough you may join together two or three smaller sheets by folding according to drawing on page . Take care that these joints are placed on the bottom of the trough and if possible in the middle. If the sheet is only a few cm too small, the width of the bottom of 40 x 40 cm can be reduced. - Now the trough is formed in the following way: Bend up first the four sides along the dotted lines one after the other by pressing a sharp edged piece of hardwood or metal on the edge of the bottom. Hereupon you put the respective two points A, B, C and D (see drawing page 14) together in the four corners and then only press the resulting triangular lappet in the middle together. These lappets must then be bent so that they lie close and flat on a side (as shown in the drawing page 8).

Put the trough into the frame for stove bottom and nail it with four respectively seven nails 40 per side.

Paint the bottom of the trough with the black, mat and heatproof colouring 44.

In case that the stove bottom sags too much because you use very thin sheet metal, we recommend to strengthen it from below by one or two supporting strips (profile e.g. as item 30). You fasten them rectangular at the front- and back-wall with nails as e.g. item 41 in a way that the strips cannot twist.

7. Insulation:

S/F Fill the cavity between the sidewalls and the trough as well as the space between the trough bottom and the lower edge of the sidewalls with the insulation material 45. With loose material you take care to push in so much that no cavities are left and that it cannot set (sag) with the time. But you must not cram too much because there must be enough air between the fibers for the best insulation.

S/F Before fixing the floor 32, 33, you have to cut out the recess for the legs on all four corners. The floor is fastened without glue with five respectively nine screws 34 per side, so that it can be removed easily lateron if necessary for exchanging the insulation.

8. Window lining:

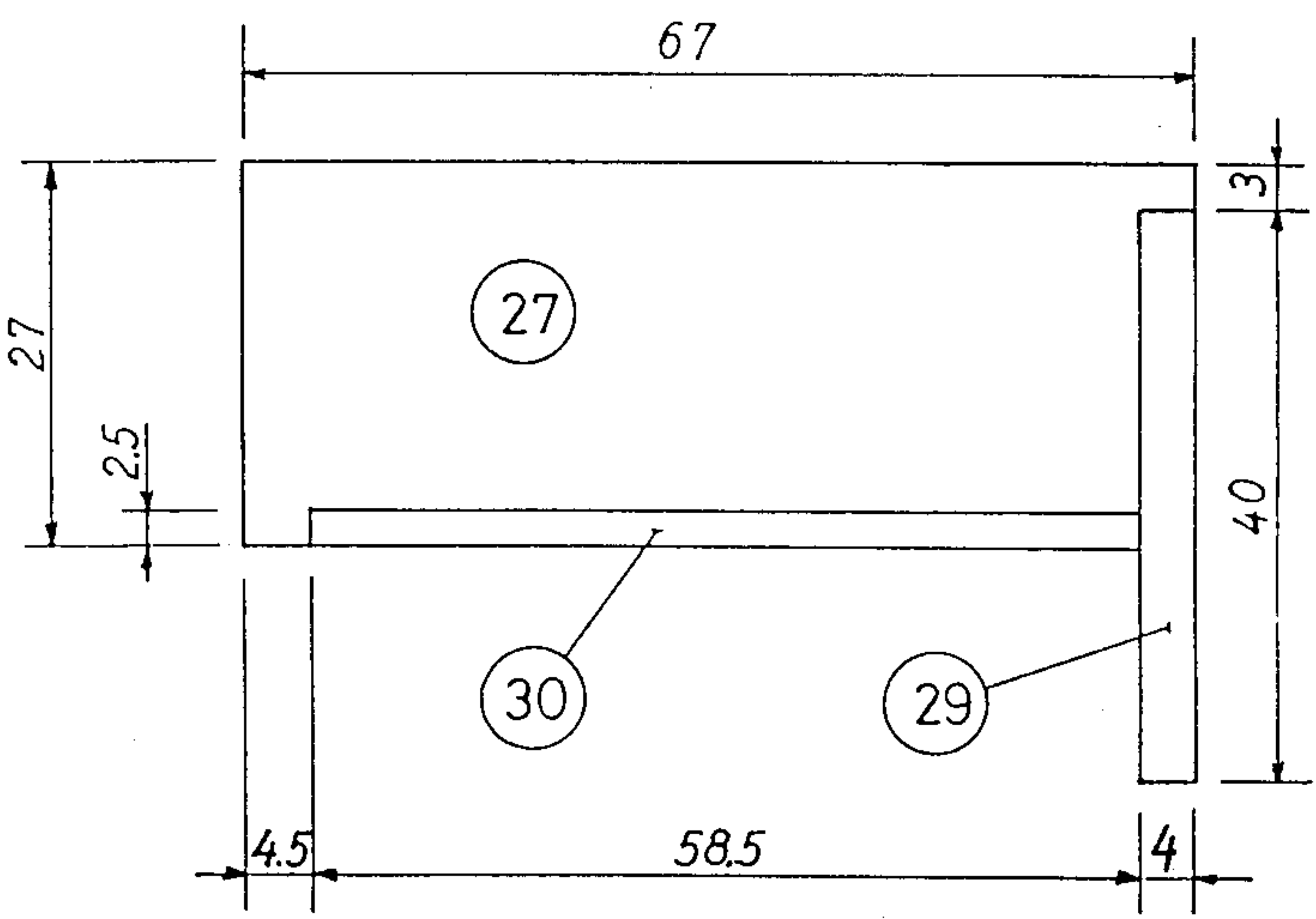
S/F To fix the revetment 17, 18, 19 you put first the window in the right position on the frame for stove bottom. Place then the four parts narrowly adjecent to the frame for the glass, so that the parts for the frame of the stove bottom overlapp in the corners, and nail them down with nails 41.

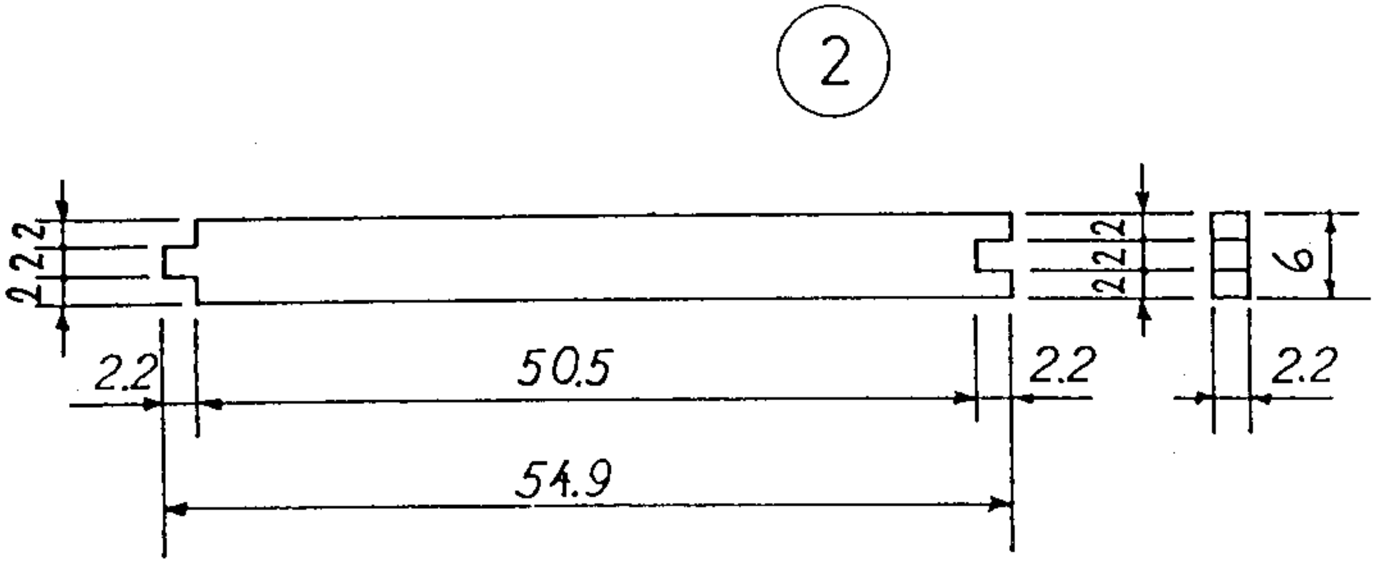
9. Final works:

S/F Fasten with four screws 36 a handle 20 in the middle in front of the glass frame close to the upper ridge, so that the fingers find comfortably space for opening the window. To carry the box fix the two other handles at both sides outside on the revetment with four screws 37 each.

S/F A locking device should prevent the window from shifting when it is opened. This consists on one hand of two window holding ledges 15 which are fixed on the back part of the glass frame with three screws 34 each, so that they protrude two cm on both sides, and on the other hand it consists of two buffer blocks 16 which are screwed onto the lateral revetment with two screws 37 each adjacent as well to the frame for the glass as to the window holding ledge 15.

S/F The whole finished soler cooker should be treated with a weather protection 46, except the bakelised plywood which is allready waterproof.

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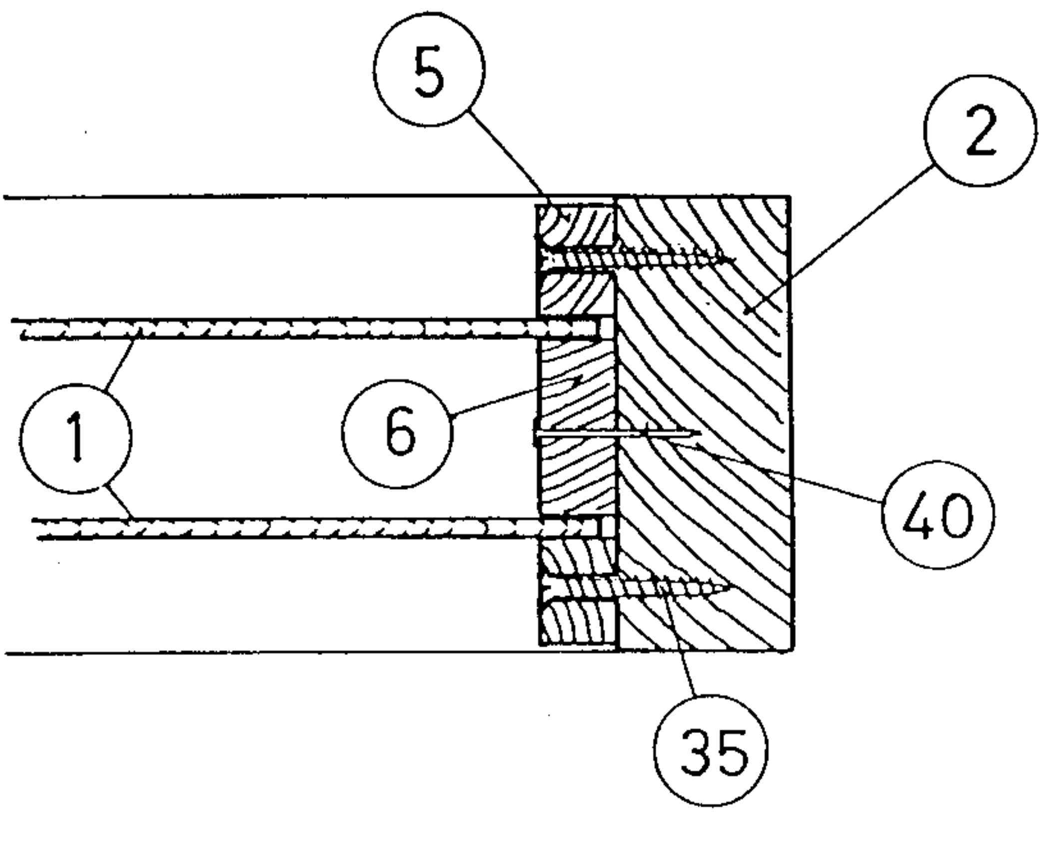
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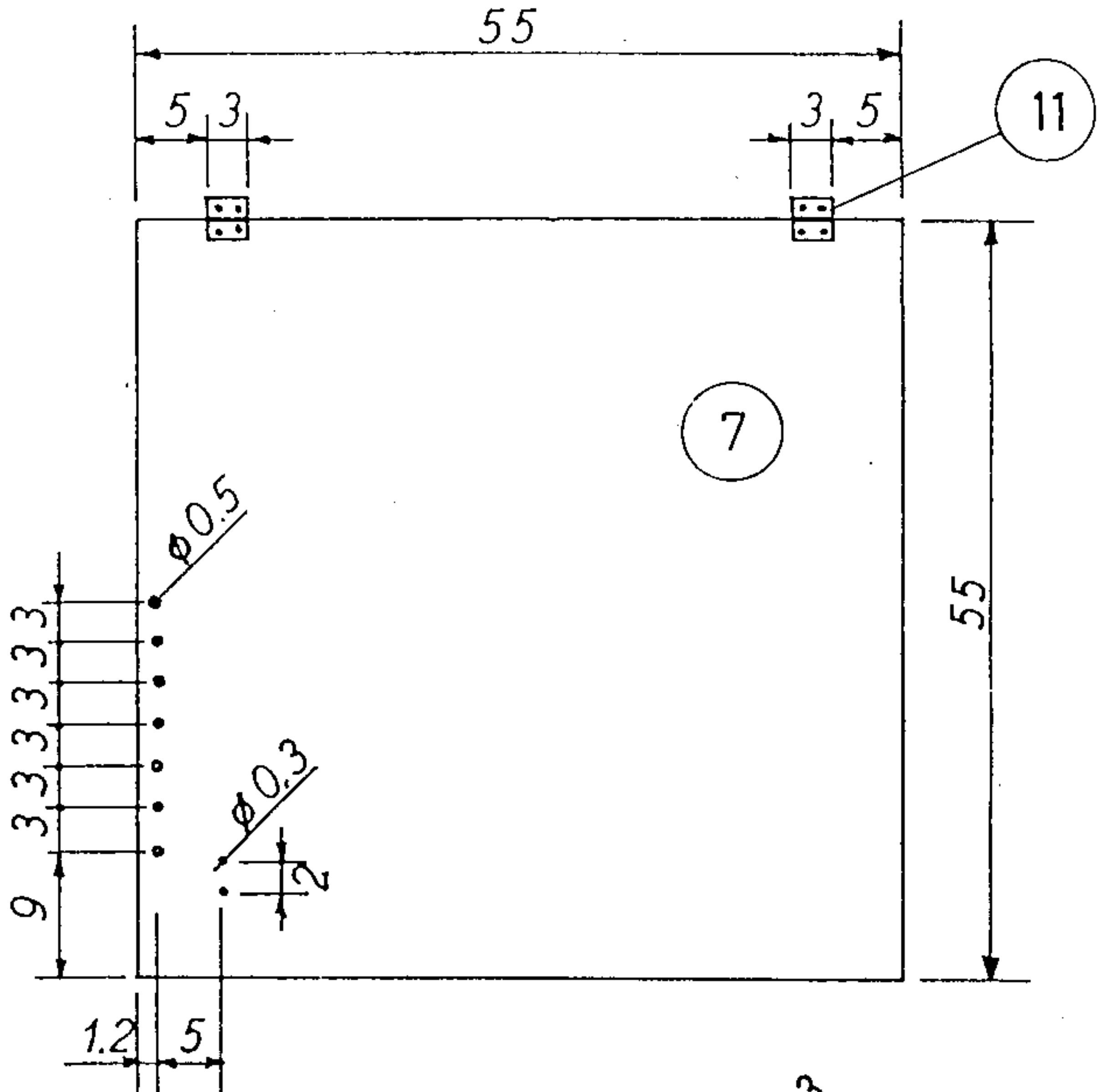
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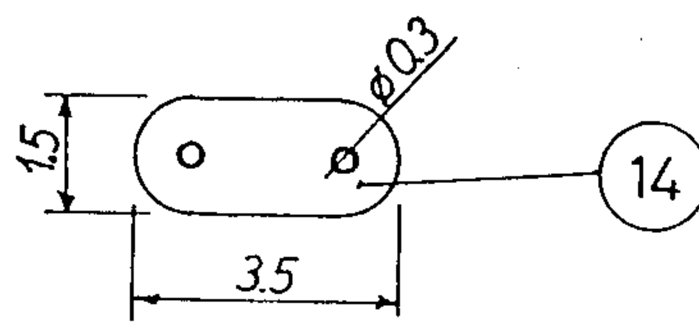
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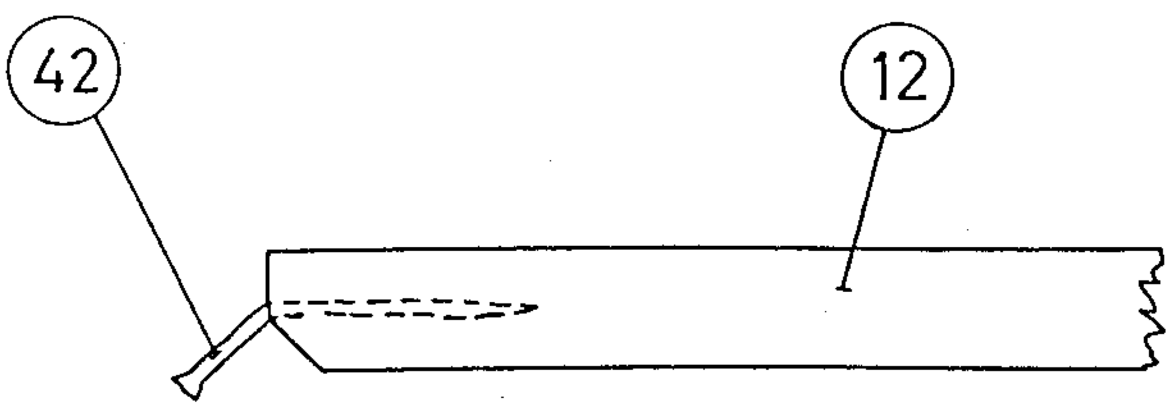
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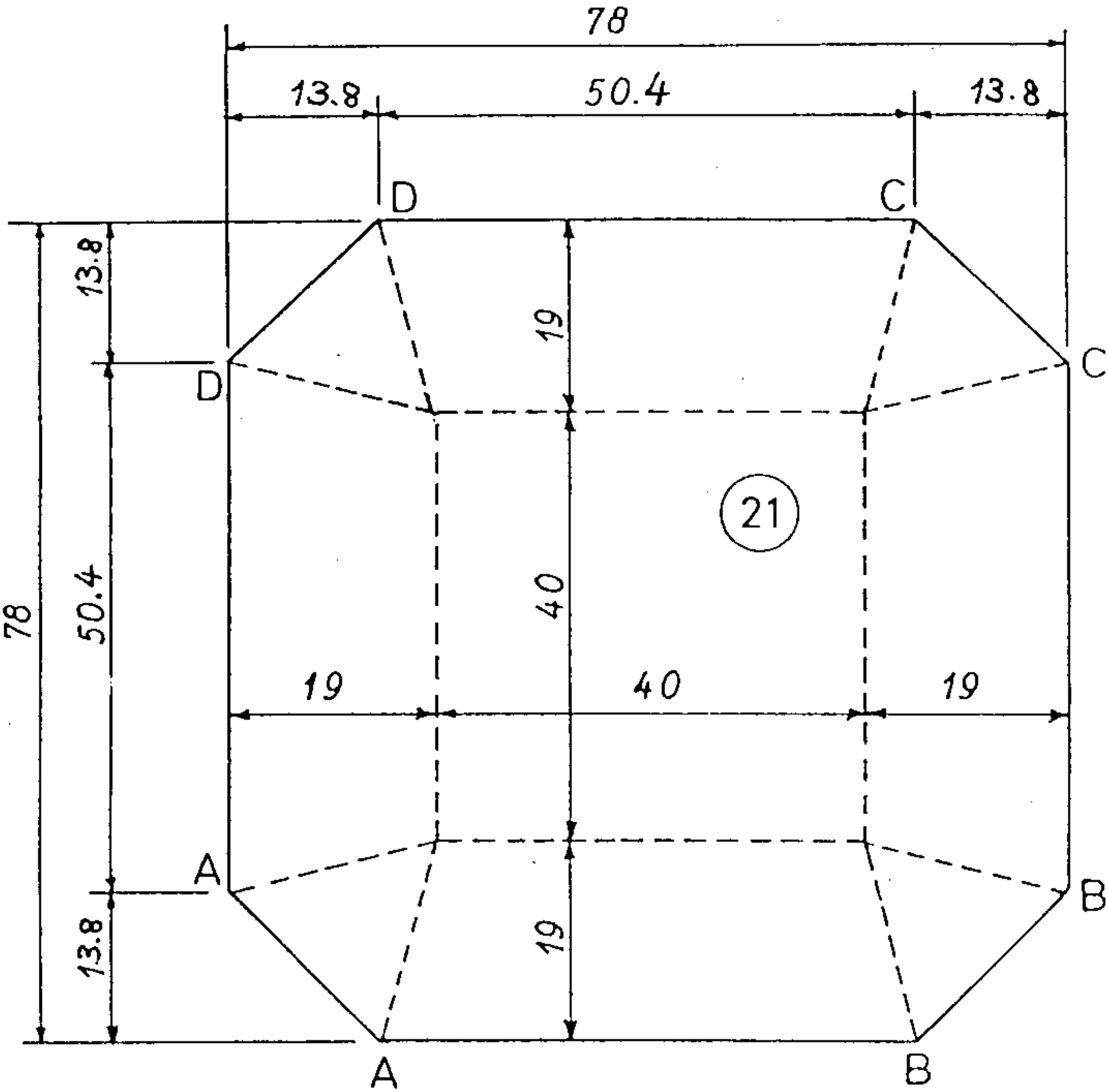

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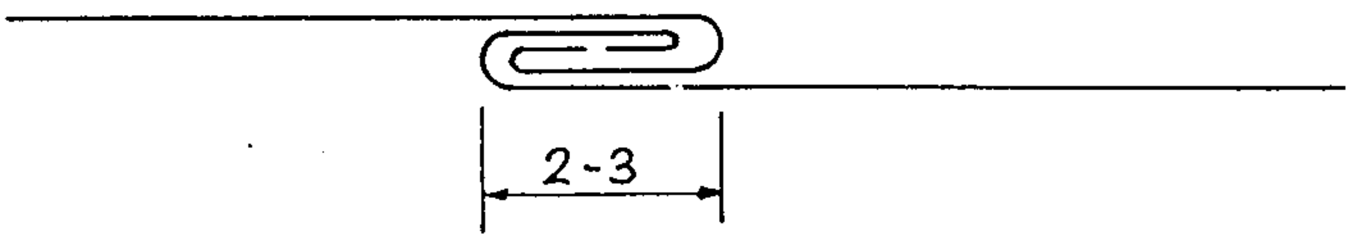


Making Your Own Solar Cooker

Given the choice, making your own solar cooker is highly recommended, for it's one more way to become more intimately involved with the food you prepare and know exactly how it's cooked. You can easily create your own solar cooker using inexpensive materials. Here's what you'll need:

List of Supplies

1. Two cardboard boxes: The smaller one (your inner box) should be close to the desired cooking area size and depth, at least 18" x 18" x 8" (need not be square). The inner box does not need flaps. The larger one (your outer box) should be 1½"-3" bigger on each side than the smaller box and at least 20" high, including the flaps. (For example, if the inner box is 18" x 18", the outer box should be approximately 21" x 21" x 20".)

Note: Bigger isn't better. It's better to make two smaller cookers (18"-24" on a side) than one bigger one, for better solar efficiency in cooking more than one dish at a time. A box smaller than 18" on a side can be used to warm foods up to 150°F (the restaurant industry standard for hot foods), but does not allow enough movement of heat around the pot for adequate cooking, which requires reaching more than the boiling point (212°F).

2. Pocket knife or small utility (razor blade) knife to cut cardboard
3. Pencils, including one without a point (or a tracing wheel from a sewing store) to score cardboard for bending
4. Yardstick or other linear measuring device
5. 8 oz. of nontoxic yellow wood glue, thinned to 2 parts to 1 of water, or homemade flour-and-water paste
6. Empty container to hold glue, and foam-rubber (or other small) paintbrush to apply it
7. 50-75 feet of aluminum foil

8. Newspaper (avoid pages with colored ink) for insulation between boxes
9. Extra sheet of *firm* cardboard for the reflector, the size of the top of your outer box (21"x 21" for the example above)
10. Aluminum flashing (or other thin metal plate, like a cookie sheet) the size of the bottom of your inner box, to line the bottom
11. Flat, black, *nontoxic* poster paint and brush to paint the metal plate
12. Sheet of clear, clean window glass, at least the size of your outer box (21"x 21" for the example above). An old window in an aluminum frame is easy to handle. If the glass is unframed, edge it in tape for safe handling. There's a trade-off between using single- or double-strength glass. The sun enters more easily through single, but stays in better with double.
13. Approximately ¼ yard of white felt or wool (optional)
14. Oven thermometer (optional)
15. 3 yards of self-stick plastic paper, used for shelf linings (optional)

How to Make a Simple Box Cooker

1. Cut the inner box so the sides are 8" high all around. Glue the bottom flaps of the inner box into place if they aren't already; weight down to hold until glue dries.

Glue down the bottom flaps of the outer box the same way, and weight down to dry.

2. Line the inside of the bottom of the inner box with aluminum foil; glue into place by putting the glue on the box, and lay in the foil, dull side down, on the glue. (Fig. 1) Run the foil up the sides an inch or so to assure good sealing; make sure the foil fits tightly into edges and corners. Cover the outside of the inner box with aluminum foil for extra insulation, glued with shiny side

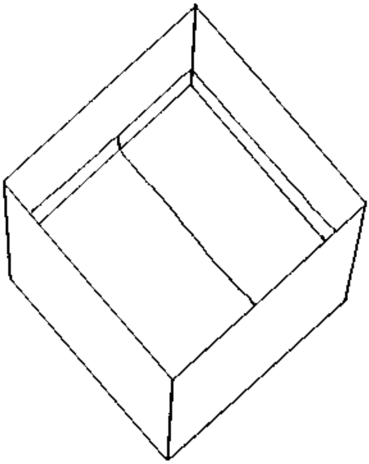


Fig. 1

toward the glue in order to obtain the best reflection of sunlight and make a heat barrier. Patch foil as needed for complete coverage to minimize air leaks.

3. Cut four of the pieces left over from the top of inner box a little smaller than the size of the sides of the inner box; cover the pieces with aluminum foil (glue dull side of foil toward the cardboard). (Fig. 2) Glue these pieces to the inner sides of the inner box for extra insulation.

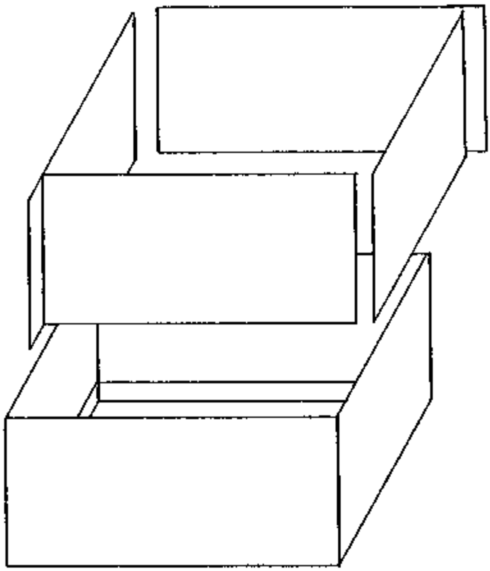


Fig. 2

4. Cut three or four strips of cardboard 2" x 10". Cut a slit ½" in from each end, as shown in Fig. 3. Position these in the bottom of the outer box so that they will steady the inner box when it is placed on top of them. That way, wherever you set your cooking pots inside the inner box, they will be supported by these tripods.

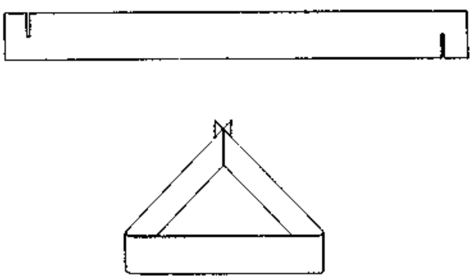


Fig. 3

5. Crumple half-sheets of newspaper into loose balls, and stuff them lightly into the bottom of the outer box around the tripods, but not on top of them.

6. Put the inner box in place inside the outer box. Stuff the space between the sides of the boxes with more crushed newspaper, tightly but not bulging. (Fig. 4)

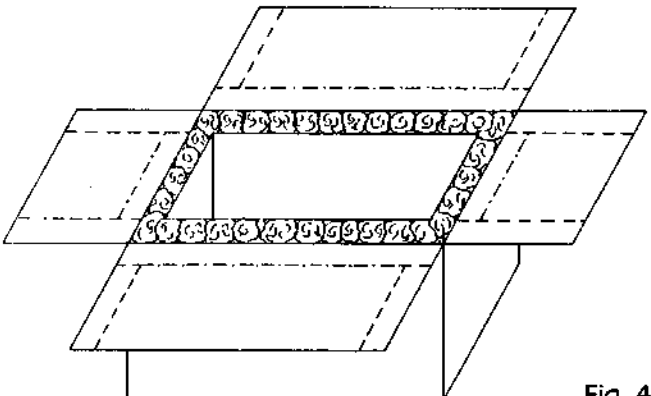


Fig. 4

7. Fold one flap of a long side of the outer box onto the nearest side of the inner box. Score (but do not cut) along the underside of this flap where it meets the edge of the inner box. (Score with a dull pencil or a tracing wheel, being careful and accurate as this process produces the vital flat surface where your glass will rest.) Cut in from each edge of the flap up to the score line just a little deeper than the sides of the inner box, so the resulting flap will fold down loosely into the inner box. (Fig. 5) Repeat this step with the opposite long side. With the remaining short sides, cut in from the edge of the flaps a little deeper than the sides of the inner box, but past the score line all the way to the edge of the outer box.

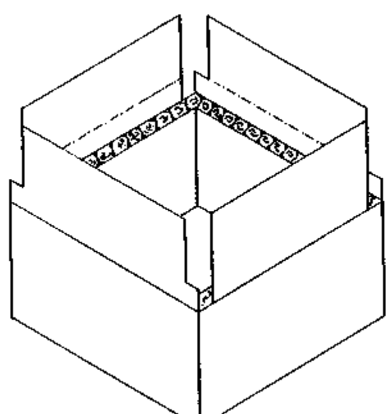


Fig. 5

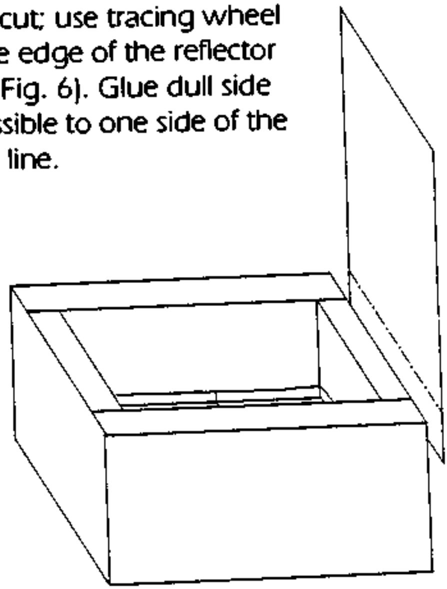
8. Glue the dull side of foil all around the flaps on the outer box, keeping foil especially smooth on the side that will show inside the inner box.

9. Fold the flaps down into place, and glue if necessary to hold them in place.

Your box is now finished! All that remains is to create the reflector and black metal liner:

1. Score (but do not cut; use tracing wheel if possible) 1½" from one edge of the reflector piece of firm cardboard (Fig. 6). Glue dull side of foil as smoothly as possible to one side of the reflector, up to the score line.

Fig. 6

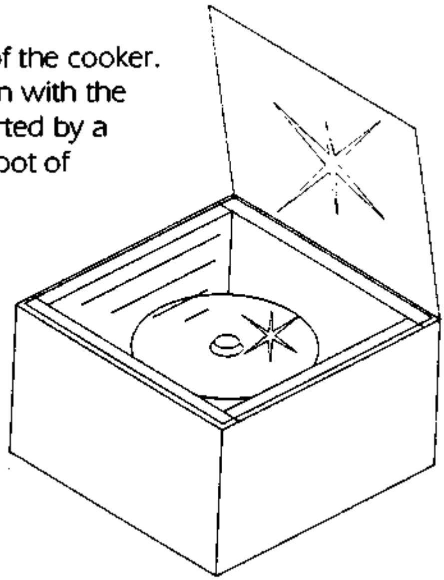


2. Bend on score line and glue the reflector to the top of the outer box, flush with one long edge of the box, foil side facing the inner box. Weight down to hold until glue dries. (Note: You may use mylar or foiled cardboard instead of foil—whatever you can get that is smoothest and thus most reflective.)

3. Cut the metal liner to the size you want. Paint with flat, black, nontoxic paint; set aside. When dry, lay plate in the bottom of the inner box carefully, so you don't tear the aluminum foil. (If you do tear the foil, patch it well to avoid air leaks.)

4. Cut pieces of felt to glue along the top edges of the box, to provide a smooth, firm resting place for the glass and to seal in the heat. Use extra thicknesses if necessary in places to make the top edge as level as possible and avoid air leaks between the glass and the cooker.

5. Put the glass on top of the cooker. Set the cooker facing the sun with the reflector at an angle (supported by a rock or brick) so the bright spot of sunlight is *within* the box.



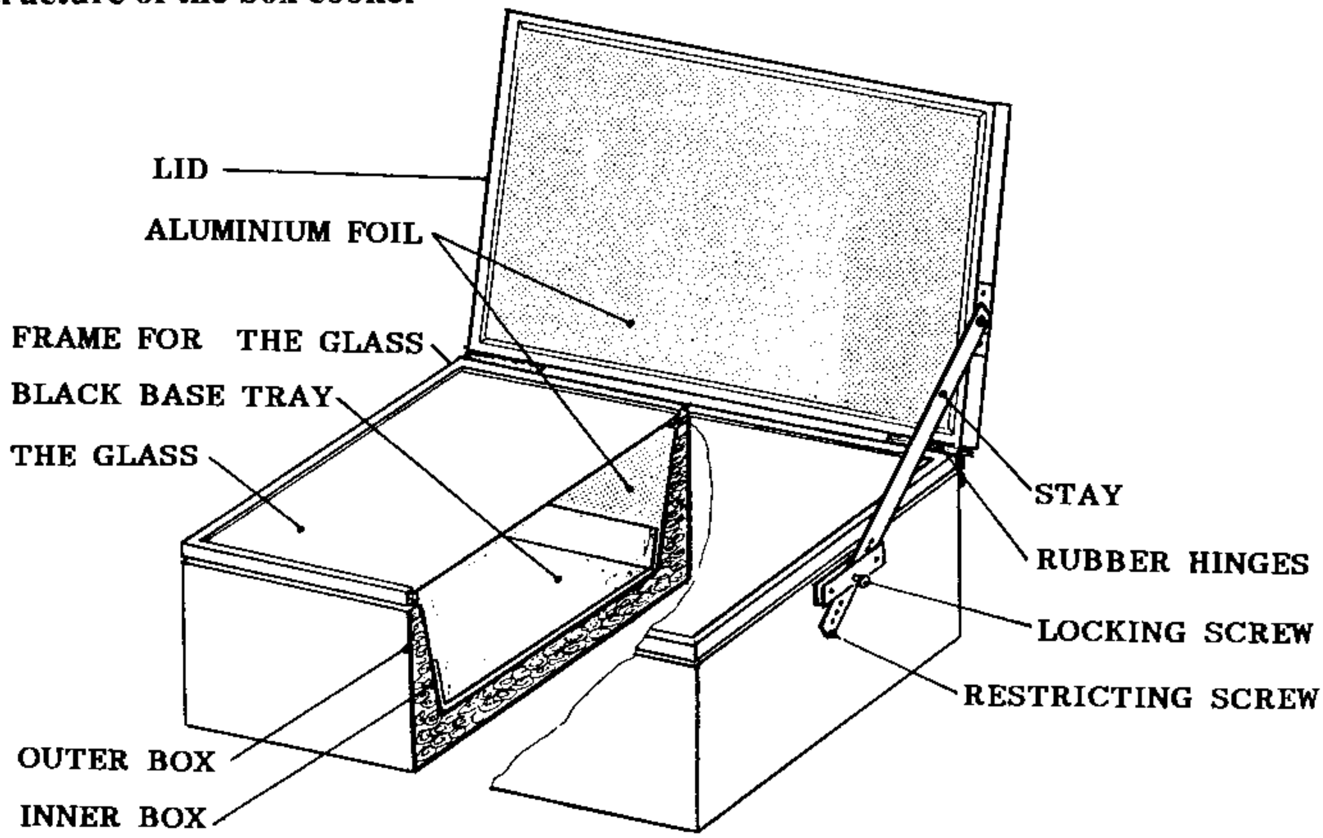
An oven thermometer helps you to see how it's doing; it will go to at least 200°F within an hour in bright light, and soon go higher.

6. Put in your food, relax, and wait for dinnertime!

Optional finishing touch : Apply self-stick plastic shelf paper to the outside of the box and to the back side of the reflector to give extra protection from sudden showers and create a finished look to your cooker. Or you can draw designs or messages on the outside. It's your chance to be creative with the original piece of art that you've now completed.

How to build a box cooker

Structure of the box cooker



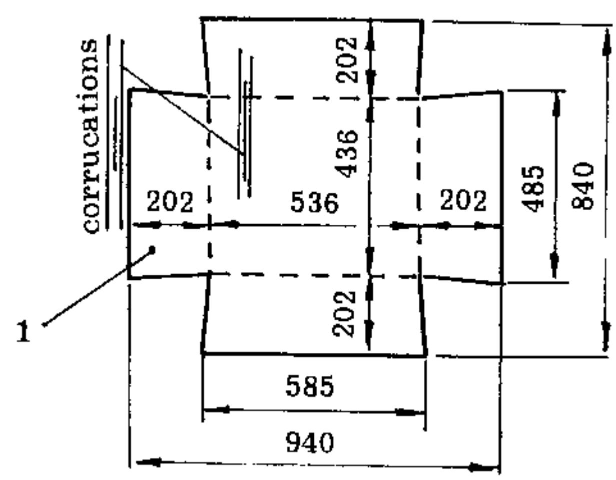
Inner box.

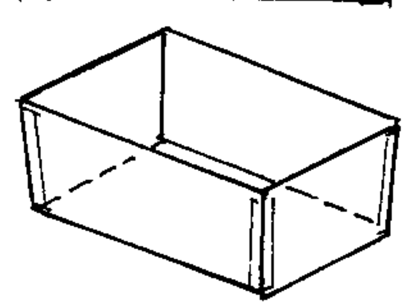
Following the diagram, measure, Draw and cut a model out of strong 7-8 mm thick 2-wave corrugated cardboard (1). You can also tape together smaller pieces.

Use a blunt tool and straight wooden bar for pressing the folds and bending the sides up.

Tape the corners together with foil tape or glue strips of aluminium foil on both sides.

Glue aluminium foil to the outside of the box. You can use smaller pieces to save material!



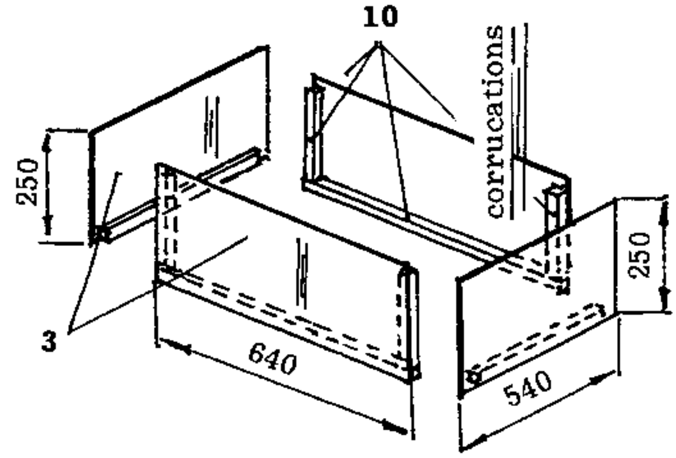


Side panels

Cut side panels (3) out of cardboard 2 x 250x540 mm + 2 x 250x640 mm (Or use pre-cut hardboard or plywood panels.) With cardboard, be sure that the corrugations are vertical!

If pre-cut battens (10) are not available, first cut boards into 20 x 20 mm battens; saw the battens into the following lengths: 2 x 640 mm + 2 x 500 mm + 4 x 204 mm.

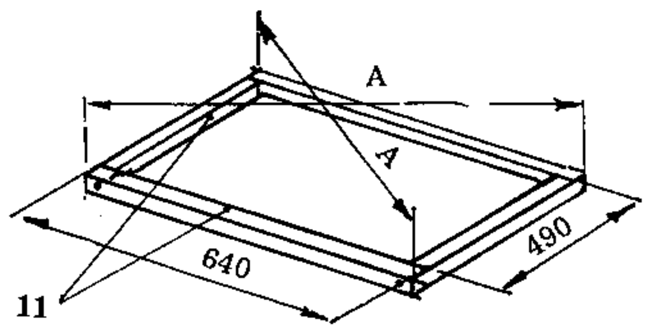
Glue the battens to the panels and press them together with clamps or tape.



Box Frame

Saw or use precut 25x25 mm battens (11), 2 x 640 and 2 x 490 mm length.

Screw the battens together on a jig or on the table.



Both cross-distances A must be exatly the same!

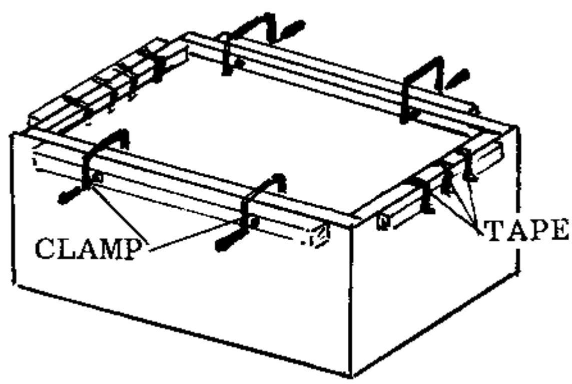
If they aren't, you must make them so by using a temporary batten nailed across the frame to keep it symmetrical during assembly.

Assembly of the box

If possible, use a jig on the table.

Put glue on the contact surfaces and then fasten the sides and frame together. Use clamps or tape for keeping the parts together.

Glue the foil to the inside.



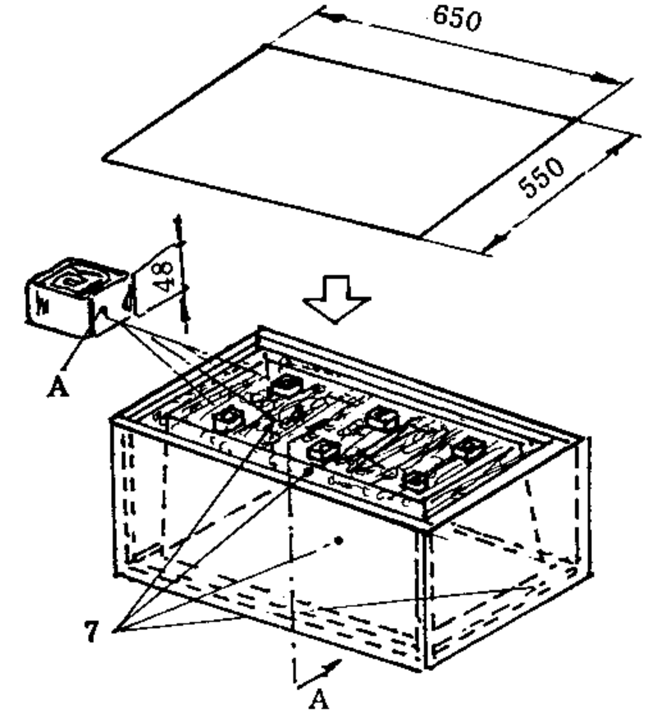
Then glue together the inner box and the outside box on the table with the bottom of the box upwards.

Insulate the space between the walls of the outer and inner boxes with newspaper rolls, dry straw, rice hulls etc.

Roll 6 supporting parts (A) about 48 mm tall (check the height!) out of cardboard and glue them to the bottom of the outside of the inner box.

Insulate the bottom space too. Glue the hardboard (or plywood) bottom plate (2) on and nail it in place.

Line at least the inside of the inner box with foil, bending it 20 mm. over the edges.

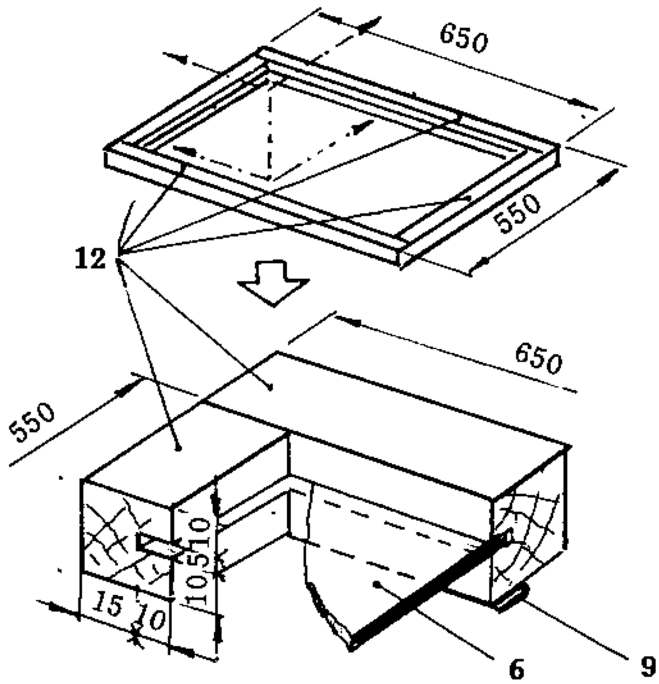


The glass cover

Cut 25x25 mm battens (12) (with a groove), 2 x 650 mm and 2 x 520 mm.

Place the glass (6) carefully in the groove, check the crossdistance and screw the corners together.

Glue the sealing silicone strip (9), 3-6 x 10 mm with silicone glue to the underside of the frame.

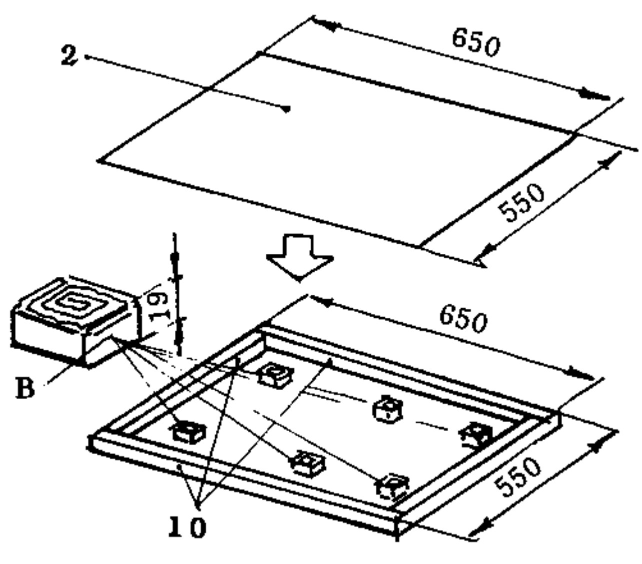


The lid.

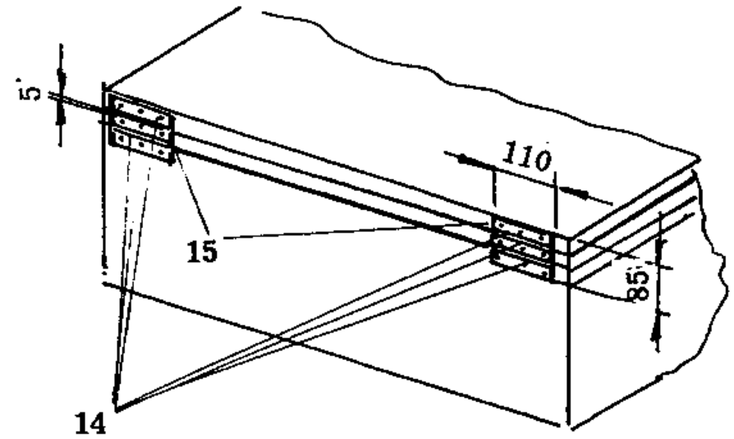
Take the 550x650 mm piece of hardboard (21) and glue 650 mm and 510 mm long 20x20 mm battens (10) on top of the board along its edges.

Make 6 supporting rolls (B) out of 19 mm wide strips of cardboard (about 500 mm long), and fasten them with glue and tape onto the hardboard (or plywood).

Glue a 650 x 550mm inner cardboard onto the battens and supporting rolls of the hardboard, pressing them together against a straight surface. Then line the cardboard side with aluminium foil and tape the edges.



Hinges.



Put the glass frame and the lid in their place precisely over the box and temporarily tape them together in a few places.

To fasten, drill (first the middle bar) with a 2 mm drill bit and use 30 mm screws (19) to attach the 1x25x110 mm bars (14a) over the rubber plates (15). Leave a 5 mm space between the bars.

Stay (to hold up the lid in the desired position).

Cut the stay bar (14a) out of 1 mm thick steel to a length of 375 mm and a width of 50 mm, fold it over lengthwise 90 degrees and then press it flat (or hammer between two battens), so that it forms a 25 mm wide length.

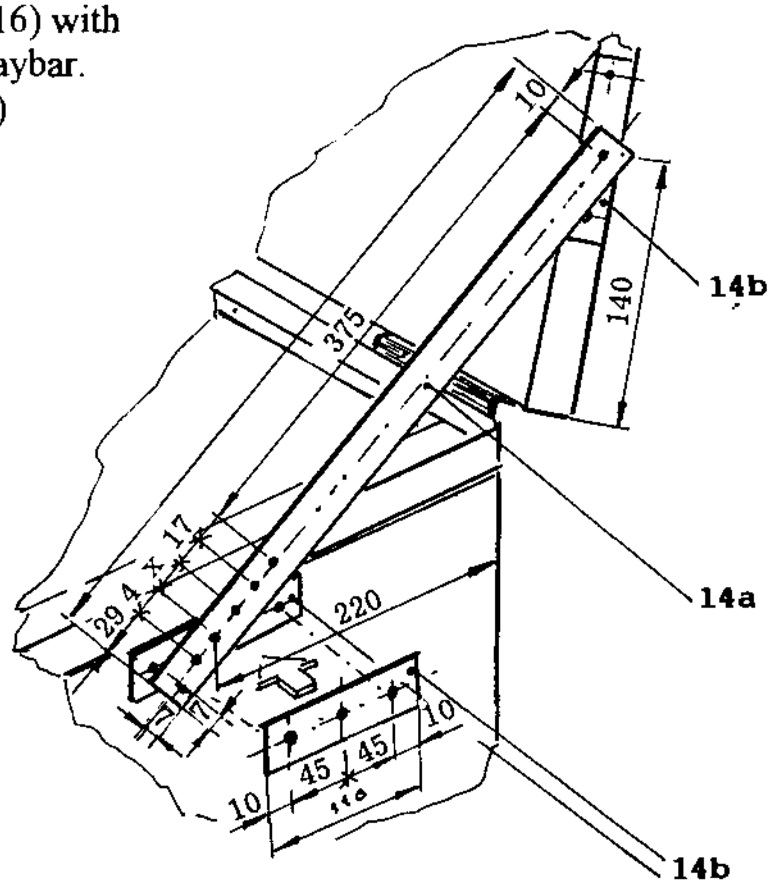
Fold and press another 9 bars (14b) out of a 1x50x110 piece for fastening the stay bar and hinges.

Drill 5 mm holes as in the diagram.

Install the restricting screw (16) with a nut in the bottom end of the staybar. Then fasten the hinge screw (16) for the stay on the 110 mm bar and screw it onto the side of the lid as in the diagram. Secure it with glue.

Install the bars (14b) on the side of the box with 3-4 washers (18) between the bars.

Drill a hole 5 mm for the locking screw (17) (cotter pin) and fasten it with a rope to prevent it from getting lost.



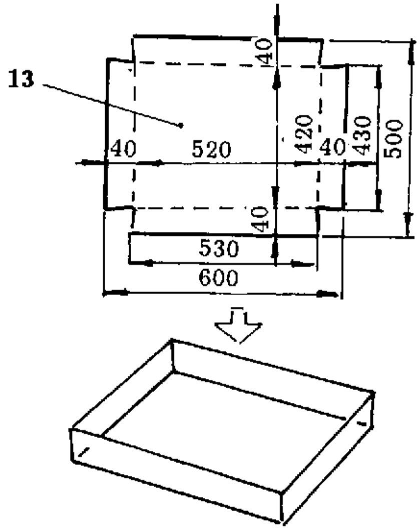
Black base tray.

The tray (13) is necessary for the proper functioning of the cooker and makes the cooking space durable.

Any metallic material is possible, **but the surface absolutely must be painted black!**

If a suitable tray is not available, cut and bend one out of a 1 mm plate as in the diagram.

You can leave some space under the tray for an extra layer of thin insulation.

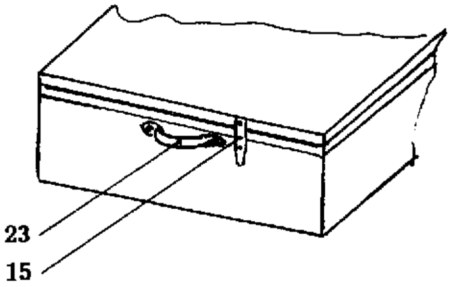


Finishing.

Install a handle (23) for carrying the box and make a rubber latch for keeping it closed during transportation.

Paint the box well to protect it against moisture and insects, and paint the bottom twice.

A good way to prevent insects from eating the box is to install an extra strong aluminium foil outside the bottom of the cooker!



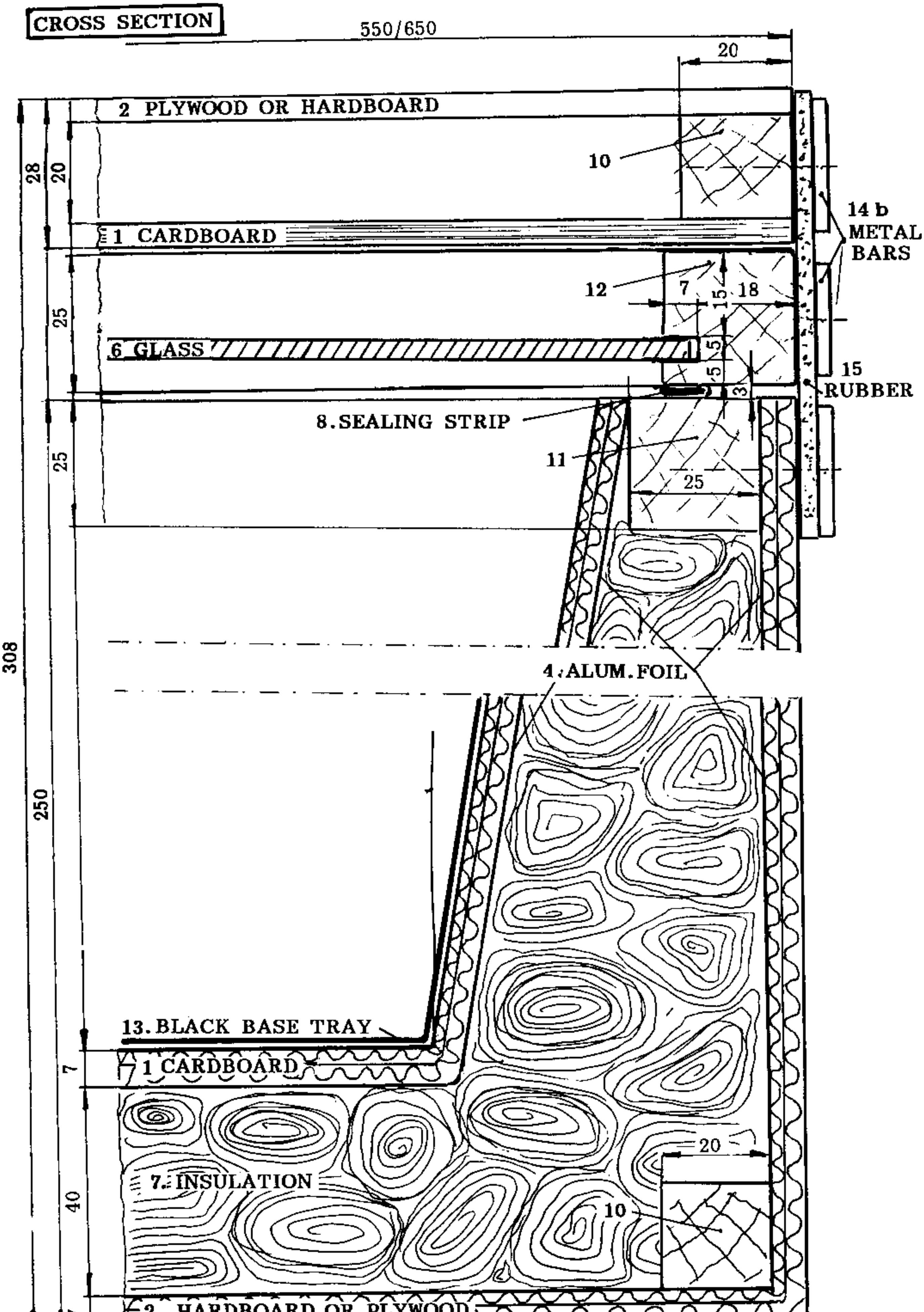
Tools necessary for building the cooker

1. Pencil or crayon
2. Scissors
3. Knife or special knife for carpet cutting
4. Metric measure
5. Ruler, of metal or wood
6. Brush or spatula (homemade cardboard) for spreading glue
7. Screwdriver
8. Drill + drill bits 2 and 5 mm
9. Saw
10. Some clamps for pressing

THERE ARE HUNDREDS OF WAYS OF BUILDING SOLAR COOKERS; FEEL FREE TO IMPROVE UPON OUR DESIGNS!

Materials for the box cooker:

Material	Measures	Amount	Estimated Price in $US
1. Cardboard 6-7 mm			
	840x940 mm, (or used)	1	-
	650x550 mm, (or used)	1	-
2. Hardboard 3 mm,	650x550 mm,	2	2.00
3. Side panels, cardboard or hardboard			
(or used)	250x540 mm	2	1.00
	250x640 mm	2	1.00
4. Aluminium foil		2.0 m2	4.00
5. Glue, water based whiteglue		0.7 liter	5.00
6. Glass, 4 x 510 x 610 mm, (or used)		1	6.00
7. Paper for insulation, used			
8. Padding tape 3-6 x 10 mm, **silicone**		2.2 m	1.00
9. Silicone glue, some			
10. Wooden battens 20x20 mm			
length	640 mm	2	0.60
	500 mm	2	0.50
	204 mm	4	0.50
	650 mm	2	0.60
	510 mm	2	0.50
11. Wooden battens 25x25 mm			
length	640 mm	2	0.70
	490 mm	2	0.60
12. Wooden battens 25x25 mm, with grooves			
length	650 mm	2	1.20
	520 mm	2	1.00
13. Base tray 1 mm steel 500x600 mm		1	2.40
14. Metal bars, 1 mm steel			
25x375 mm (from 50x375 mm)		1	0.30
25x110 mm (from 50x110 mm)		9	0.70
15. Rubber for hinges 4 x 85 x 110 mm		2	0.20
16. Screw	5 x 12-15 mm	2	0.10
17. Locking screw	5 x 40-50 mm	1	0.10
18. Washers 4 mm		15	0.20
19. Screws	3.5 x 30 mm	25	1.00
20. Nails, length	20 mm	25	0.20
21. Tape with foil		5 m	1.00
22. Tape, paper		10 m	0.40
23. Ribbon, for carrying the box		1	0.20
24. Paint, black for base tray		0.1 liter	1.00
25. Paint, for outside use		0.2 liter	2.00
Total			**$ 36.00**

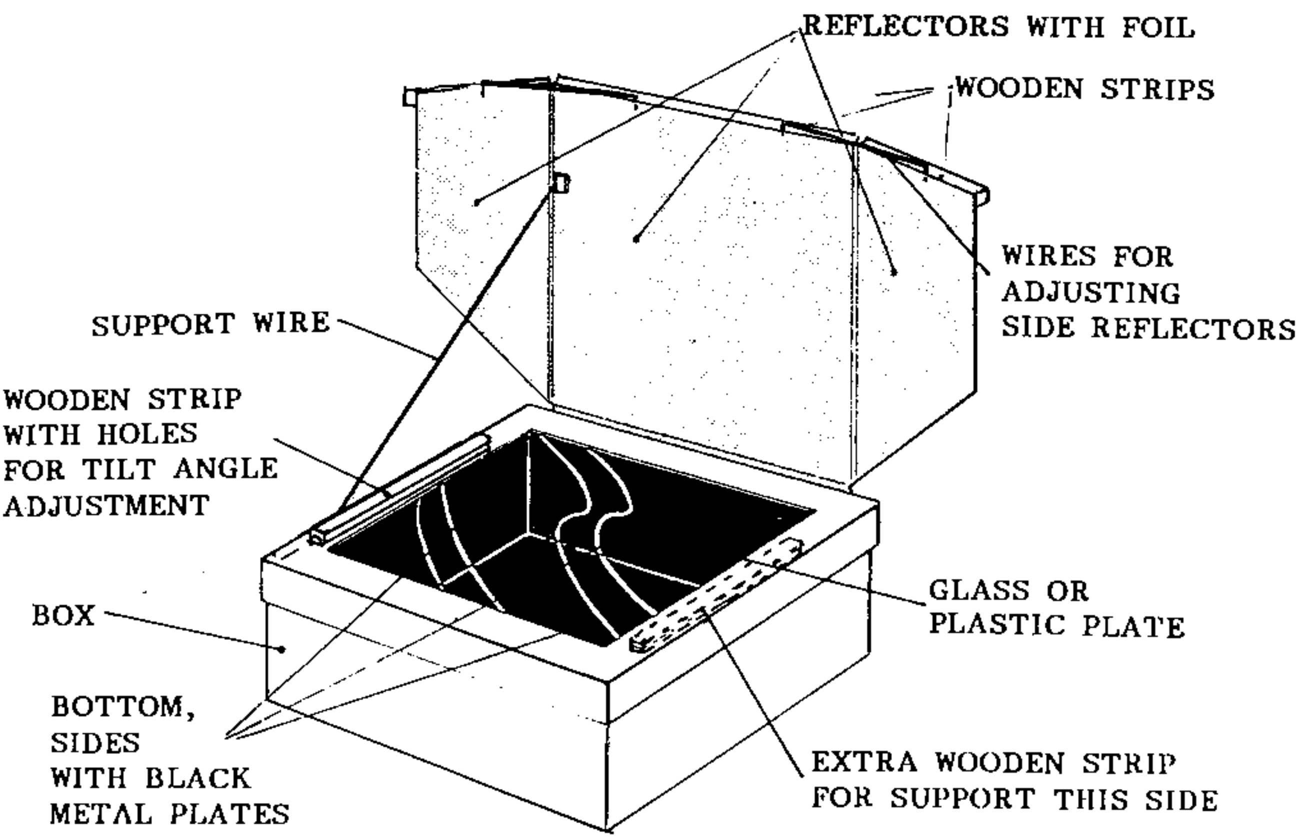

CROSS SECTION
550/650
20
2 PLYWOOD OR HARDBOARD
10
28
20
1 CARDBOARD
14 b
METAL
BARS
12
7
15
18
25
6 GLASS
5
5
3
15
RUBBER
8. SEALING STRIP
11
25
25
4. ALUM. FOIL
308
250
13. BLACK BASE TRAY
1 CARDBOARD
7
7. INSULATION
20
10
40
2. HARDBOARD OR PLYWOOD
7

Box cooker - 2

Suitability:	Areas with over 1000 W /m2 radiation For relatively short-term use. Good for refugee camps
Manufacture:	Needs craftmanship and guidance at the beginning Final composition is quite simple
Qualities:	Cheap to transport parts separately at a small package Weight only about 2 kg. Materials cost about 20 US-dollars

General

Box cooker - 2 can be delivered in parts. Final assembly can be done at the place of use.



1. Basic box

These drawings are for 3 mm thick cardboard.

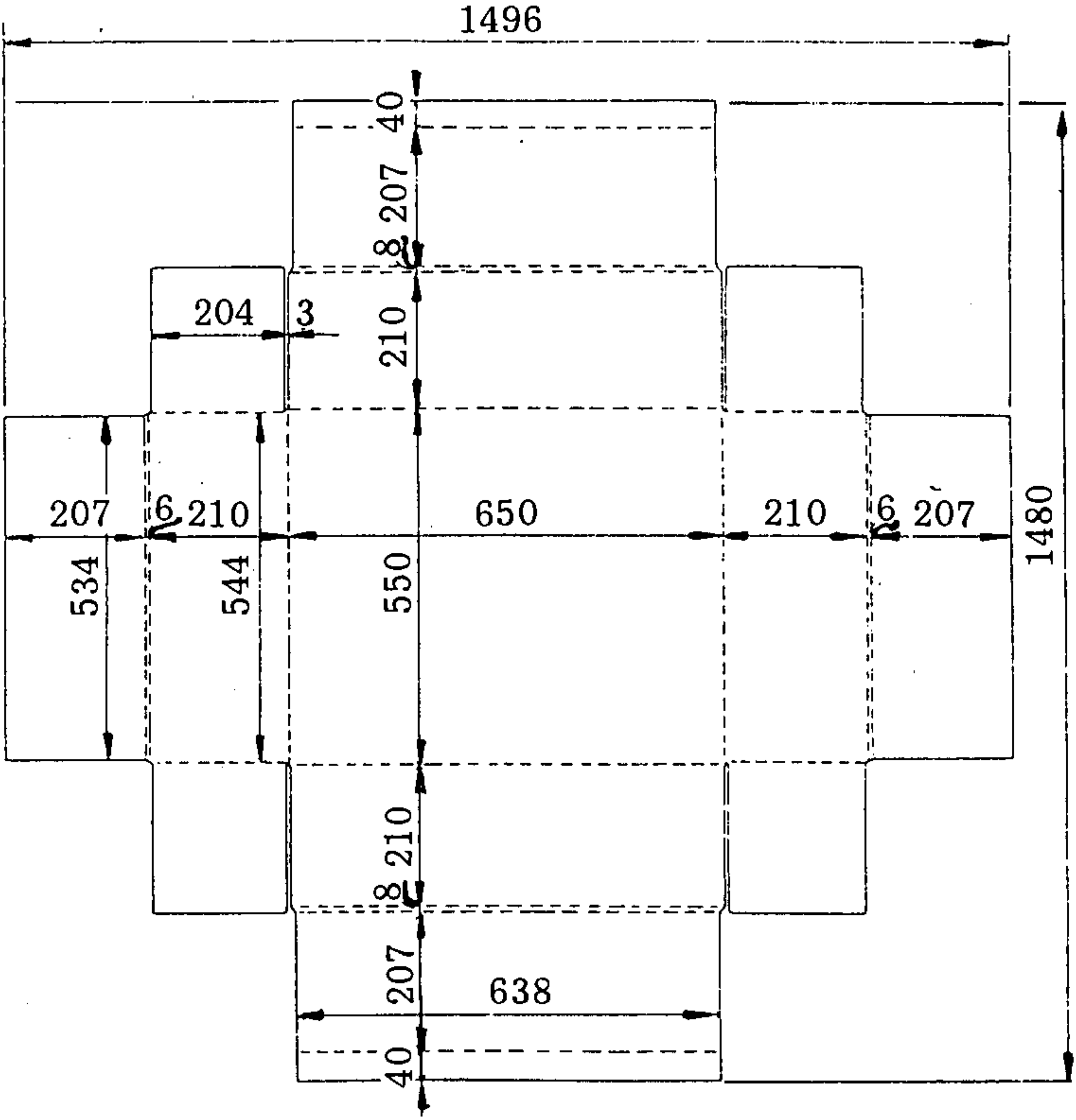
Mark the bending points to the models with small holes (for example)

Make the bending folds with a blunt instrument and bend the cardboard

Manufacturing of the parts

If you construct more than one cooker it is advisable to make templates using e.g. fibreboard or plywood.

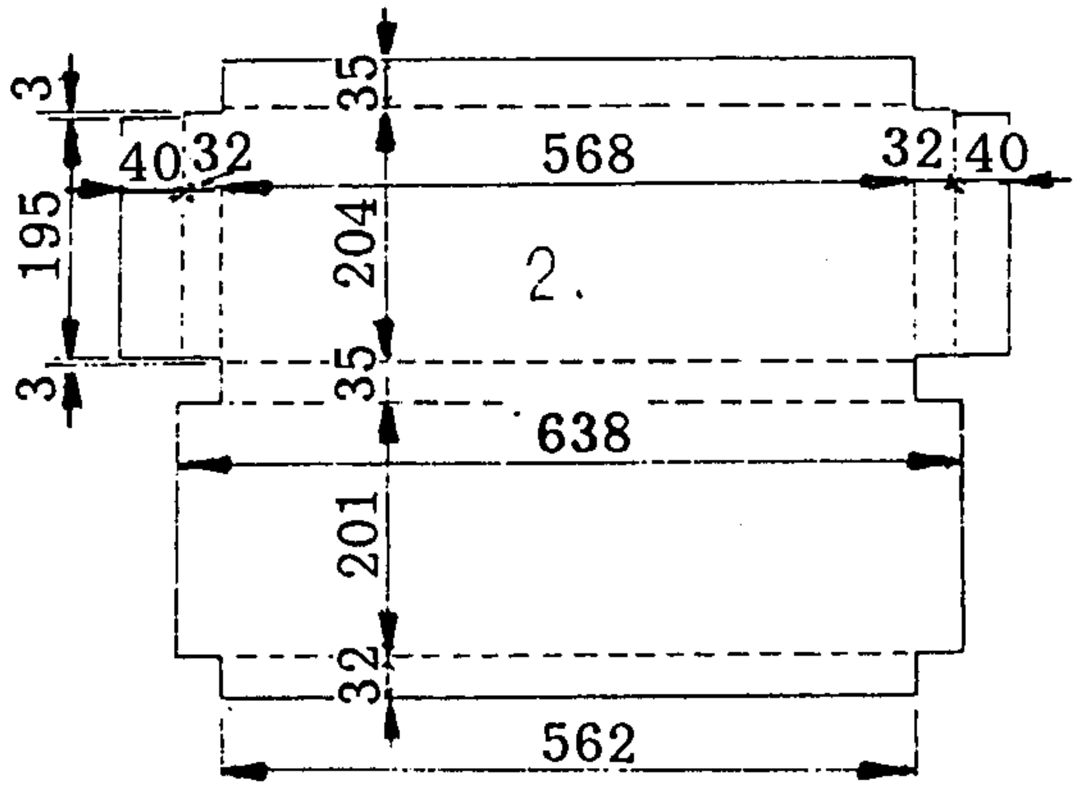
You can order the cardboards by measures from factory, if series are big enough

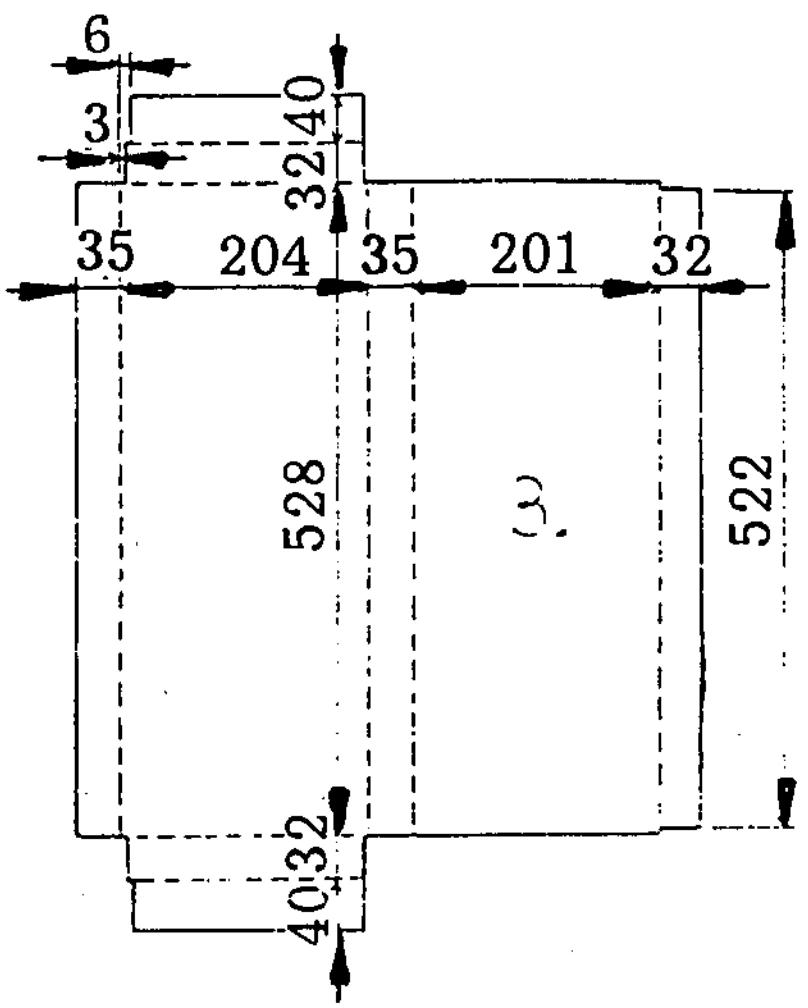


2. - 3. Side parts

Make 2 pieces of both.

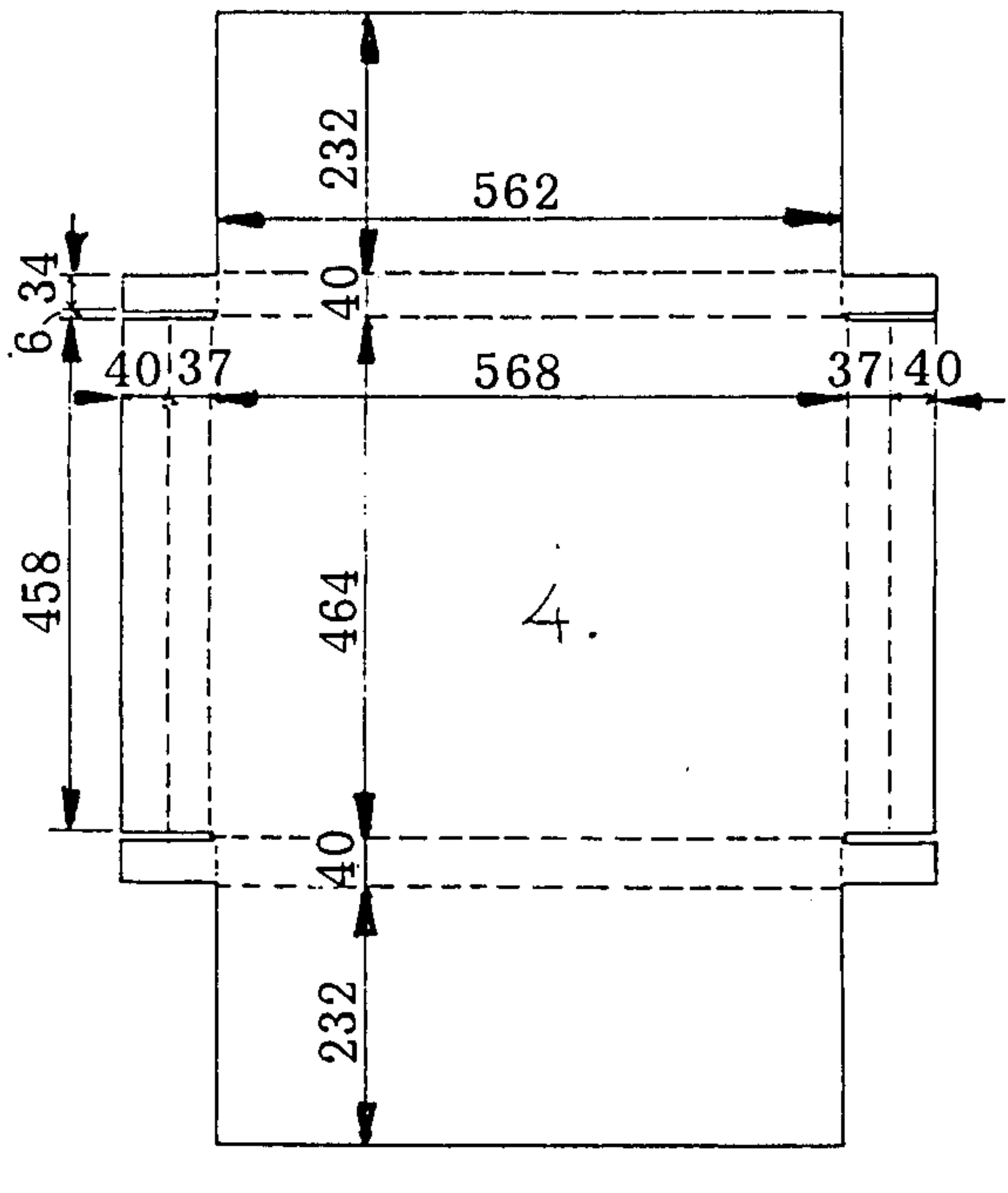
Insulate side parts with newspaper, wood chips, dry grass or dry moss (for example).





4. Bottom

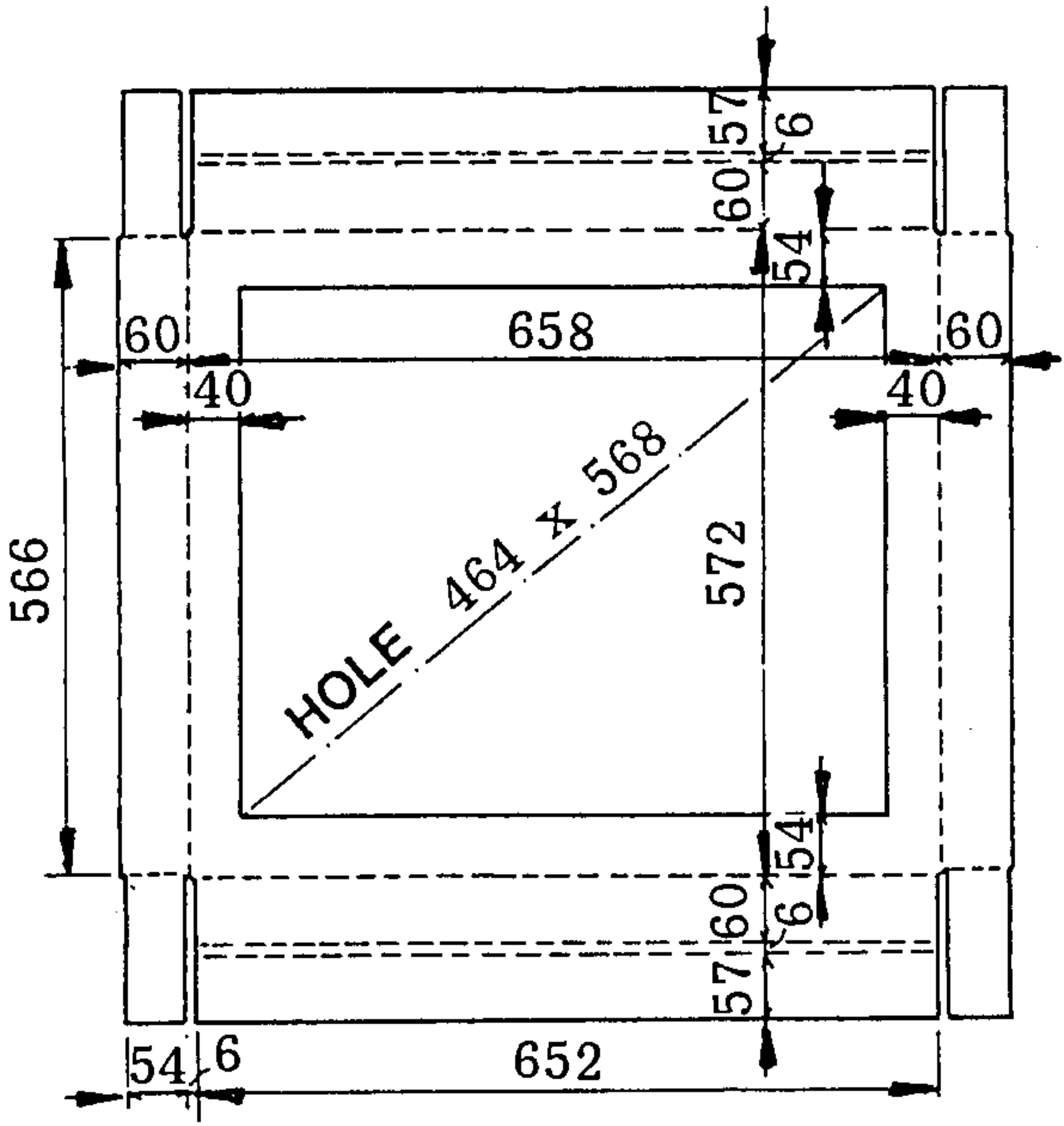
Insulate the bottom the same way as you did the sides.



5. Lid

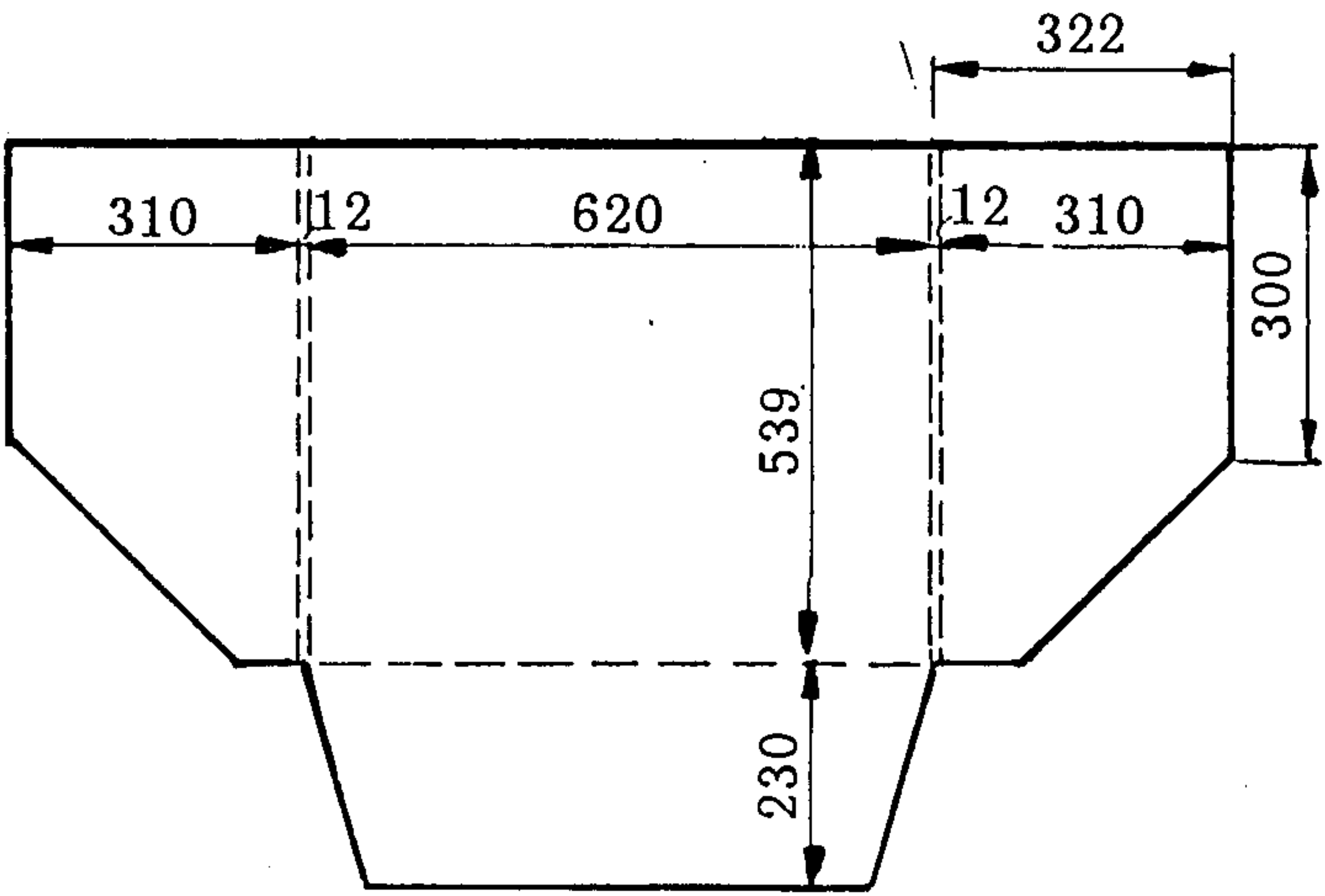
Glue bright 1 mm thick plastic (polyester) films to the both sides of the lid.

Glue wooden battens 6 x 15 x 200 mm to the edges.

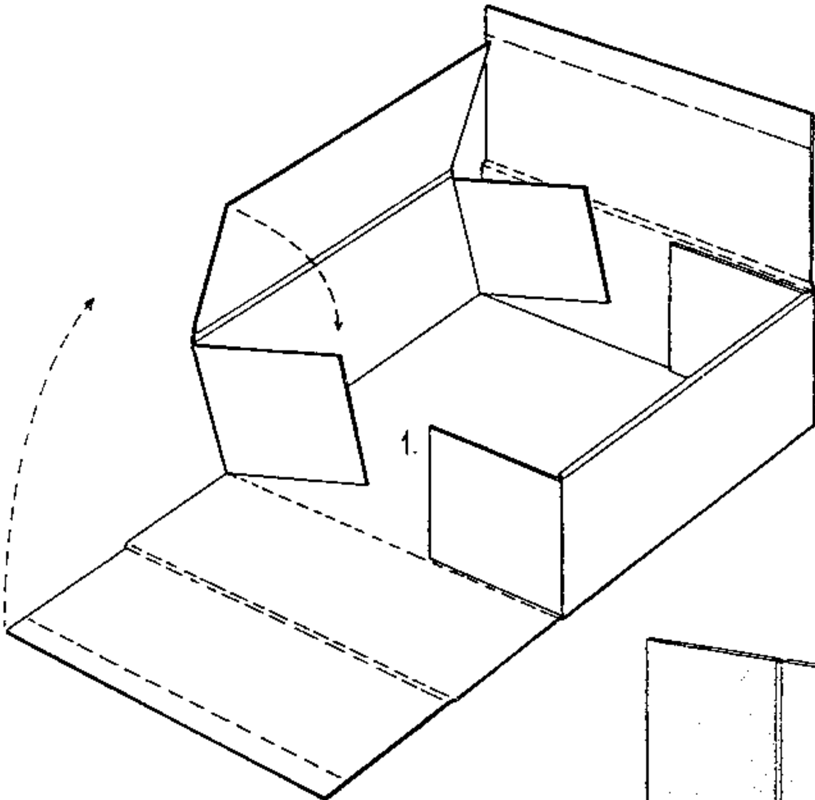


6. Reflector

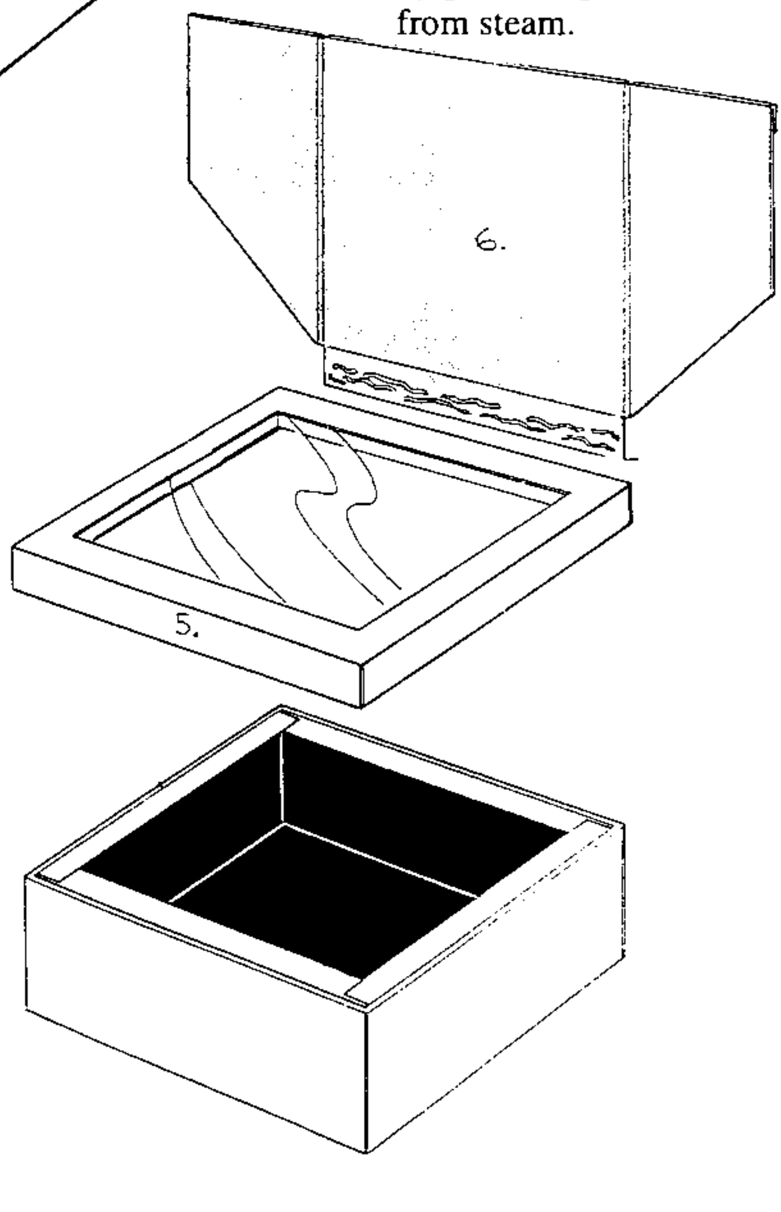
Glue aluminium foil to the inner side. Glue 6 x 15 mm battens to the upper edge of the outer side. Put small pieces of wood to the outer side of the reflector for supporting rod.



Composition



Fold the basic box as shown in the picture, add folded side insulator boxes and the bottom insulator box. Glue or tape is not needed here because the pieces support each other. Paint the inside of the cooker with a black heat-resistant paint. The paint is not obligatory but it raises the inside temperature by a few degrees and increases the lifetime of the cooker by protecting the cardboard from steam.



Glue the reflector from its lower side to the back edge of the lid. Stick the support on.

Add a black metal plate at the bottom (566 x 462 x 1-2 mm).

It is advisable to paint the box from outside (with a dark colour) to protect the box against humidity

Drum cooker - 1

Suitability: Equator area +/- 10 degrees

Also for relatively big families

Manufacture: Suitable for do-it yourself construction

Needs a little bit of craftmanship

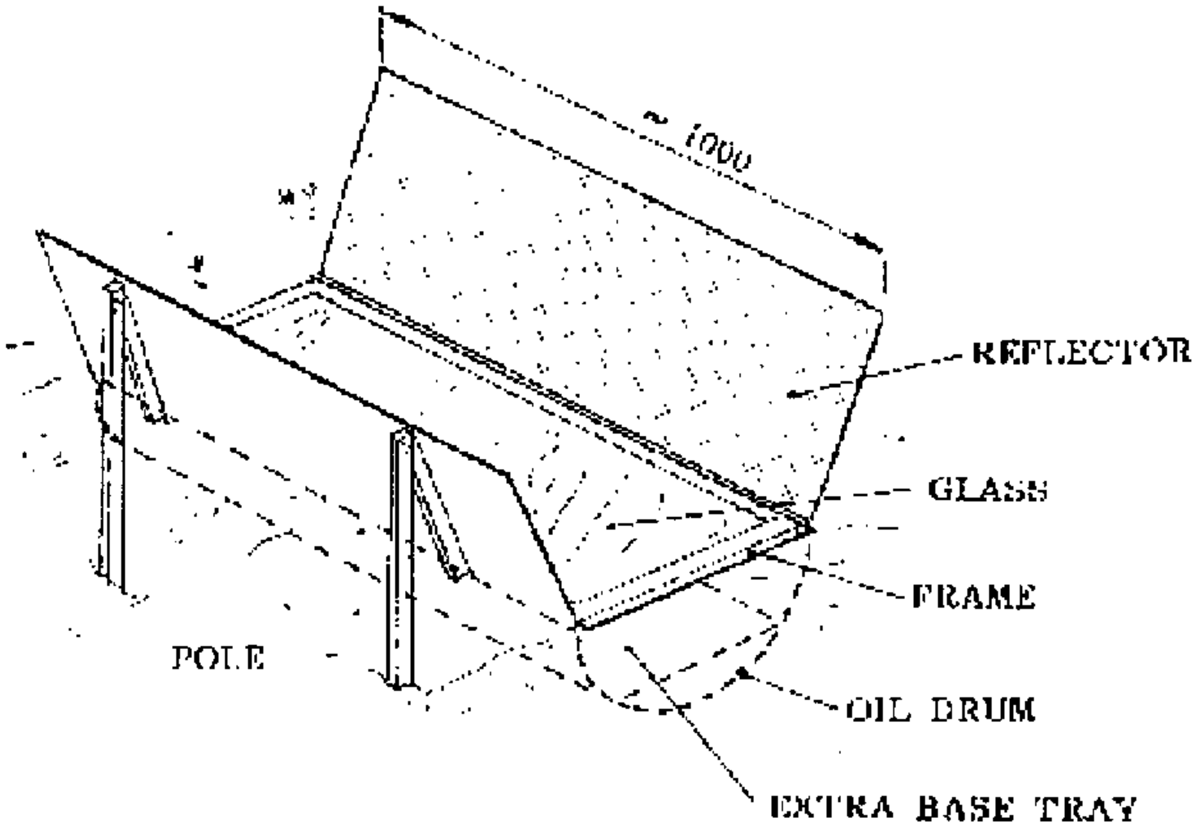
Qualities: Operates very well in equatorial regions

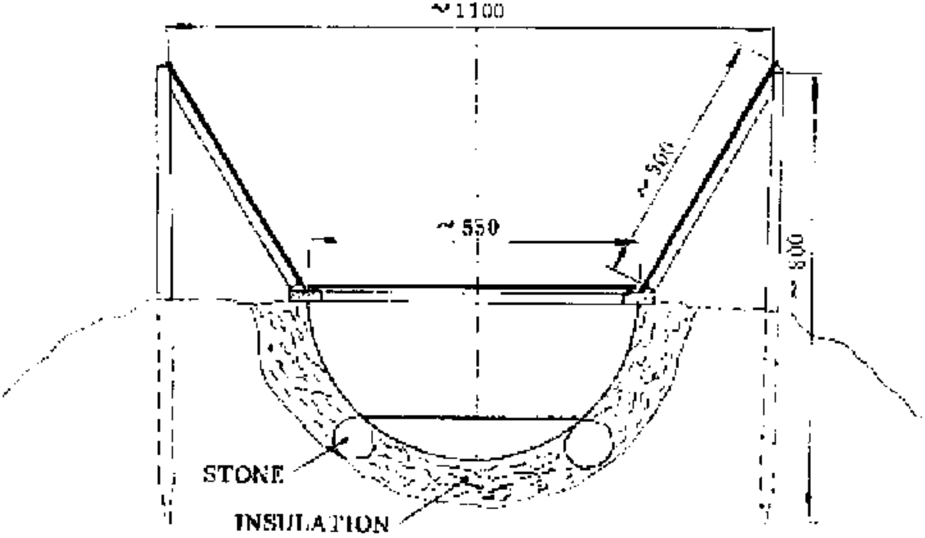
Measures: 600 x 1000 mm. Volume 150 l

Materials cost about 20 US-dollars

Needs a protecting plate for rains

(Drum cooker - 1 is fixed)


~ 1000
REFLECTOR
GLASS
FRAME
POLE
OIL DRUM
EXTRA BASE TRAY

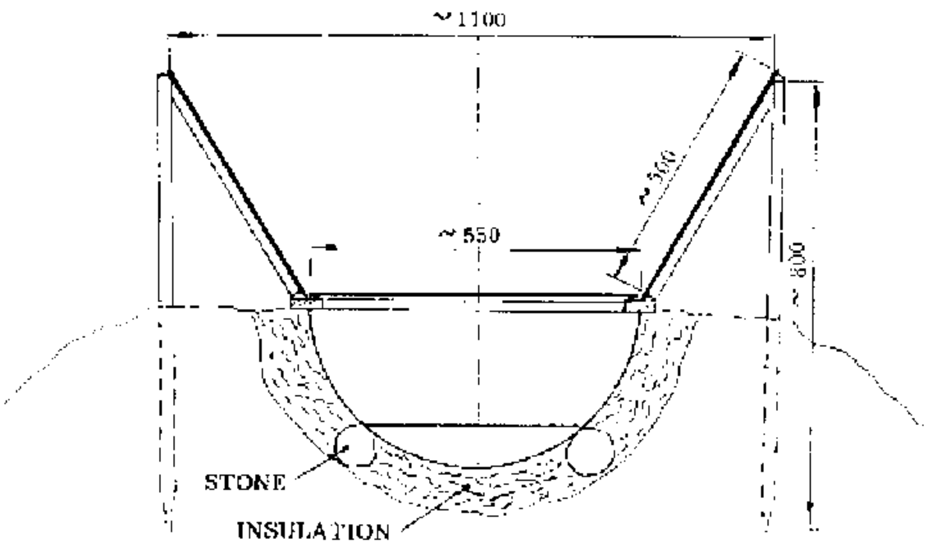

~1100
~500
~550
~800
STONE
INSULATION

Installation of the cooker

Place the cooker in an open field, so that trees does not obscure the sun's rays. IMPORTANT: Place the long sides in an East-West direction.

Make it, it's easy:

Split an oil drum so that you get material for two cookers. (If you do not have the oil drum, you can use plywood or iron sheets for the sides of the box!). Hit a hole in the bottom of the drum as a rain outlet and paint the inside of the drum black. Make a place in the soil for the drum, and leave a space of about 15-20 cm for insulation.



Put four stones, about 15 cm in diameter, on the ground as support for half of the oil drum. Then insulate the sides with dry hay or grass. Make a roof for insulation, cover it from the rain with hardwood boards or corrugated iron sheets. Make a frame of wood and nail it to the half-drum. Use plywood, hardboard or iron sheets for the side reflectors.

Install the reflectors so that there is about a 30-degree angle between the sun's rays and the reflecting surface. The recommended mirror size, in two pieces, is about 1 x 0.5 meter. The material can be aluminium foil, bright aluminium or used mirror pieces. Do not forget to keep the surfaces clean!

Make the glass lid of thick glass with finished edges. If not available, use ordinary window panes; but make a frame for them. Ensure that the lid fits tightly on the cooker. Do not leave gaps between the frame and the lid; make a seal if necessary. NOTE! Leaving your cooking pot inside the cooker for the night may not be wise because of "wadudu"; ants and insects. When the sun is shining, there will certainly be no such problem, because the heat kills everything inside the cooker. It is advisable to have a flat protecting plate over the cooker at nights and rainy weather.

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FAX 916-455-4498. Tel. 916-455-4499.
email: sbci@igc. apc.org.

23: Different designs downloaded from Internet. - www.accessone.com

The "Minimum" Solar Box Cooker

A great solar oven you can build quickly from two cardboard boxes

Experiments in Seattle and Arizona have proven that solar box cookers can be built more simply than even the simple method we have been using. These discoveries have paved the way for a simpler construction method that allows a cooker to be built in a few hours for very little money.

The following developments make this design possible:

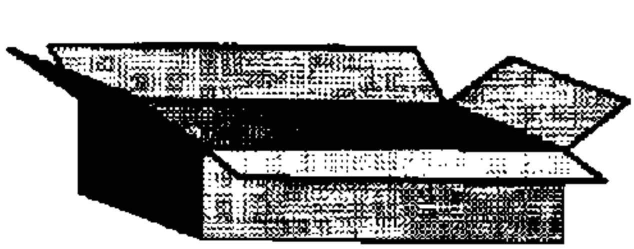
- Insulation material is not essential in the walls -- a foiled airspace is all that is necessary.
- Aluminum foil can be reduced to just one layer (though a layer on the inside of each box makes a hotter oven).
- The airspace between the walls can be very small.
- Almost any size oven will cook. In general, larger ovens get hotter and can cook more food, but the limiting factor is still the ratio between the mass of the food and the size of the oven. In general it is best to make an oven as large as is conveniently possible so that it will perform adequately even under marginal conditions.
- Our experience shows that a double layer of plastic film (such as Reynolds Oven Cooking Bags®) works at least as well as a single sheet of glass.
- Shallower ovens cook better since they have less wall area through which to lose heat. It's best for the inside of the oven to be just slightly taller than the biggest pot you plan to use.

A New Simpler Design

Taking these factors into account, we are able to take our best shot at describing the minimum solar box cooker -- one that can be built by anyone with access to cardboard, foil, glue, and plastic or glass.

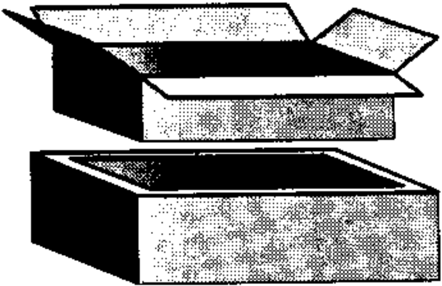
What You Will Need

- Two cardboard boxes. Almost any size will work. The proportion between the two boxes is not critical. We would suggest that you use an inner box that is at least 15" x 15" (38cm x 38cm), but bigger is better. The outer box should be larger all around, but it doesn't matter how much bigger, as long as there is a half inch (1.5cm) or more of an airspace between the two boxes. Also note that the distance between the two boxes does not have to be equal all the way around.
- One sheet of cardboard to make the lid. This piece must be approximately 3" (7.5cm) larger all the way around than the top of the finished cooker.
- One small roll of aluminum foil.
- One can of flat-black spray paint (says on can "non-toxic when dry") or one small jar of black tempera paint.
- At least 8 ounces of white glue or wheatpaste.
- One sheet of glass or one Reynolds Oven Cooking Bag®. These are available in almost all supermarkets in the U.S. and they can be mail ordered from Solar Cookers International. They are rated for 400° F (204.4° C) so they are perfect for solar cooking. They are not UV resistant; thus they will become more brittle and opaque over time and may need to be replaced periodically.



Building the Base

Fold the top flaps closed on the outer box and set the inner box on top and trace a line around it onto the top of the outer box. Remove the inner box and cut along this line to form a hole in the top of the outer box



to form a hole in the top of the outer box (Figure 1).

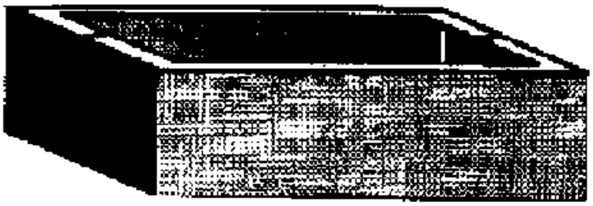


Figure 1

Decide how deep you want your oven to be (about 1" or 2.5cm bigger than your largest pot and at least 1" shorter than the outer box) and slit the corners of the inner box down to that height. Fold each side down forming extended flaps (Figure 2). Folding is smoother if you first draw a firm line from the end of one cut to the other where the folds are to go.

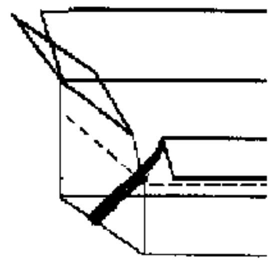


Figure 2

Glue foil to the inside of both boxes and also to the inside of the remaining top flaps of the outer box. Don't waste your time being neat on the outer box, since it will never be seen, nor will it experience any wear. The inner box will be visible even after assembly, so if it matters to you, you might want to take more time here. Glue the top flaps closed on the outer box.

Figure 3

Place some wads of crumpled newspaper into the outer box so that when you set the inner box down inside the hole in the outer box, the flaps on the inner box just touch the top of the outer box (Figure 3). Glue these flaps onto the top of the outer box. Trim the excess flap length to be even with the perimeter of the outer box. The base is now finished.

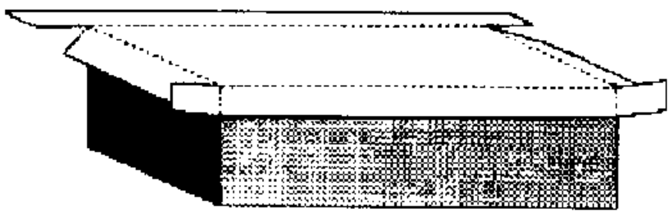


Figure 4

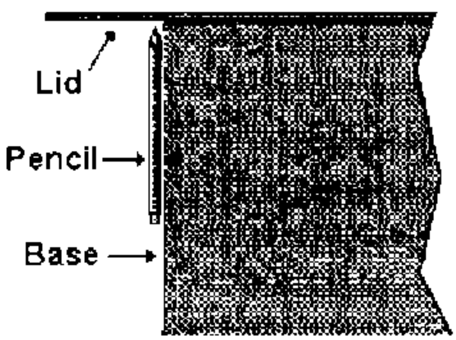


Figure 5

Building the Removable Lid

Take the large sheet of cardboard and lay it on top of the base. Trace its outline and then cut and fold down the edges to form a lip of about 3" (7.5cm). Fold the corner flaps around and glue to the side lid flaps. (Figure 4). Orient the corrugations so that they go from left to right as you face the oven so that later the prop may be inserted into the corrugations (Figure 6). One trick you can use to make the lid fit well is to lay the pencil or pen against the side of the box when marking (Figure 5).

To make the reflector flap, draw a line on the lid, forming a rectangle the same size as the oven opening. Cut around three sides and fold the resulting flap up forming the reflector (Figure 6). Foil this flap on the inside.

To make a prop bend a 12" (30cm) piece of hanger wire as indicated in Figure 6. This can then be inserted into the corrugations as shown.

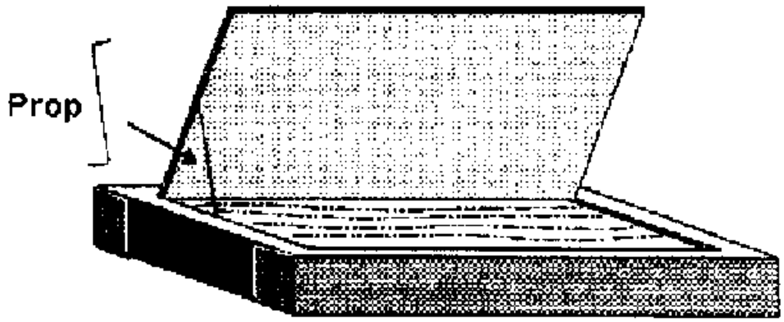
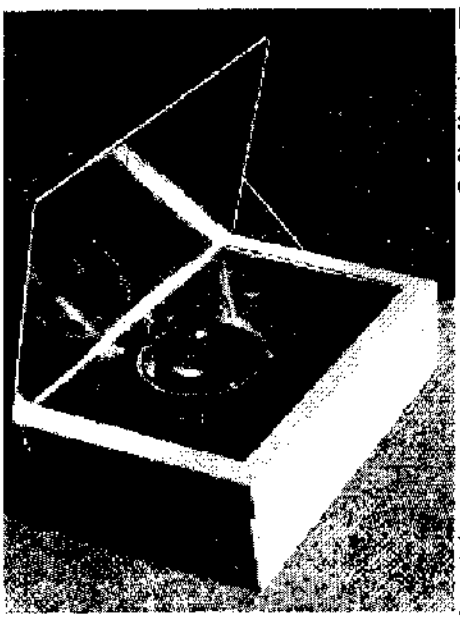


Figure 6

Next, turn the lid upside-down and glue the oven bag (or other glazing material) in place. We have had great success using the turkey size oven bag (19" x 23 1/2", 47.5cm x 58.5cm) applied as is, i.e., without opening it up. This makes a double layer of plastic. The two layers tend to separate from each other to form an airspace as the oven cooks. When using this method, it is important to also glue the bag closed on its open end. This stops water vapor from entering the bag and condensing. Alternately you can cut any size oven bag open to form a flat sheet large enough to cover the oven opening.

Finally, to make the drip pan, cut a piece of cardboard, the same size as the bottom of the interior of the oven and apply foil to one side. Paint this foiled side black and allow it to dry. Put this in the oven (black side up) and place your pots on it when cooking.



Improving Efficiency

The oven you have built should cook fine during most of the solar season. If you would like to improve the efficiency to be able to cook on more marginal days, you can modify your oven in any or all of the following ways:

- Make pieces of foiled cardboard the same size as the oven sides and place these in the wall spaces.
- Make a new reflector the size of the entire lid (see photo).
- Make the drip pan using sheet metal, such as aluminum flashing. Paint this black and elevate this off the bottom of the oven slightly with small cardboard strips.
-

For more information contact:

Solar Cookers International

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The "Easy Lid" Cooker

Designed by Chao Tan and Tom Sponheim

Although designs for cardboard cookers have gotten simpler, fitting a lid can still be difficult and time consuming. In this version, a lid is formed automatically from the outer box.

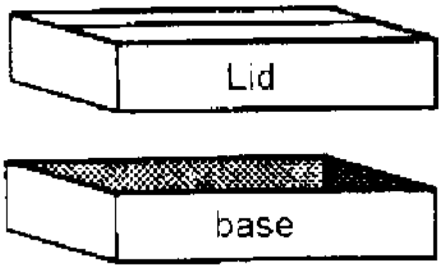


Figure 1

Making the Base

1. Take a large box and cut it in half as shown in Figure 1. Set one half aside to be used for the lid. The other half becomes the base.

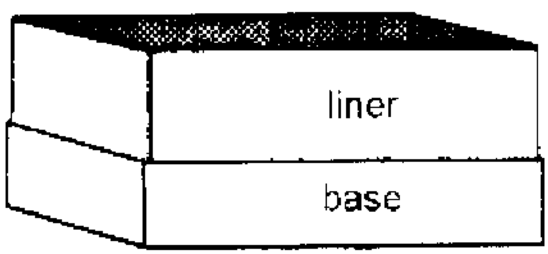


Figure 2

2. Fold an extra cardboard piece so that it forms a liner around the inside of the base (see Figure 2).

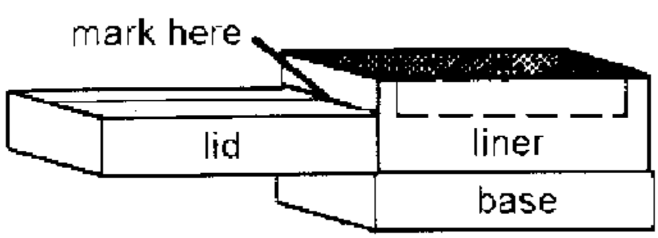


Figure 3

3. Use the lid piece as shown in Figure 3 to mark a line around the liner.

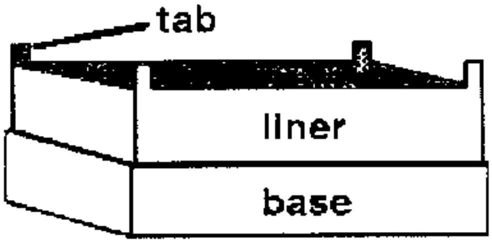


Figure 4

4. Cut along this line, leaving the four tabs as shown in Figure 4.
5. Glue aluminum foil to the inside of the liner and to the bottom of the outer box inside.

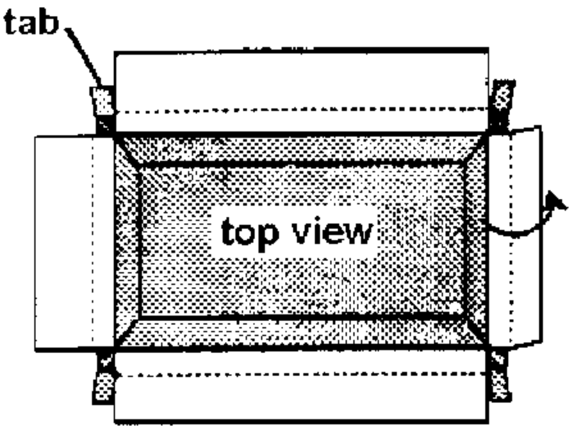


Figure 5

6. Set a smaller (inner) box into the opening formed by the liner until the flaps of the smaller box are horizontal and flush with the top of the liner (see Figure 5). Place some wads of newspaper between the two boxes for support.
7. Mark the underside of the flaps of the smaller box using the liner as a guide.

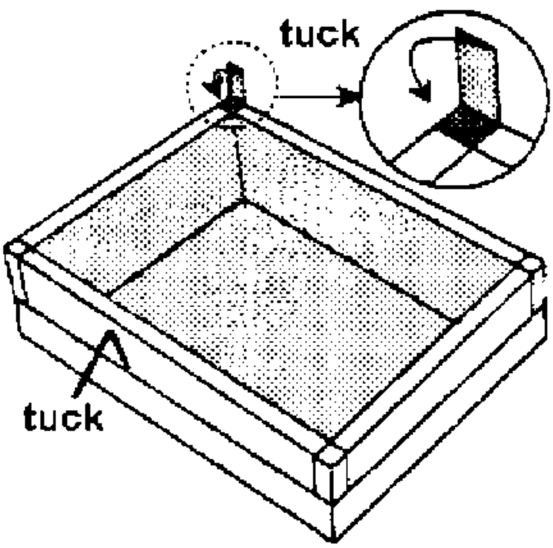


Figure 6

8. Fold these flaps down to fit down around the top of the liner and tuck them into the space between the base and the liner (see Figure 6).

9. Fold the tabs over and tuck them under the flaps of the inner box so that they obstruct the holes in the four corners (see Figure 6).
10. Now glue these pieces together in their present configuration.
11. As the glue is drying, line the inside of the inner box with aluminum foil.

Finishing the Lid

1. Measure the width of the walls of the base and use these measurements to calculate where to make the cuts that form the reflector in Figure 7. Only cut on three sides. The reflector is folded up using the fourth side as a hinge.
2. Glue plastic or glass in place on the underside of the lid. If you are using glass, sandwich the glass using extra strips of cardboard. Allow to dry.

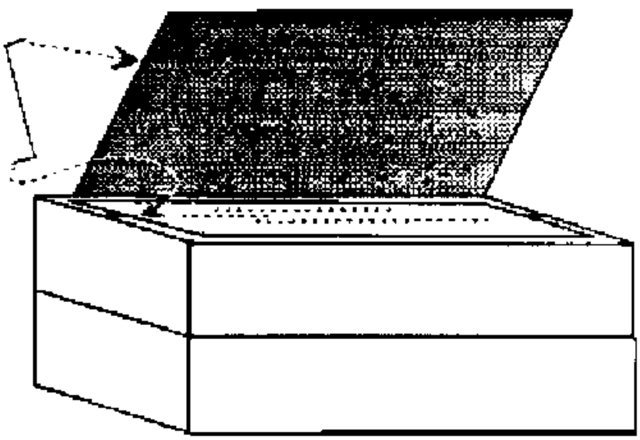


Figure 7

3. Bend the ends of the wire as shown in Figure 7 and insert these into the corrugations on the lid and on the reflector to prop open the latter.
4. Paint the sheet metal (or cardboard) piece black and place it into the inside of the oven.

Improving Efficiency

1. Glue thin strips of cardboard underneath the sheet metal (or cardboard) piece to elevate it off of the bottom of the oven slightly.
2. Cut off the reflector and replace it with one that is as large as (or larger than) the entire lid. This reflects light into the oven more reliably.
3. Turn the oven over and open the bottom flaps. Place one foiled cardboard panel into each airspace to divide each into two spaces. The foiled side should face the center of the oven.

For more information contact

Solar Box Cookers Northwest
7036 18th Ave. NE
Seattle, WA 98115

or email: sbcn@accessone.com

Make A Pizza Box Solar Oven

This solar oven is adapted from a design created in 1976 by Barbara Kerr. The construction enables the user to cook anything that can be prepared on a conventional oven or stovetop and eliminates the need for stirring or basting. For a manageable project in the classroom you might try s'mores (graham crackers with melted marshmallows and chocolate) or English muffin pizzas.

The oven can reach temperatures of 275 degrees, hot enough to cook food and kill germs in water. A general rule for cooking in a solar oven is to get the food in early and don't worry about overcooking. Solar cookers can be used six months of the year in northern climates and year-round in tropical locations. Expect cooking time to take about twice as long as conventional methods and allow about half an hour to preheat.

What You'll Need

- one large box
- one pizza box, small
- old newspapers or other insulating materials
- black construction paper
- cardboard
- aluminum foil
- drinking straw
- scissors
- heavy-weight clear plastic laminate (often available in schools)
- *avoid using any materials that could give off toxic fumes when heated, such as duct tape and styrofoam pellets.

How To Make Your Pizza Box Oven

1. Take your large box and line the bottom with insulating materials like crumpled newspapers.
2. Set your pizza box inside the big one (this will serve as your oven).
3. Fill the space between the sides of the two boxes with crumpled newspaper.
4. Use cardboard pieces to fold over the insulated space between boxes, secure tightly
5. Line the sides of the inner box with aluminum foil adhered with non-toxic glue
6. Line the bottom of the inner box with black contruction paper
7. On the top cover of the small pizza box draw a square 1" from all the sides.
8. Cut along three of the lines but leave the fourth line near the box's hinge uncut. Carefully fold open the flap.
9. Wrap a piece of aluminum foil around the flap, smooth wrinkles, secure with glue
10. Tightly stretch or lay your plastic over the inside top of the box. Smooth the plastic and secure it around the sides with glue or tape so no air can escape
11. Use straws or another device to prop open the flap and allow aluminum lining to reflect the maximum sunlight.

Feel free to improvise and improve the design while maintaining its essential structure

Construction of solar box cooker

Advice on how to build one

Materials needed

5 large pieces of cardboard (see#2 TIPS AND STRATEGIES);at least two should be 4 and one half feet across;Flatten cartons from bicycles,appliances or furniture are excellent (see step 1A,alternated reflector regarding cardboard)

50 feet regular aluminium foil 12 inches wide.

1pint white glue.

window glass 20" by 24"

* 8 feet wood molding;window screen moulding is best(see section on alternate Reflector)

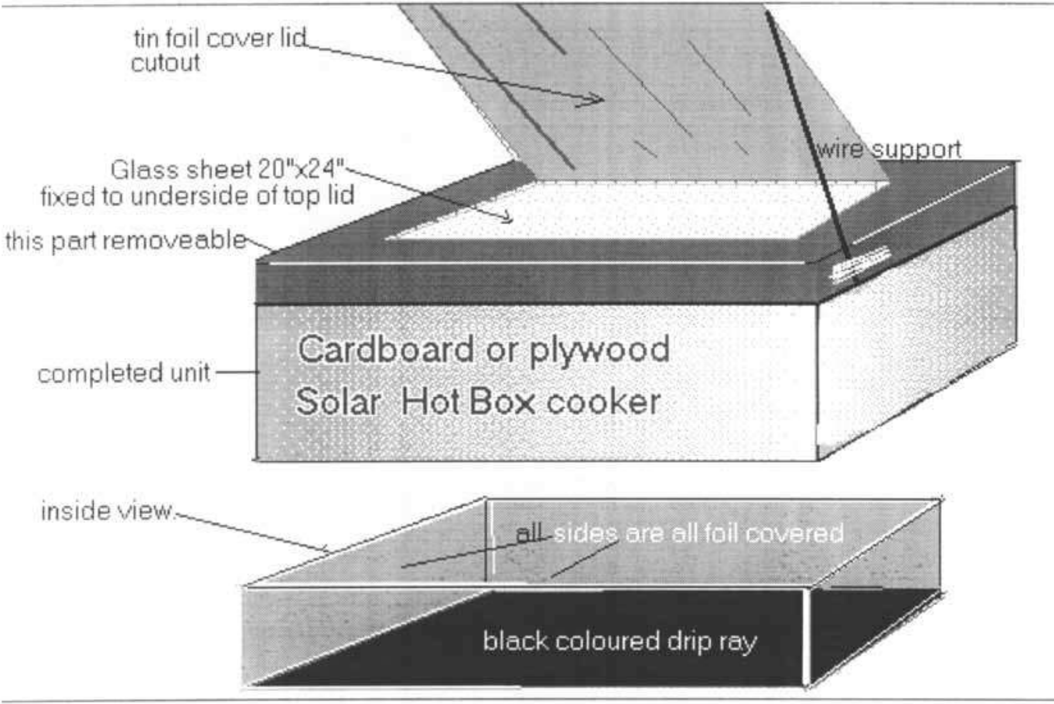
one tube clear silicone caulk

4 feet slash cord or similar heavy string

Insulation 2 inch stack of newspapers

Black metal tray approx 17 inches by 21 inches (see step 4 cooker completion)

Masking tape.


tin foil cover lid
cutout
wire support
Glass sheet 20"x24"
fixed to underside of top lid
this part removeable
Cardboard or plywood
Solar Hot Box cooker
completed unit
inside view
all sides are all foil covered
black coloured drip ray

Tools needed:

Box cutter or sharp knife

Pan or bowl to mix glue.

brush or small roller to spread glue.

Straight edge (eg yardstick) plus blunt tools pliers handle or large screwdriver) for scoring cardboard.

Saw

3/16" drill

Caulk gun

Tools for holding cardboard while glue dries(eg clamps,clothes pin bricks masking tape etc.)

Scissors

Tips and Strategies

1 Cut all patterns with scissors on solid lines;dotted lines show where cardboard will be folded. Place patterns and hold in place using masking tape.

2 regular cardboard is easier to work with than double strength cardboard and is satisfactory for most parts of the box.Double strength cardboard is useful for the reflector and lid and may avoid need for reinforcement.

3 Use full strength glue for fastening cardboard pieces together;dilute half glue;and water) for glueing foil to cardboard.

4 Score cardboard (using straight edge and blunt instrument)prior to folding .Score on the side toward which the fold is to be made in order to avoid tearing the cardboard.All folds are UP,towards the side on which pattern was placed .Except narrows flaps on the inner box ,which are scored on the reverse side and folded in opposite direction.

5 Place pattern on cardboard to take advantage of folds pre-existing on cardboard,otherwise place patterns on cardboard so that the new folds are as far way from pre-existing folds as possible.

6 When working on the floor don't kneel on the cardboard you are going to use;it makes dents.kneel on a scrap of cardboard it protects the knees.

7 Start with the lid;there are several step; requiring glue to dry in between ,go to another part of the box while it is drying.

8 A second piece of glass is useful in marginal weather (where there is wind or intermittent clouds.place on top of lid to avoid heat loss.

Step 1 Construction of the lid

After cutting and scoring cardboard fold tabs at corners outside the side flaps and glue,securing with clamps and or tape.

Allow time for glue to dry before proceeding.

Invert top and adhere glass to underside of top using silicone caulk.Make a bead of caulk about 1/2 inch in from the edge.Press flat with something heavy until dry.Fill in the space between the glass and sides of top with strips of cardboard about 2 inches wide (measure to fit exactly) and glue in place.

place.

After caulk is dry on underside ,invert top and put a bead of caulk around glass window where it is framed by the cardboard.

Step 1A Construction of the Reflector.

Pattern is design to provide a reflector from the same piece of cardboard from which the lid is made.

Simply cut along the three dotted lines in the center of the pattern and score on the reverse s(top of lid) of the fourth side providing a large flap which will serve as the reflector.

An ALTERNATE REFLECTOR(which provides a larger reflecting surface and protects the window better when cooker is not in use) can be made by cutting a separate piece of cardboard (double strength cardhoard is useful here) to fit the full size of the lid.In this case the larger flap provided by following the pattern will be cut off along the fourth side and removed.This is a piece can be later used to improvise a drip pan(see section on cooker completion)

Which ever reflector is used .completely foil the side facing towards the glass .If the alternate reflector ,score three inches from the edge of the back side and glue to lid.

If regular strength cardboard has been used ,it is suggested that the reinforcement sticks be glued to the three unsupported edges of the reflector.

Prop mechanisms for the reflector.

[A] Punch holes through side of the lid and reflector.Tie stick in each location so that in each location so that it can be slid up and down to adjust the reflector.

or

[B] Glue blocks of wood about 3/8" thick 6 inches to 8 inches long,with holes drilled in side to lid and reflector .Use heavy wire(such as from coat hanger) for support

Construct an inner box to fit inside larger box on all side of this inner box glue the al foil to each inner side.

ADD black metal pan to bottom of inner .It is essential to have a black drip pan in the bottom of the cooking chamher.

If a metal pan is not available it is satisfactory to improvise a pan by covering one side do a piece of cardboard with foil cutout and then painting the foil black

GETTING BOX READY TO COOK

After the box is complete ,but before cooking allow box to dry several hours in hot sun so that no chemical odours from glue or caulk are absorbed by food.

Make sure there is a black drip pan in the bottom of the box and that any cooking pots have black or dark lids.

Finishing touches.

Line the underside of the lid with foil in order to cover all spaces between glass and cardboard.

Cover all corners with two inch paper tape such as sheet rock tape or brown paper bags cut into two inch strips using

full strength glue.

This helps protect the corners.Don't use pre adhesive tape, such as masking tape or duct tape ,as it fails to hold up against

repeated exposure to sunlight.

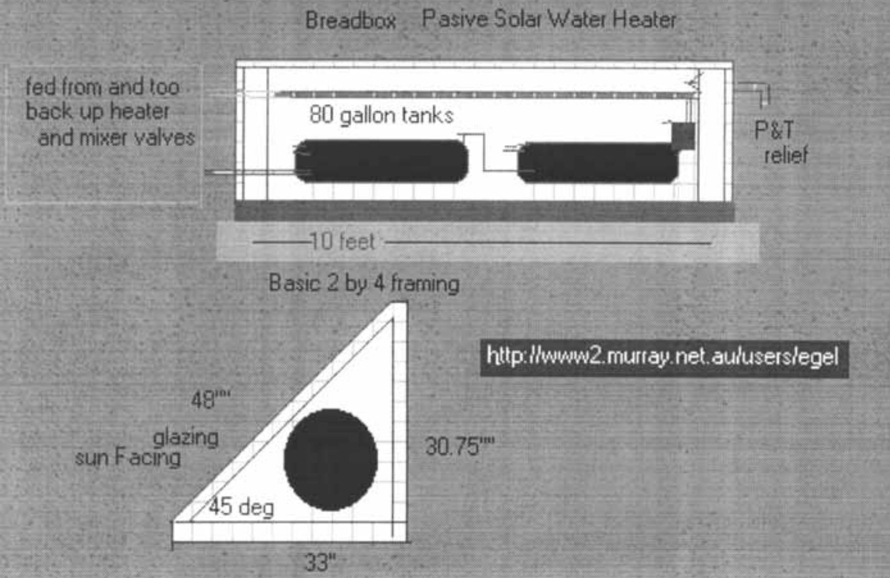
Make short feet for your cooker of 2 inch squares of wood ,plywood or several layers of cardboard to protect the bottom of cooker.

Cover cooker with wallpaper ,cloth,contact paper or exterior paint. two coats of exterior paint are especially helpful in making your cooker more waterproof.

The information provided came from an individual know to me as IM

A solar water heating system based on the hot has been also constructed to provide hot water.

a simple diagram is presented below.

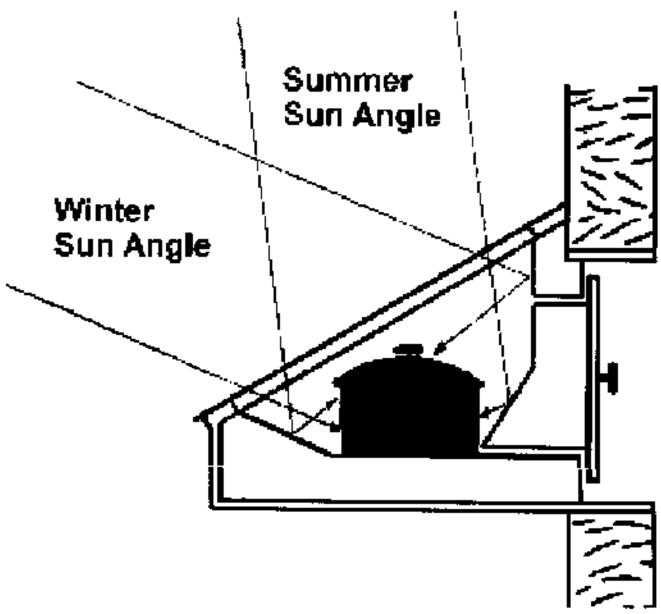

Breadbox Pasive Solar Water Heater
fed from and too
back up heater
and mixer valves
80 gallon tanks
P&T
relief
10 feet
Basic 2 by 4 framing
http://www2.murray.net.au/users/egel
48""
glazing
sun Facing
30.75""
45 deg
33"

Through-the Wall Ovens

Weather-proof ovens that allow access from inside the kitchen

The new South African government announced recently that, along with land redistribution, more than a million new homes will be built for the poor. We believe that serious consideration should be given to building a solar oven into the wall of every one of them. Paul Funk's design as described below is perfectly suited to South Africa's location just south of the Tropic of Capricorn. I recently installed a prototype solar cooker in the south- facing wall of a straw bale house in Mexico. It is now being field-tested and an evaluation is pending. The concept is attractive as were the results of my preliminary working models. This through-the-wall cooker has a hinged door inside the kitchen which allows access to the interior of the oven. This eliminates many hassles such as inclement weather, storage, thievery by people or animals, and wind. To quote a dear friend and source of inspiration and encouragement, "The wall solar oven is the ultimate convenience and my choice whenever I'm not testing other models." - Barbara P. Kerr

On the down side however, the wall solar oven has a distinct disadvantage in that, being attached to your house, it is not able to track the sun. This eliminates the use of multiple reflectors since these would block the light altogether during the morning and afternoon. In order to cook throughout the day, the wall oven must rely solely on the light energy striking its glazed area.



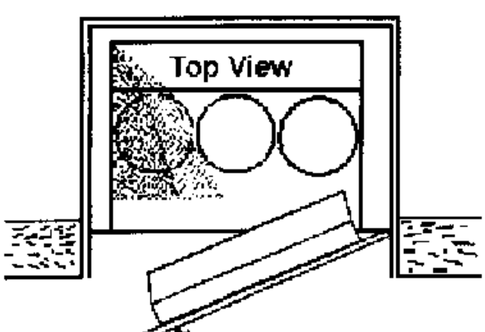


Figure 2

Enhancement is limited to internal reflectors, and possibly one external reflector on the wall of the house. Therefore the wall oven must be robust (not sensitive) to the following changes:

- **Robust to changes in sun angle**: In the design I have applied a simplified form of the compound parabolic concentrator (CPC). It is a concentrator that can reflect both winter and summer sun onto the row of pots. See Figure 1. Note that the house walls in this illustration are thick because it is a straw bale house. The design works as well or better on conventionally built homes.
- **Robust to changes in clearness index**: The wide acceptance angle of the CPC design also collects diffuse radiation more effectively. On partly cloudy days higher relative temperatures have been observed in the CPC oven compared to reflector equipped models. I assume that this means it will also perform well in humid or polluted air.
- **Robust to changes in hour angle**: In the design that I am currently developing I have made the cooking chamber long and narrow along the east-west axis. This is to minimize the effects of morning and evening shadows in the box. This makes the best use of the sun throughout the day. See Figure 2.

Built into internal surface of the door is an angled surface or "nose" that contributes to the CPC effect and enhances thermal performance by about 10%. It does not interfere with loading pots because the door opening is wide. The nose also forced me to hinge the door on one side. Space is needed in the kitchen for the door to swing into. Preliminary comments on the design include appreciation for the large entry.

Special Considerations

The typical four reflector solar cooker design doubles input energy, resulting in a more forgiving device. This box, with no external reflector, had to be very well built to achieve similar performance levels. It was doubled glazed, well insulated (9 cm of fiberglass) and sealed to prevent infiltration losses and food moisture entrance into the insulation.

Since this cooker is part of someone's home, it had to be attractive and durable. It is built of half-inch outdoor grade A/C plywood, the A side stained and varnished. To resist weather, flashing and caulk were used on the prototype installed in Sonora, Mexico. For privacy and security considerations, the outer glazing was a tough translucent fiber reinforced plastic typically applied to greenhouses.

Conclusions

The wall oven meets a demand for permanence and convenience. The design in its present configuration can only be applied to homes located above the Tropic of Cancer or below the Tropic of Capricorn with a south wall in the kitchen. Results from an evaluation are expected in time for the Second World Conference on Solar Cooking.

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Fax: (309) 677-3453

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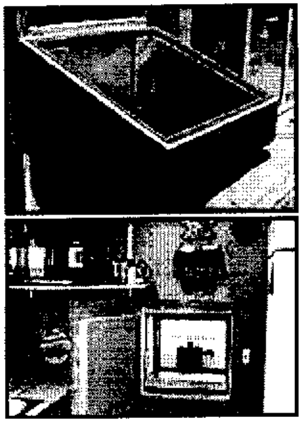
http://bradley.bradley.edu/~paulfunk/
Plans available here.
Back

Complete plans for a "through-the-wall" solar oven are now available.



The Kerr-Cole Solar Wall Oven cooks using only the heat from the mounted to the outside of a south-facing wall. A reach-through pas from inside your home to the oven provides convenient access. On this Through-The-Wall Solar Oven can experience 6 to 7 hours of t ranging from 250 to 300 degrees F. It is designed with internal refle the exterior profile. If higher temperatures are desired, additional re added but usually are not necessary. The gentle cooking of this ho oven produces delicious foods and cooks unattended for hours with burned food or house fires.

The oven is approximately 32" wide by 26" deep. The height slants The outer shell is constructed with ¼ inch plywood and the inner sh covered with foil or sheet metal.

Full-scale template-type plans are based on wood framing filled wit insulation and glazed with two layers of tempered glass or heat resi blackened sheet metal tray lines the bottom. The reach-through pa the house is similar to an opening used for an air conditioner. Insul the entrance to the oven and on the interior wall of the house keep oven and restore the protection of an insulated house wall.

The plans, with a materials list and construction plans as well as ins using the Solar Wall Oven are available for $25 that includes shippi Overseas addresses may have an additional shipping charge.

To order plans, write to

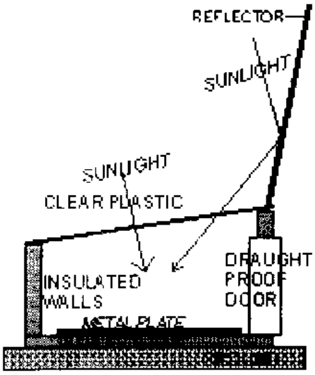
The Kerr-Cole Sustainable Living Center
POB 576
Taylor, AZ 85939
USA

(520) 536-2269

Write Barbara Kerr for details.

For information on another wall oven design click here.

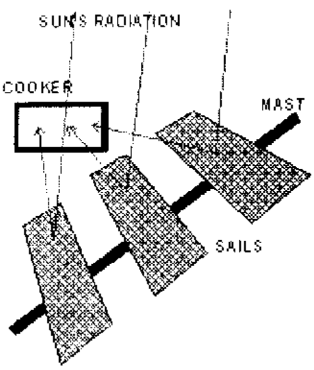
Click here for discussion about wall ovens in our Solarcooking-L dis



Section thro' adobe cooker

Adobe solar cookers

In 1992, to make a cheaper SERVE cooker, we started to develop our adobe cookers. These are built into the ground, and are insulated with natural materials, such as straw and leaves. They will cook 2 kg of (cooked) rice, and 2 kg of beans or other foods in half a day. In rural areas, this cooker is so cheap that it might be built by people to supplement scarce wood fuel.In mid 1994 we turned our attention to larger solar cookers, suitable for use by refugees in equatorial countries. The unit needs only a sheet of clear plastic, a sheet of reflective plastic, and a third plastic sheet to keep the insulation dry. Such DIY cookers have a material cost of £8 to £12, depending on size.



The clipper mast cooker

We have spread the design of these cookers in Tanzania during recent summer seasons. Further trials and comparisons are needed to show how acceptable they are. In the past two years thousands of adobe cookers have been put in by SERVE. Thousands of cardboard cookers have gone into a refugee camp in Kenya. These are made from folded, waxed, reflective, corrugated cardboard. These are far quicker to build -- taking hours not weeks -- but they may have too short a lifetime (little over a year) or too small a capacity.

High-efficiency cookers. In 1993, we also developed a bread cooker, for our own use. This will cook up to 8 kg of bread in a day. It has a reflector sending light into a small box with a pitched glass roof.

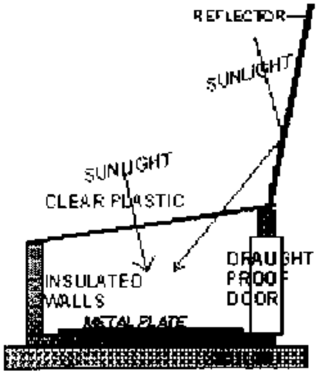
"Clipper-mast" cookers

Any institution, such as Sunseed or a school, will find it easier to cook with large pots and pans. But these pots will not fit into a small family solar-cooker. Solar cookers for larger pots will need focused sunlight. (Doubling the dimensions of pot and cooker will lead to four times the solar heat, but eight times the weight of food.) We consider that one particular design would be cheaper and more user friendly than any we have seen in the literature.

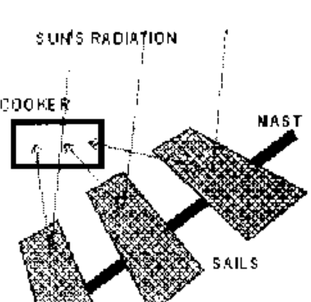
A single mast is mounted parallel to the axis of the earth. Several large flat boards are mounted on the mast, like sails. Each board carries nine small mirrors, individually angled to focus the sun's rays onto the cooker.

The mast rotates around its axis. This rotation can be used to keep the sun's image directed onto the oven. Each board can be moved to face the new altitude of the sun, say, once a week. (It turns about its "yard", in clipper-ship terms.)

Small models have been built to prove the geometry of such a cooker, to examine the positioning of the oven at two different foci -- in the morning and afternoon.



Section thro' adobe cooker



The clipper mast cooker

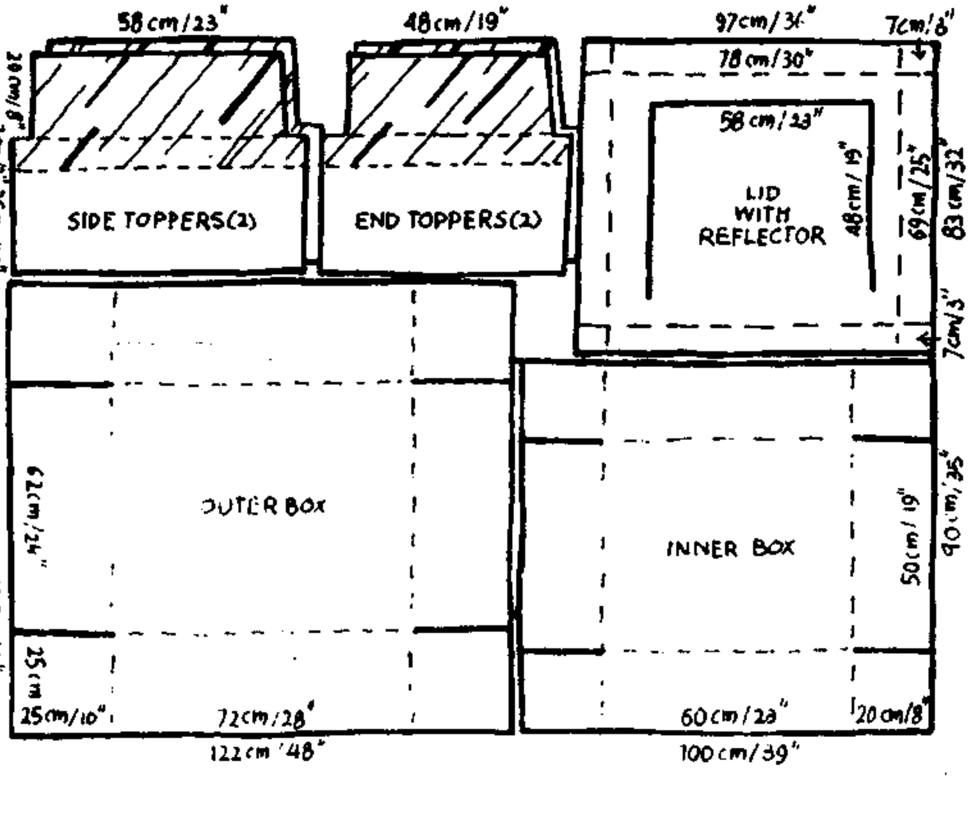
SOLAR COOKER

Box-type solar cookers are commercially available and thousands of families all over India use them regularly to cook their meals. In the Box-type solar cooker, solar radiation is transmitted through the glass into the interior where it is absorbed by the food containers to cook the food. Very little heat is re-radiated out through the glass and therefore the heat is trapped and there is a net heat gain inside the cooker. (For your information, technically, this gain in heat is called the greenhouse effect.) The solar cooker must be placed in a south facing direction in an unshaded spot in your home's terrace or courtyard which gets maximum direct sunlight. Early morning and late evening solar radiation is not enough for cooking, so don't load you cooker before 9.00 a.m. and do not try to cook after 3 p.m. Solar cookers capture and retain the Sun's heat through the use of glass, mirrors, reflective foil, insulating materials and so on, depending on their design. Even you can make a solar cooker yourself ! Here's the way to do it.

1 Preparing your Boxes

To make clean straight folds in cardboard, press first with a blunt edge such as a spoon handle, then fold against a firm straight edge.

If you don't have big pieces of cardboard, glue together small ones overlapping slightly.

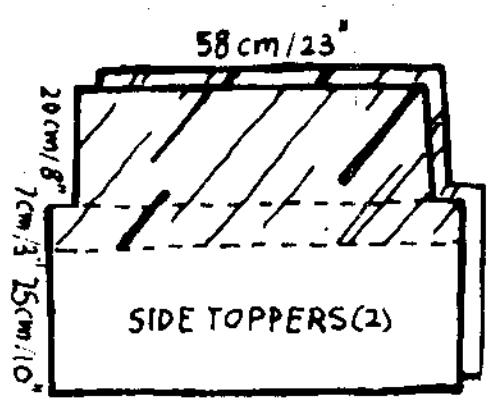


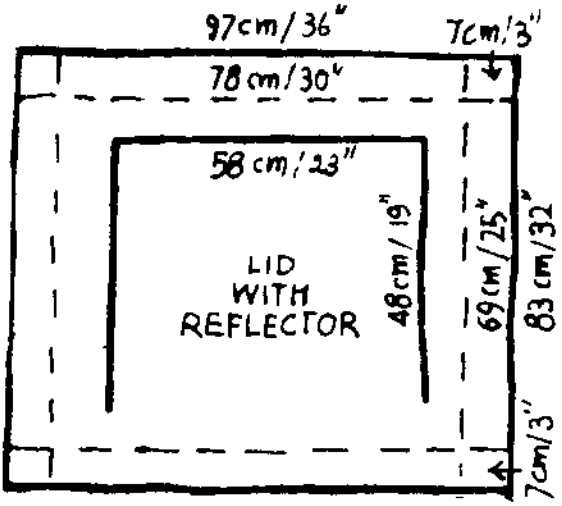
You will need

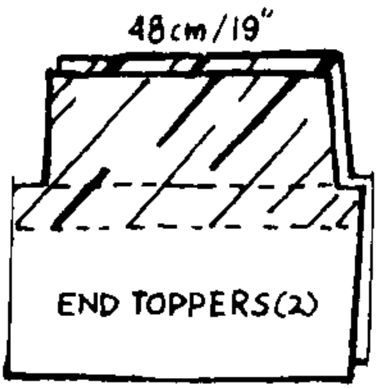
- **GLASS** - Ordinary (untempered) window glass about 50 x 60 cm
- **CARDBOARD** - about 4 square meters, 60 square feet, and a knife to cut it
  - For two large boxes and a lid. Finished size Lid 61 x 71 x 8 cm

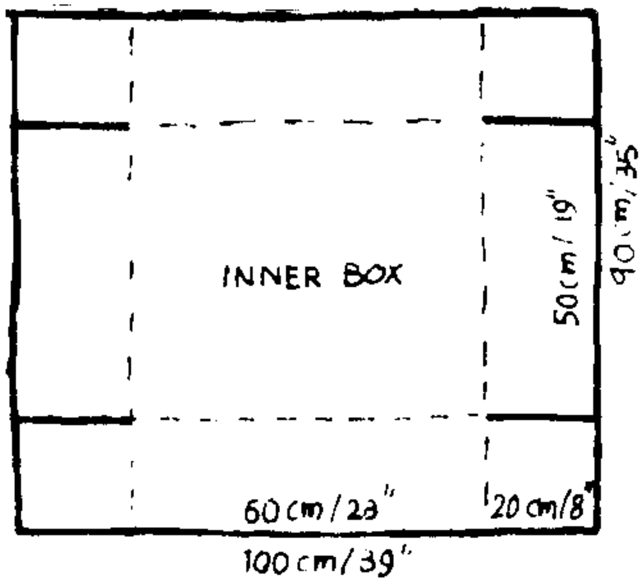
    Inner box 46 x 56 x 20 cm

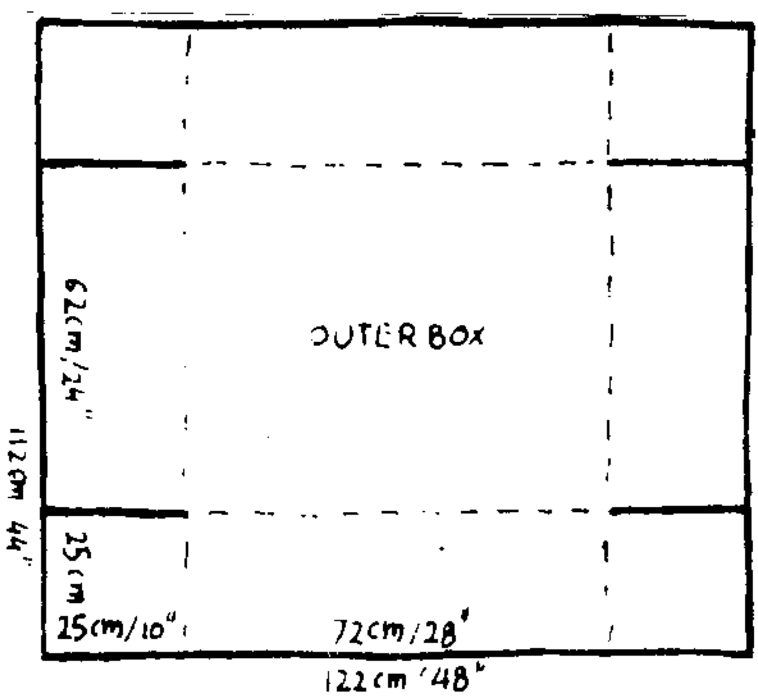
    Outer box a little longer, wider and taller 56 x 66 x 25 cm
  - BOTTOM SUPPORTS - small scraps glued to make six stacks 3 cm tall
  - INSULATOR PIECES like the walls of the bigger box to fit between boxes
  - "TOPPERS" if boxes don't have flaps
- **ALUMINIUM FOIL** - 20 x 3 meters
- **SILICONE CAULK** to glue window to lid and/or
- **DARK, COOKING POTS WITH DARK LIDS and BLACK METAL OR ALUMINIUM FOIL TRAY** - to fit inside the inner box - 44 x 54 cm
- **PROP STICK** - 70 cm length of stick and string


58 cm/23"
20 cm/8"
7cm/3"
25cm/10"
SIDE TOPPERS(2)


97cm/36"
7cm/3"
78 cm/30"
58 cm/23"
LID
WITH
REFLECTOR
48cm/19"
69cm/25"
83 cm/32"
7cm/3"


48 cm/19"
END TOPPERS(2)


INNER BOX
50cm/19"
90cm/35"
60 cm/23"
20 cm/8"
100 cm/39"


OUTER BOX
62cm/24"
112cm 44"
25cm
25cm/10"
72cm/28"
122cm/48"

From Big, Ready-made Boxes :
Look for about these sizes, sometimes found at appliance stores
Ideal inner box : 46 l x 56 b x 20 h cm
Ideal outer box : a little longer, wider and taller - 56 x 66 x 25 cm

Ideal space between boxes : 3 cm

Lid : 61 x 71 x 8 cm

Adjust height of boxes.

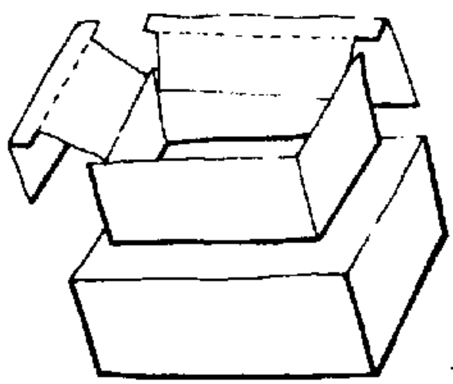
2 Fold Down

The walls of the inner box to about 20 cm in height, and the outer box to 25 cm. Be sure your covered pots will fit inside without touching the window.

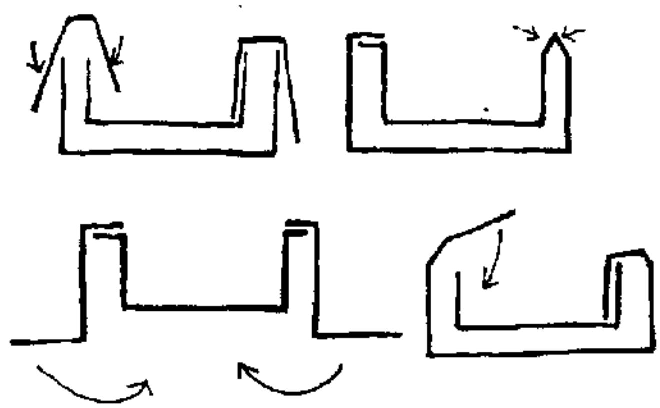
3 Cut Cardboard for Boxes

Pick one of the following ways to seal the space between the boxes. Don't glue yet.

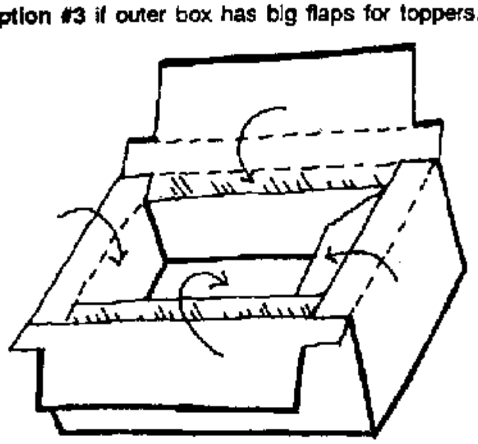
- **Option #1** with Toppers when both boxes have no flaps : Cut 4 separate T-shaped "toppers".



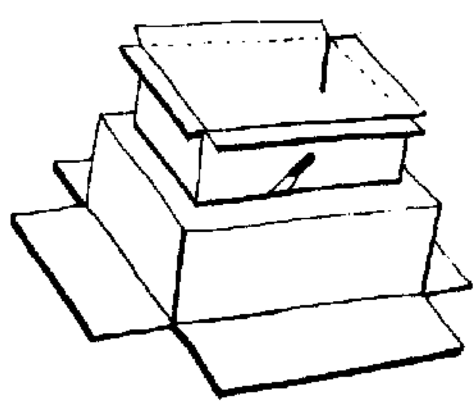
- **Option #2** with Small Flaps on both boxes.



- **Option #3** if outer box has big flaps for toppers.



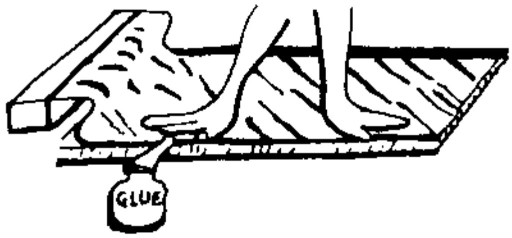
- **Option #4** if inner box has small flaps and outer has big flaps, you can make a QUICK UPSIDE-DOWN COOKER.

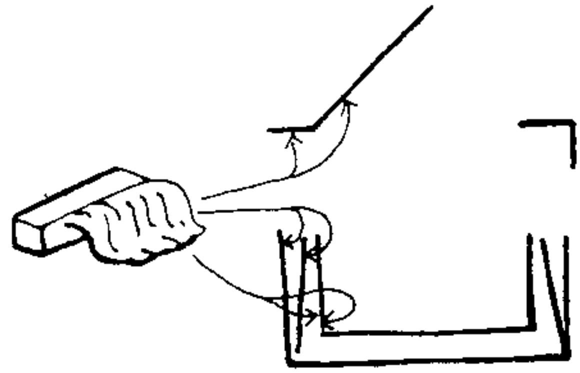


Turn the big box over, centre the little box on it and trace around. Cut out this piece so the little box drops in. Trim little box flaps as narrow as the rim left on the big box.

Fit the Lid : a large flat piece 15 cm longer and wider than the outer box.

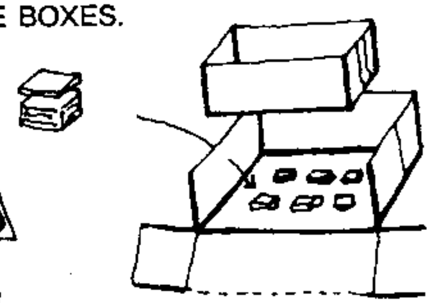
4 Glue aluminium foil to





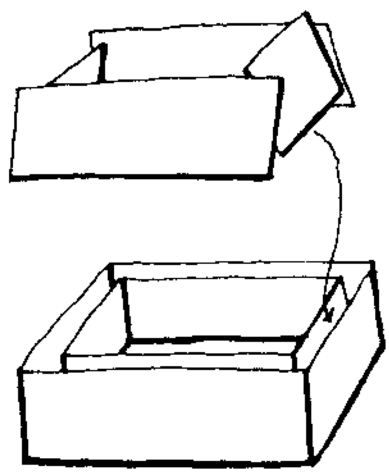
* both sides of little box.
* the inside of the larger box and lid, one side of insulator pieces.
* flaps or toppers, if any, that will be inside the inner box. Add water to glue half-and-half, and spread all over THINLY and press foil so it sticks like wallpaper. Don't worry about a few air bubbles or wrinkles.

If you started with flat cardboard, now fold up and glue box sides to MAKE BOXES.



5 Add bottom support

Glue six little stacks of cardboard 2-3 cm high to support inner box. Tape or glue supports to the underside of the inner box or to the inside bottom of the outer box.

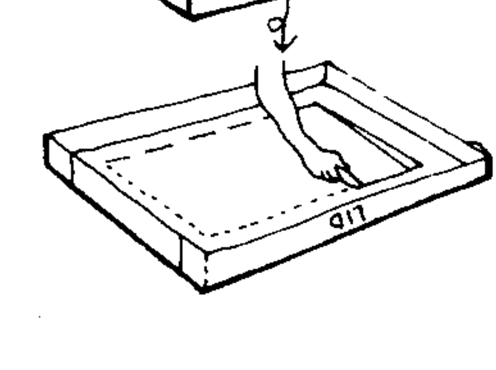


6 With one box inside the other, add insulation

If you have extra cardboard and foil, make insulator pieces the size of the outer box walls and foil on one side to place between the walls. Seal space between the boxes. Glue cardboard patches over any holes in the boxes.

7 Make a Lid

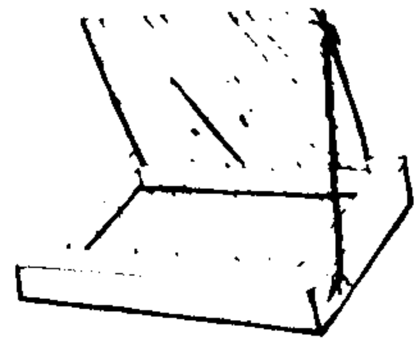
Centre the flat lid piece on the box, foiled side down. Fold edges over the finished box for a good fit. Cut and fold the corner flaps and glue.



8 Make window and reflector

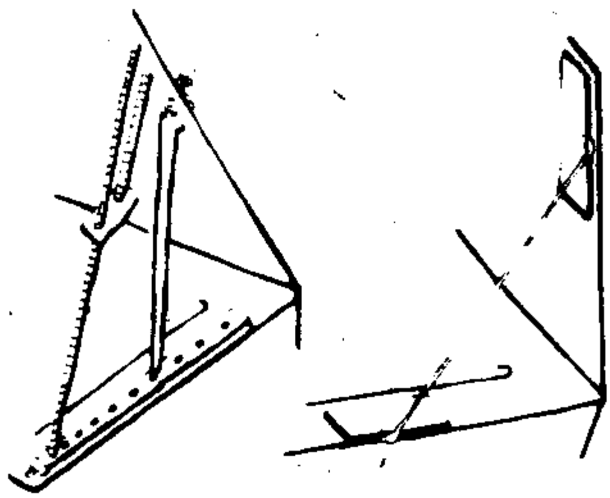
Draw a window opening in the center of the lid the size of the inner box (and a little smaller than the window piece). Cut three sides, leaving one long side to fold up for a reflector. The opening in the lid will be the window frame.

Spread glue along the edge of the window and press it against the inside edge of the window frame to make a good seal. Press flat with something heavy until dry.



9 Make a prop

Attach a notched stick with string to the corner of the reflector and one side of the lid. In windy areas you may need a prop on both ends of the reflector. The notched stick and string will hold firm at both ends.



10 Variations

Steady stick and string prop for windy weather. After the glue dries put empty solar box in the sun for several hours to enable drying of box itself.

Now you are ready to cook with this Solar Cooker.

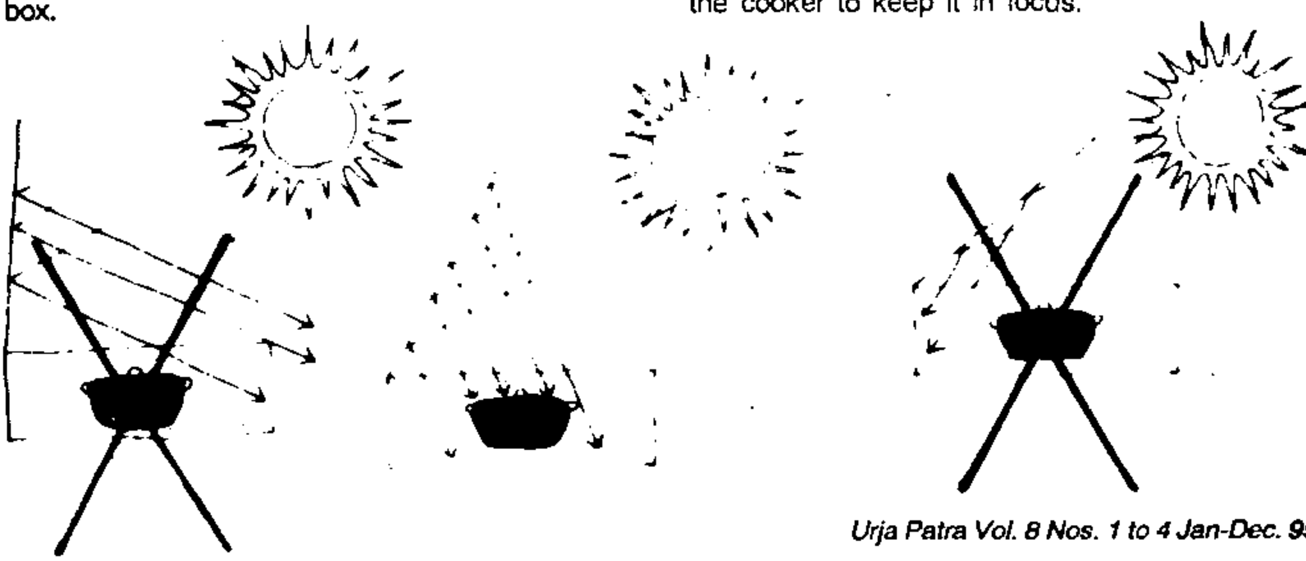
Position the Solar Box Cooker.

Place the cooker in full sunlight, on a dry surface. Prop the reflector open in any position temporarily.

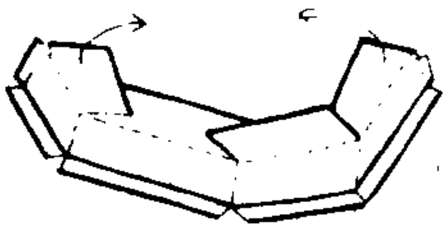
Move the box until the shadow of the prop falls directly behind the stick, parallel to the edge of the box.

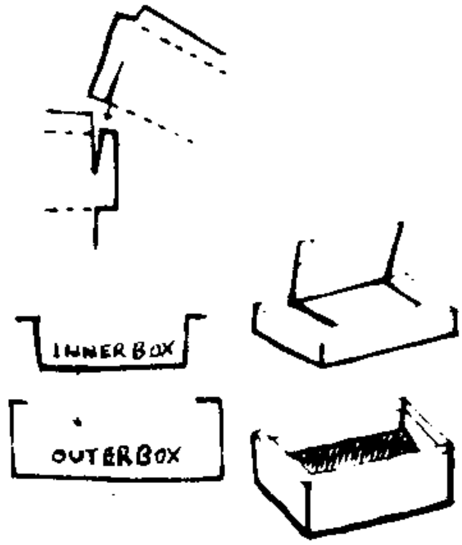
Move the reflector until the reflected sun lights up the inside bottom and front of the cooker. Move the props until they hold the reflector in this position. Tighten the cord adjuster firmly.

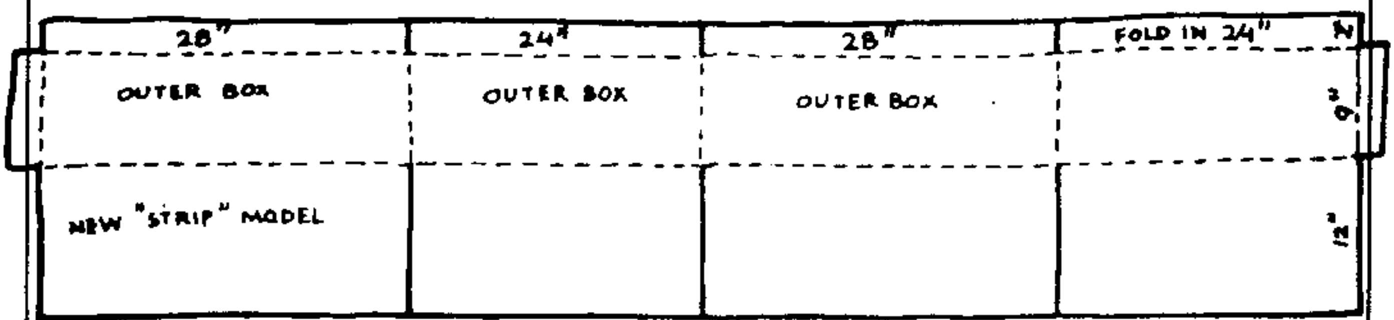
If it is windy, put rocks or some kind of weights around the cooker to keep it in focus.

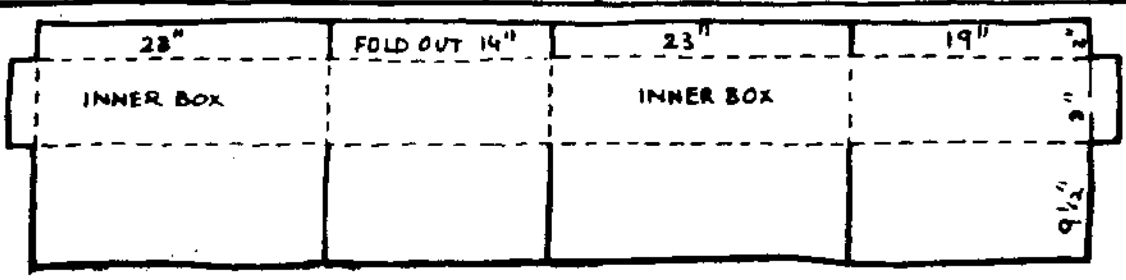


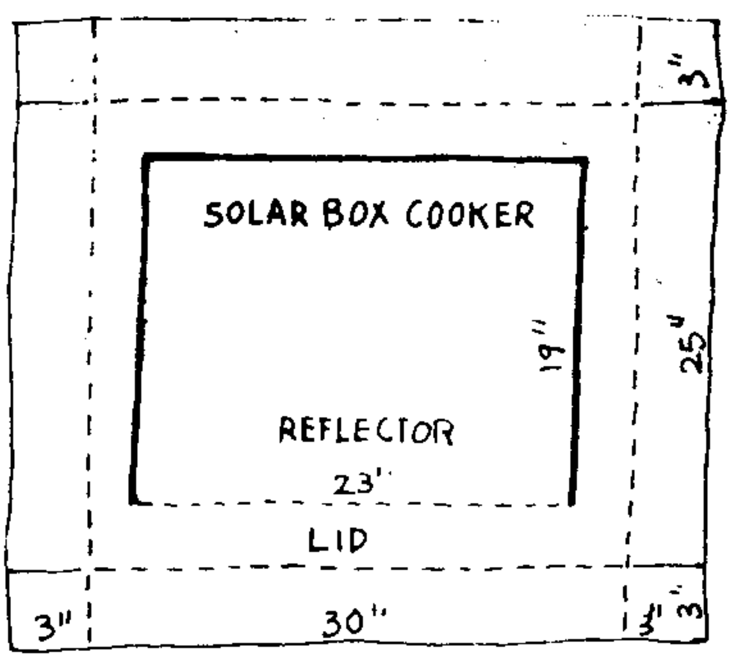
Making a Solar Cooker from Cardboard strips

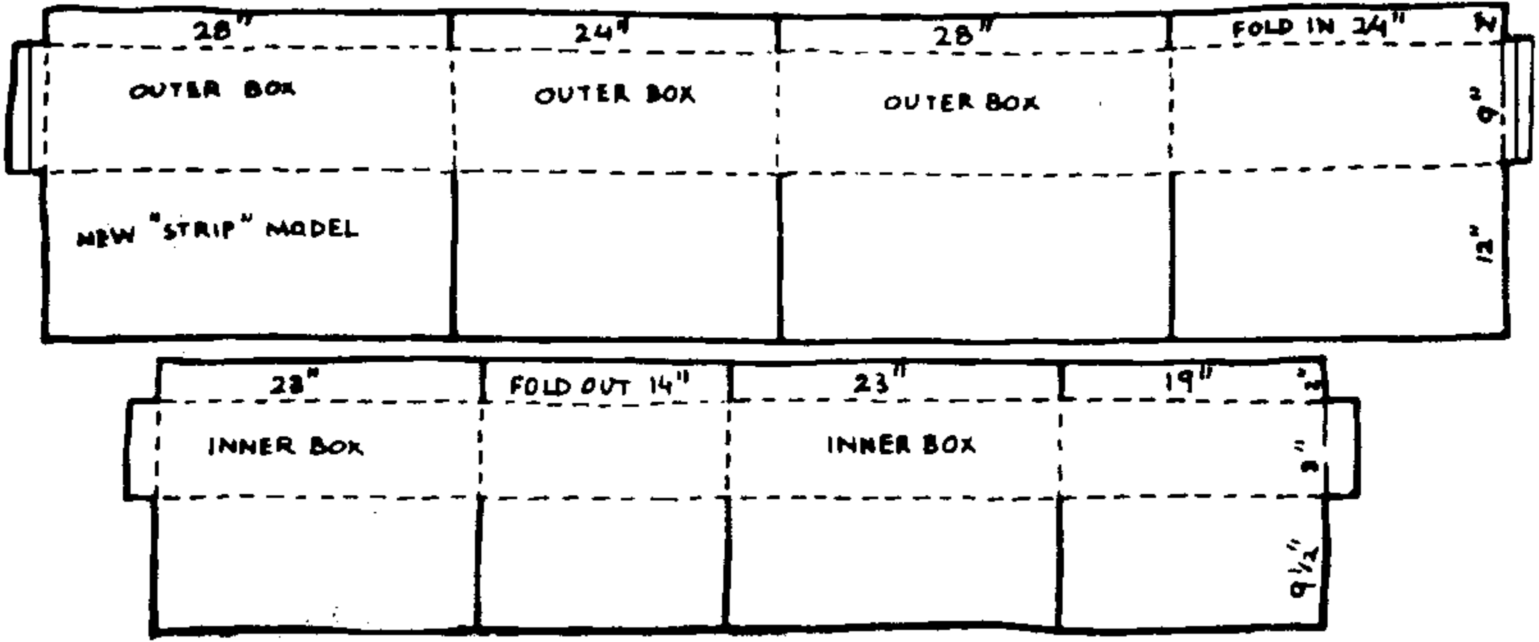




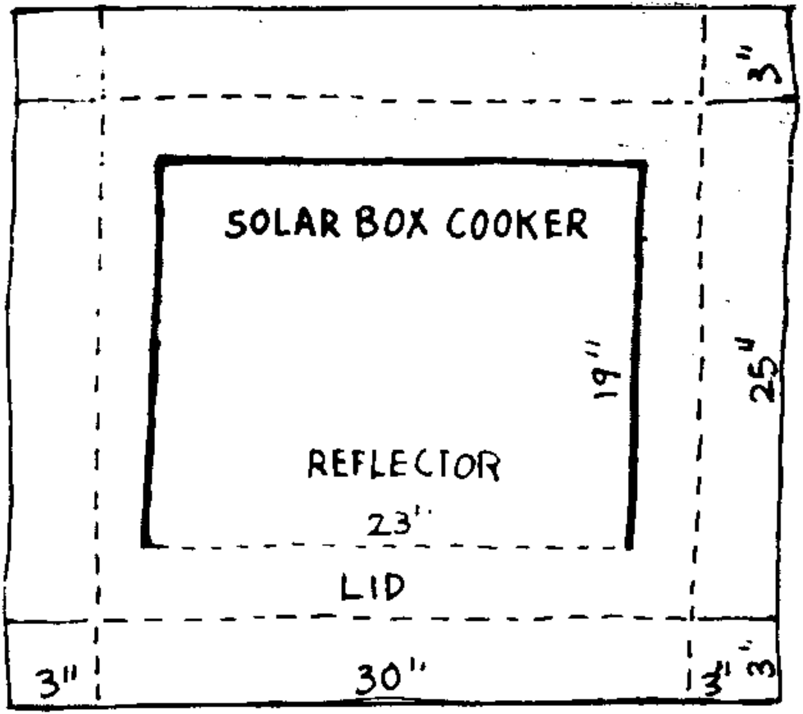








28"
24"
28"
FOLD IN 24"
OUTER BOX
OUTER BOX
OUTER BOX
NEW "STRIP" MODEL
12"
28"
FOLD OUT 14"
23"
19"
INNER BOX
INNER BOX
9½"


SOLAR BOX COOKER
REFLECTOR
19"
25"
3"
23"
LID
3"
30"
3"
3"

FLAT-PLATE TYPE COOKERS

Flat-Plate type cookers are so named because they resemble flat plate solar collectors used for water heating. One or more tubes or pipes containing water are thermally bonded to highly conductive fins and placed in a well insulated collector box with two or more layers of glazing. The collector so formed is mounted on an incline. Typically the upper end of the tube or pipe is connected with an insulated chamber in which sits the pot of food to be cooked.

The water contained in the pipes and insulated chamber assembly is in an essentially closed system. As the water is heated up in the collector, any steam generated rises to the insulated chamber, condenses on cooler surfaces (for example the cooking pot and sides of the chamber) and drops back down into the pipe whence it is reheated. In such closed systems, it is relatively easy to boil the water in the pipe(s) and to generate a considerable amount of steam.

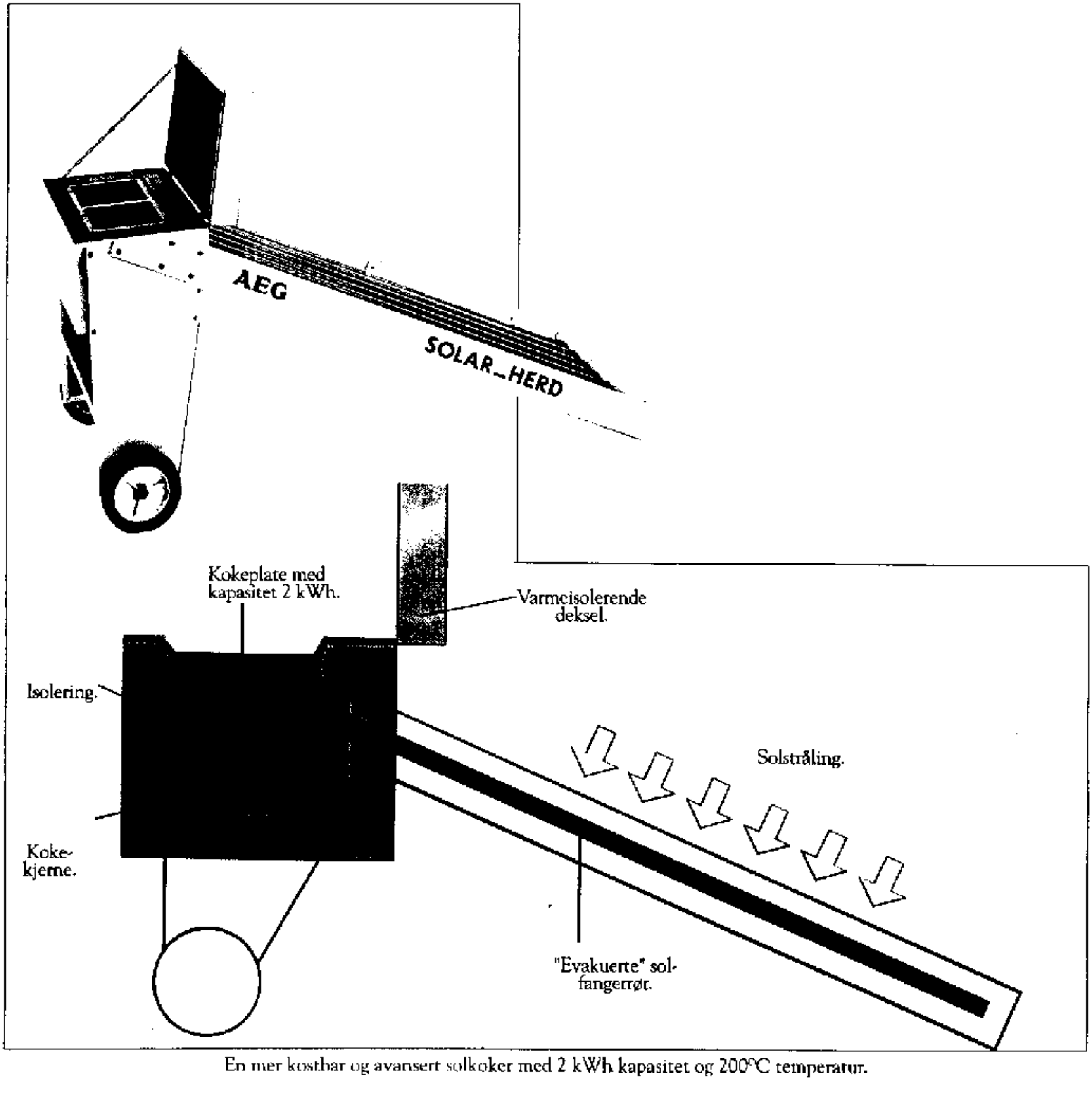
Heat is transferred to food in the cooking pot primarily by conduction of the latent heat of condensation of the steam through the wall of the pot. The temperature of the boiling water and steam is 100°C. A temperature difference must exist across the wall of the cooking pot for heat to be transferred thus the temperature inside the cooking pot is usually a few degrees below 100°C. The result is that the food and water in the cooking pot never quite reach the boiling point therefore the rate of cooking is slow. These cookers tend to be best suited for preparing food requiring long, slow boiling, such as soups, stews, cereals and vegetables.

Flat plate type cookers use both direct and diffuse components of the total radiation, allowing some heating to continue during intermittent and lightly cloudy periods. These cookers are often mounted on simple pivots so that periodic adjustments can be made to the collector orientation to permit tracking the sun.

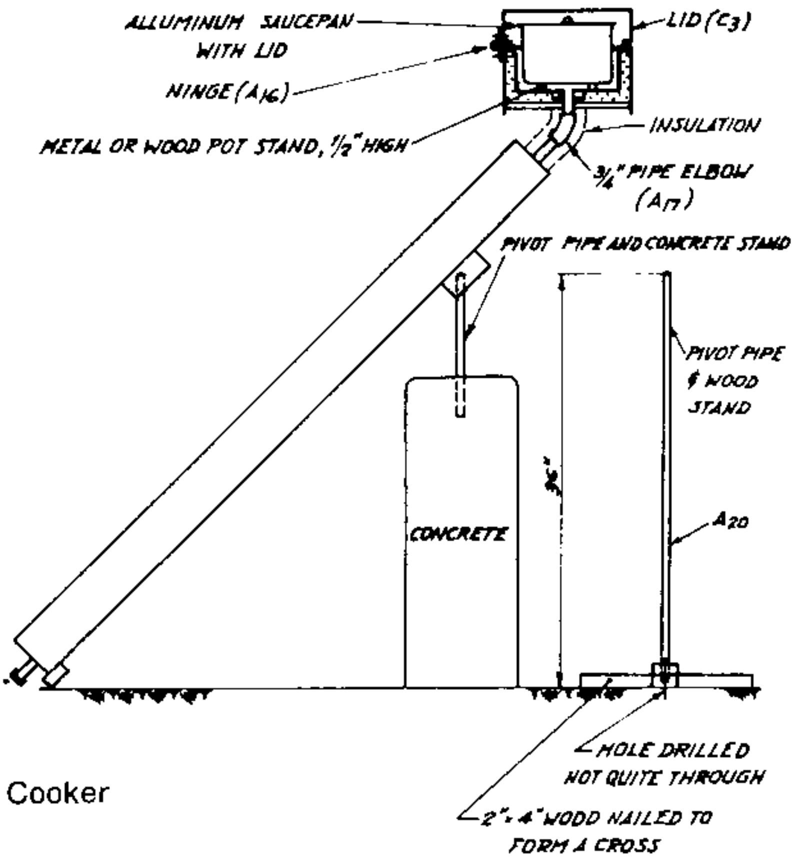
Because flat-plate type cookers usually cook at low temperatures, the food may sometimes not reach a temperature at which sterilization can take place. If there is any doubt as to whether or not this could present a health hazard, it is very important to consult with the local health authorities. Sterilization of food is necessary at some period during the cooking process if either the food or the water or the interior of the cooking pot may be contaminated. Sterilization can usually be accomplished by raising the cooking pot and contents to the boiling point for several minutes. If the health authorities indicate that sterilization is necessary, then it is important to advise users of these cookers to boil their food for a few minutes over their traditional cooking fires either before or after cooking in the solar cooker.

It is important to note that most foods will start to cook at temperatures as low as 60° to 70°C, temperatures easily attained by flat plate cookers. Some foods will even begin cooking at 50°C. However, at these low cooking temperatures heat transfer to and within the cooking food is slow. Even though food spoilage and food poisoning organisms will not grow and multiply at these temperatures, these organisms are not necessarily destroyed and can become active again once the food temperature decends below 50°C. This gives additional impetus to raising the temperature of the cooking foods to the boiling point using traditional cookers for a short period of time, especially if the food is not be be consumed immediately.

25: Sunshine Revolution. Norway/USA 1992.



En mer kostbar og avansert solkoker med 2 kWh kapasitet og 200°C temperatur.



The Brace
Solar Steam Cooker

How to Build a Solar Steam Cooker, leaflet with dimensional drawings and assembly information, 13 pages, Brace Research Institute, 1972, $1.25 from BRACE.

MATERIALS: wood frame, plywood, ¾'' steel pipe, .025'' metal sheet, 26 gauge sheet metal, 1/8'' windowglass, galvanized wire, local dry fibrous insulation.

PRODUCTION: some metal-cutting and soldering.

''This manual describes a relatively simple, yet effective device for steam cooking of food using solar energy.'' Designed for village use in areas where sunshine is abundant and most food is cooked by steaming or boiling. It is best used for slow cooking at low temperatures, and **cannot be used for frying or baking**.

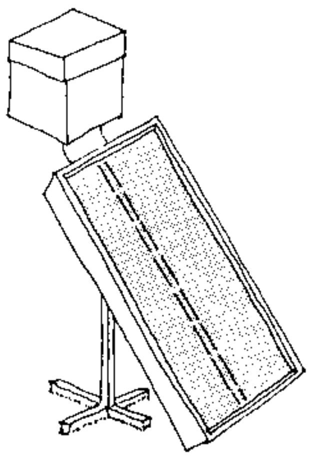
''The cooker consists of two parts that are rigidly and permanently joined to each other. The first is the solar collector, that is a metal surface heated by the sun causing water to boil and producing steam. The second is the insulated steam cooker, in which the saucepan containing food is placed.

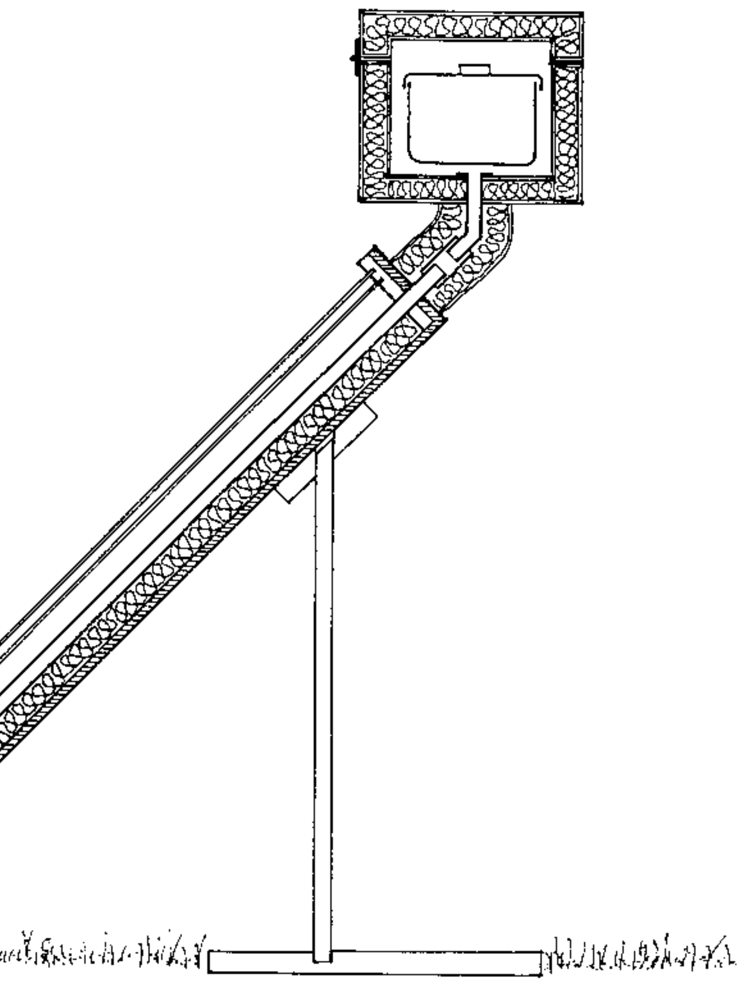
''Steam is produced within an hour of sunrise and will continue to be produced for the rest of the day as long as the sun shines on the collector...thus it is possible to cook both the mid-day meal and the evening meal...the solar cooker is a slow-cooking device and is best suited for foods that require long slow boiling, such as stews, cereals and vegetables.

''The construction of the solar cooker is simple with much margin for adaptation to locally available material, therefore, the fabrication instructions serve mainly as a guide to general proportions.''

The information and assembly instructions presented are fairly straightforward, and could be simplified by an adaptive technology center.

Type	FLAT PLATE - BRACE SOLAR STEAM COOKER
Features	A single pipe collector generates steam for cooking with one pot. The cooker is mounted on a pivot such that the unit can be pointed toward sunrise all morning and towards the point of sunset all afternoon. With these two orientations, cooking can be carried on throughout the daylight hours.
Status	Operational cooker
Description	The flat plate collector contains a single pipe, 2.0 cm in diameter, thermally attached to the center of a 0.5m x 1.5m metal absorber sheet. This absorber plate is placed in a well insulated collector box with 2 layers of glass as the transparent cover. The collector is mounted on a 45^o slope. The upper end of the collector pipe is connected to the bottom of a steam chamber, inside which sits the cooking pot. The steam chamber and connecting piping are very well insulated. The flat plate collector and cooking chamber assembly are mounted on a pivot for orientation of the unit towards the sun.





Performance This cooker is a slow-cooking device best suited for foods that require slow cooking, such as stews, cereals and vegetables.

With no food or water in the cooking pot, the cooker can be boiling water and producing steam from the collector pipe within one half hour of being exposed to direct sunlight. If food and water are subsequently placed in the cooking pot, the following are representative of cooking times required under nearly cloudless conditions:

Rice - 50 min. to 1 hour (for 2 kg.of cooked rice)

Potatoes - 50 min. to 1 hour

Peas - 40 min.

Chicken stew - 3 - 4 hours

Advantages

- Uses both direct and diffuse radiation, thus allowing some heating during cloudy periods.
- Tracking the sun is a matter of changing the orientation of the collector twice a day: The first, toward sunrise early in the morning and the second, toward sunset at solar noon.
- Not difficult to construct, using widely available materials
- Rigid and rugged.
- Easy to use
- Minimum of attention to cooking food required.

Disadvantages

- Requires cooking outdoors.
- Requires cooking at an elevated level.
- Can only cook foods that require boiling.
- Slow cooking.

Costs Materials costs are approximately $40.00 (1980 estimate).

Materials of Construction Glass, wood, steel pipe, galvanized tin sheet, aluminum sheet, insulation and flat black paint.

Dimensions Collector dimensions are approximately 0.6m x 1.6m x 0.15m. When installed, the top of the cooking chamber can be up to 1.8m above ground level.

Location Originally developed at the Brace Research Institute Field Station in Barbados in 1963. Units have subsequently been built and operated in most countries of the world.

Climatological Requirements This cooker requires direct sunlight for best operation. Intermittent cloudy periods do lengthen the cooking time, but since the cooker also makes use of diffuse sky radiation, some heat is still being supplied to the cooking chamber during cloudy intervals.

Practical Operation

Many hundreds of these cookers have been built since they were first introduced in a Do-it-Yourself leaflet by Brace Research Institute in 1965. Most have been constructed on an individual prototype or operational basis by researchers and interested users. Some have been produced in larger numbers for distribution to selected users in trial applications.

Cooking Information

Only foods that require boiling can be cooked in this cooker. Foods that have been successfully cooked include most vegetables (with the noted exception of dried beans), grains, meats and stews.

Operating Techniques

The collector is usually oriented twice a day, to face the morning sun before solar noon and to face the setting sun in the afternoon. The size and the 45^{o} tilt of the collector assure that adequate heat energy is available to generate steam from one hour after sunrise to 1 hour before sunset under clear sky conditions in most developing countries of the world.

Estimated Life

With proper maintenance, the cooker should last from 5 to 8 years.

Comments on the Cooker

Follow-up activities, including letter correspondence and direct technical assistance have revealed that these cookers, as most solar cookers, only work well if they are well constructed. Common faults in construction are the lack of adequate insulation both behind the absorber plate and surrounding the steam chamber and connecting piping, insufficient thermal bonding between the absorber plate and the pipe, and improper glass mounting. All of these factors usually lead to excessive heat losses, which severely restrict the cooker's capabilities.

References

Whillier, A., "How to Make a Solar Steam Cooker", Brace Research Institute, McGill University, Do-It-Yourself Leaflet L-2, January 1965, revised in 1972.

Whillier, A., "A Stove for Boiling Foods Using Solar Energy", _Sun at Work_, 1st Quarter, 1965.

Contact

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Canada H9X 3V9

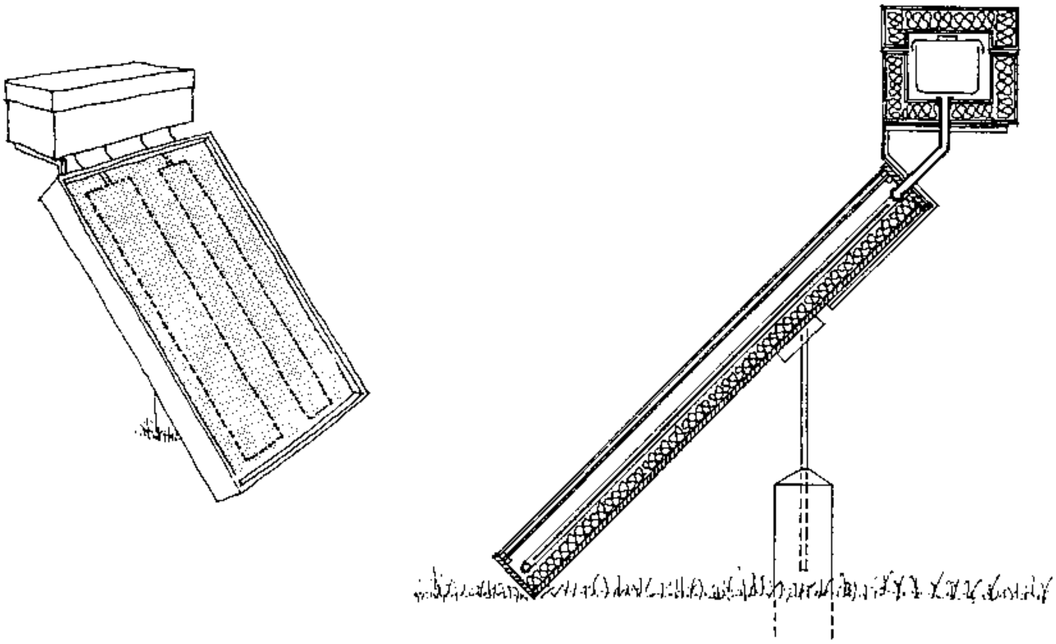
EMAIL: ae12000@musica.mcgill.ca

Type FLAT PLATE - BRACE MULTIPLE PIPE STEAM COOKER

Features The cooker has a larger collector than the Brace Solar Steam Cooker and can be used for cooking with two pots. The Collector is pivoted to track the sun.

Status Operational cooker.

Description This flat-plate steam cooker has an absorber area of approximately 0.8 m x 1.5 m, made up of four 12 mm galvanized steel pipes thermally bonded to a black painted 25 gauge aluminum sheet. The absorber plate is enclosed behind 2 layers of glass, in a shallow insulated box. The collector assembly is then mounted at a fixed tilt angle (often 45°) ari can be either supported in a permanent position or on a pivot for ease of orientation toward the sun. An insulated cooking chamber, containing two cooking pots, is located off the upper end of the collector box and is joined to the absorber plate pipes by insulated flexible or rigid pipes.



Performance This is a slow cooking device best suited for foods that require long slow boiling. Each of the two cooking pots in the steam chamber is capable of containing between 2.5 and 3 kg of food and water. With both cooking pots full and the absorber already generating steam, typical cooking times under nearly cloudless conditions were as follows:

rice	45 min.
potatoes	40 min.
peas	30 min.
cornmeal	45 min.
chicken stew	2½ hours

Performance cont'd — Steam can be generated by the absorber plate in about 20 minutes after exposure to direct sunlight. For conditions of cloud obscuring the sun between 10 and 30 percent of the cooking period, rice and some vegetables have been cooked in 1-1/2 to 1-3/4 hours.

Advantages

- Same as for the Brace Solar Steam Cooker although, if well constructed, it can cook somewhat faster.
- Can cook 2 pots of food at the same time.

Disadvantages

- Same as for the Brace Solar Steam Cooker.

Costs — Materials costs are approximately $70 (1980 estimates).

Materials of Construction — Glass, wood, steel pipe, galvanized tin sheet, aluminum sheet, insulation and flat black paint.

Dimensions — Collector dimensions are approximately 0.8 m x 1.6 m x 0.16 m When installed, the top of the cooking chamber can be as high as 1.8 m above the ground.

Location — Originally developed at the Brace Research Institute in Montréal, in 1971, in response to a request from Haiti. Several units of this design were installed at a fixed orientation on a flat roof of a school in Haiti, in 1972. A few other models have been built and tested on a prototype basis by researchers and interested users around the world.

Climatological Requirements — This cooker requires direct sunlight for best operation. Intermittent cloudy periods, with clouds obscuring the sun for approximately 20% of the cooking period, can double the length of time required for cooking.

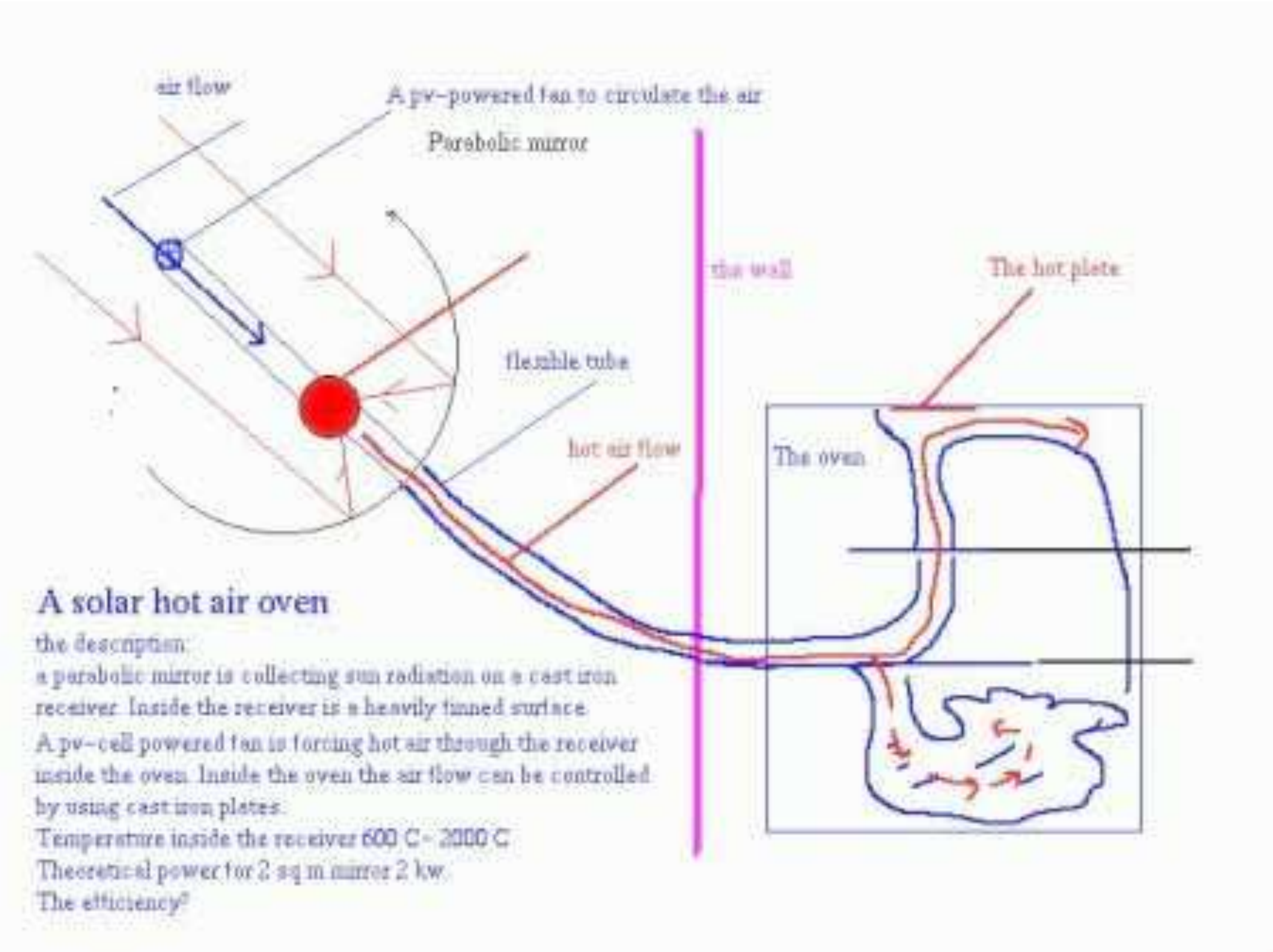
Practical Operation — Thirty units of this cooker were built on site and installed on a school roof in Miragoâne, Haiti. These were used to cook the noon meal for 240 students. After an initial period of successful operation, these cookers were abandoned by the school cooks due to inconvenience of operation and increased availability of their traditional cooking fuels.

Cooking Information — Foods that have been successfully cooked include rice, chicken and meat stews, corn meal, plantain, yams, sweet potatoes, potatoes, peas and fresh beans.

Operating Conditions — See the Brace Solar Steam Cooker.

Estimated Life — With proper maintenance, expected cooker life is from 8 to 10 years.

References — Alward, R., Lawand, T.A. and Hopley, P., "Description of a Large Scale Solar Steam Cooker in Haiti", Proceedings of the International Congress, The Sun in The Service of Mankind, UNESCO, Paris, 1973.


air flow
A pv-powered fan to circulate the air
Parabolic mirror
the wall
The hot plate
flexible tube
hot air flow
The oven
A solar hot air oven
the description:
a parabolic mirror is collecting sun radiation on a cast iron
receiver. Inside the receiver is a heavily finned surface.
A pv-cell powered fan is forcing hot air through the receiver
inside the oven. Inside the oven the air flow can be controlled
by using cast iron plates.
Temperature inside the receiver 600 C - 2000 C
Theoretical power for 2 sq m mirror 2 kw.
The efficiency?

Drying
Methods and Containers

In warm climates or in summer, sun-drying is easiest. The usual containers are flat trays with mesh on the bottom. The mesh allows the excess moisture to escape. The trays should be made so that they can be set out in the sun individually or stacked on top of each other for shade and air-drying.

The trays can be kept covered with cheesecloth to keep flies and moths from depositing eggs in the drying food. Alternatively, freezing the dried product for a few days, then thawing and storing, will effeetively kill off most insect eggs. Metal, plastic or snug wooden covers can be made for the stacked trays for fitting at night or in rain showers (e.g. for sweet potato drying in the tropics).

Andrassy (1978) records a good method of enriching dried food by first drying to 50% moisture, then plumping up by a soak in citrus, pineapple, or other fruit juices. This resembles the addition of passionfruit pulp, strawberries or acid fruits to bland pulps such as papaya and jak-fruit when making fruit 'leathers'. Vitamin C, if available, or citrus juice both preserve and fortify dried fruits. Similar methods are used in Africa for dry seaweed.

In cool climates or in areas where downpours are common all year round, a solar food dryer can be constructed. (**Figure 1.5** page 8) shows such a dryer (which can accommodate up to 8 trays made from mesh in a wooden frame). The flat-plate collector is constructed with metal and glass (or tough plastic) and is located just below the drying chamber. The essential is a black metal solar chimney to suck up hot air over the metal collector and through the drying unit. The solar chimney also exhausts water vapour from the drying product.

Oven drying temperature for vegetables, fruits, meat, fish, etc. should not exceed 50-66°C (122-150°F), even if oven doors are left open. Always check this with a thermometer. Frequent turning helps in drying.

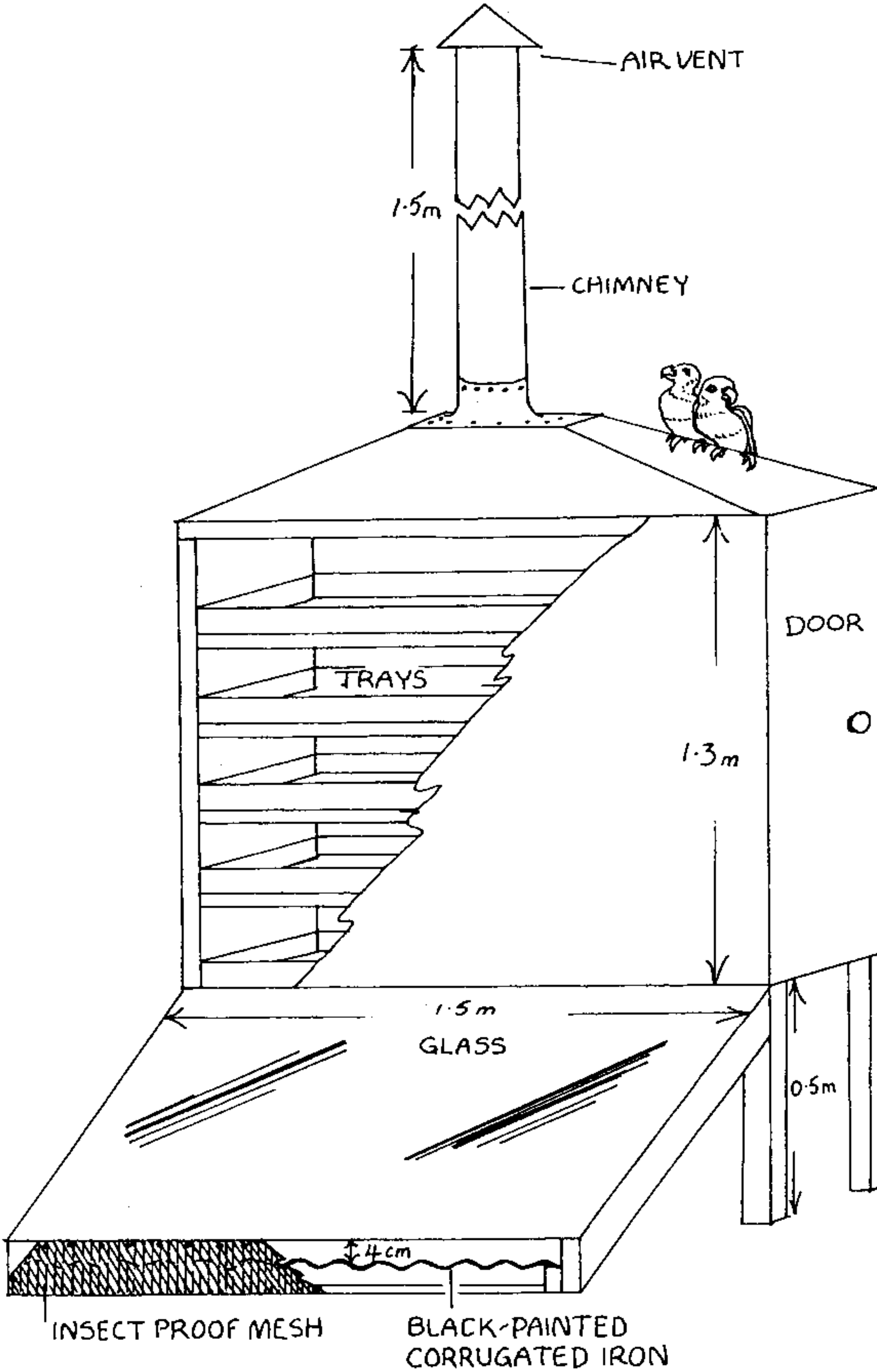


Figure 1.5 Solar Dryer

From **Introduction to food drying**

TESTS FOR DRYNESS:

Rely on appearance and feel to judge dryness.
Cool a test handful a few minutes before deciding whether the food is done.
Consider fruit dry when no wetness can be squeezed from a piece which has been cut - it should be rather tough and pliable.
Consider vegetables dry when brittle.

PRE- AND POST-DRYING TREATMENTS FOR FRUITS & VEGETABLES:

Steam blanching is safe pre-treatment which can prevent spoilage - especially of low acid foods such as vegetables.

Important post-drying treatments are:
Conditioning - i.e. leaving in open air for long periods to equalize moisture content.
Pasteurizing - i.e. exposing the dried foods to high heat to eliminate harmful organisms

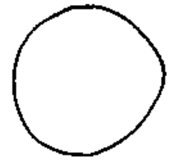
STORAGE:

Ensure food is thoroughly cool before storing.
Store in small quantities in glass or food-grade plastic.
Check supplies frequently for contamination or dampness.
Keep in a dry, cool place (between 4 C/40 F and 21 C/70 F).

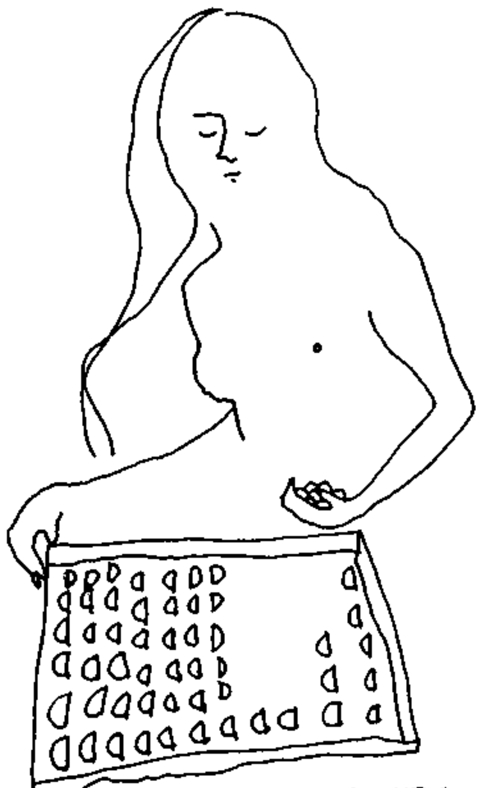
PREPARING FOR EATING:

Fruits - cover with boiling water in saucepan and simmer the fruit covered for 10-15 min.
- sweeten to taste at the very end of cooking.
- remove from heat and cool still covered Vegetables.
- soak all vegetables except greens in cold water until they are nearly restored to their original texture.
- use only enough water to cover and always cook in the soaking water.
- cover greens with enough boiling water to cover and simmer until tender.

you can dry apples pears, peaches, plums, cherries figs, grapes, coconut, guavas & asparagus, beans, beets, corn, cabbage and others (see below)



the entire process needs cleanliness of hands & equipment.



SUN-DRYING FRUITS AND VEGETABLES

1. select sound ripe produce (not bruised or over-ripe)
2. wash and peel, pit or slice as needed. Slice big fruit thin.
3. steam the vegetables in a basket over boiling water (see chart for time)
4. place on trays one layer thick and cover with a cloth or wire mesh to keep off dirt & insects.
5. turn over produce two or three times a day.
6. test for doneness by squeezing produce in your hand. It should leave no moisture and should fall apart when you let go. Berries should rattle in trays.
7. Place in a basket for a few days and stir three times a day
8. Store in closed containers in a cool dark place.
9. To restore vegetables, soak a few hours before using.

onions, sunflowers, garlic, herbs, peanuts, red peppers, and beans must be dried before storing. remove seeds from green chile peppers.

vegetable steaming chart

prepared vegetable	steaming time	
asparagus tips	4-5 minutes	
green string beans	15-20	
beets (no tops)	30-45	then peel & slice
broccoli	8-10	
cabbage (shredded)	8-10	
carrots rutabagas & turnips	8-10	then slice
corn	10-15	then cut from cob
shelled peas	10	
shoestring cut potato	4-6	
spinach & greens	4	don't wad on drying trays
sweet potato, squash & pumpkin (peeled & sliced)	'til tender	

tomatoes - dip in boiling water - then cold water - peel - cut up.

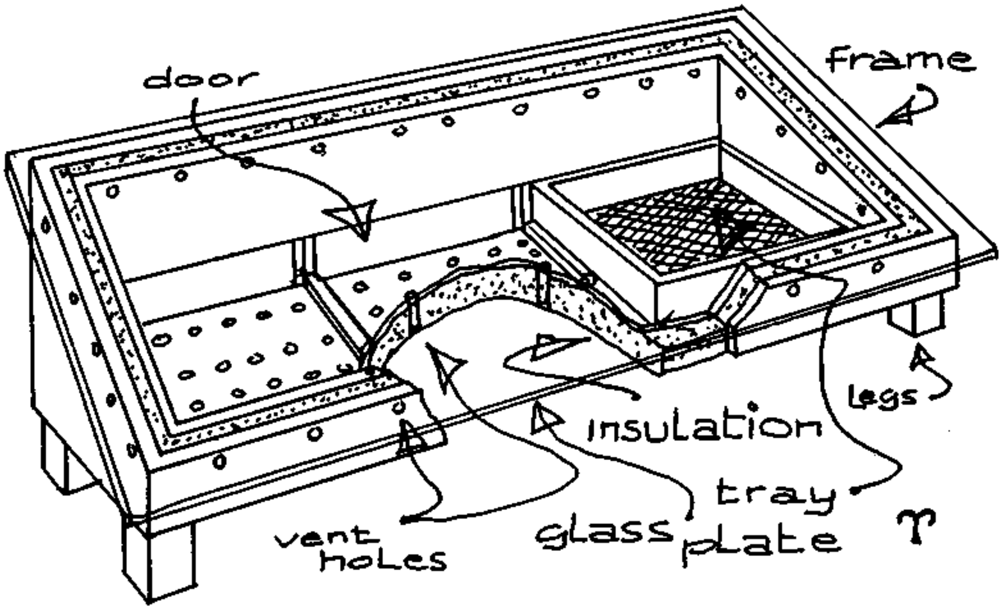


figure 1

A Solar Dryer

The usual method of drying fruits is to lay them out in the sun for a few days until they seem to have dried out enough to be stored. It's cheap but it does have its drawbacks; mainly bug and dust infestation (sun-dried apricots are nice but I sure get tired of picking dust out from between my teeth). To overcome the bugs and dust as well as improve the quality of your produce (even reduction of the moisture to the low levels required makes a longer storage time possible) you might want to build a solar dryer.

Essentially, the dryer is a solar hot-box. It consists of a rectangular container insulated at its base and preferably at the sides, and covered with a double-layered transparent roof. Solar radiation is transmitted through the roof and absorbed on the blackened interior surfaces. Owing to the insulation, the inside temperature is raised. Holes are drilled through the base to induce fresh ventilating air into the cabinet. Outlet ports are drilled on the upper parts of the cabinet side and rear panels. As the temperature increases, warm air passes out of the upper holes by natural convection creating a partial vacuum and drawing fresh air up through the base. As a result there is a constant flow of air over your fruits (or vegetables) which are placed on perforated trays inside the cabinet.

Method of construction is limited only by your imagination, available materials, and a few general rules.

The length of the cabinet should be at least three times the width so as to minimize the shading effect of the side panels.

Build the slope of the roof covering the angle designated in figure 2. This will give you the best angle for your latitude.

The transparent cover is best made of glass (1/8" or 3 mm.) although a polyester plastic film (about 0.005 inches thick) will also work.

You can build the framework out of most any building material. For the portable models use wood, metal, hardboard, plywood or even wicker or bamboo. If you wish to build something permanent, build it out of brick, stone, concrete or maybe even adobe. When insulating, try to use cheap local materials such as wood shavings, sawdust, reject wool or goat's hair.

Construct the hot box along lines similar to those outlined in figure 1. Make the insulation about 2 inches thick, both for the base and the side sections. Drill holes in the insulated base and fit them with short lengths of plastic or rubberized garden hose. If there are bugs around, cover these insulation holes with fine mosquito netting or gauze. Usually, the high heat inside the cabinet discourages insects, rodents, etc. from entering and feeding on the drying produce.

Attach the transparent (glass or plastic) covers to a frame and fit the frame onto the chassis of the cabinet, making sure that the cover is completely watertight so as to avoid deterioration of the interior and wetting of the insulation. Paint the framework black in order to absorb the maximum solar radiation.

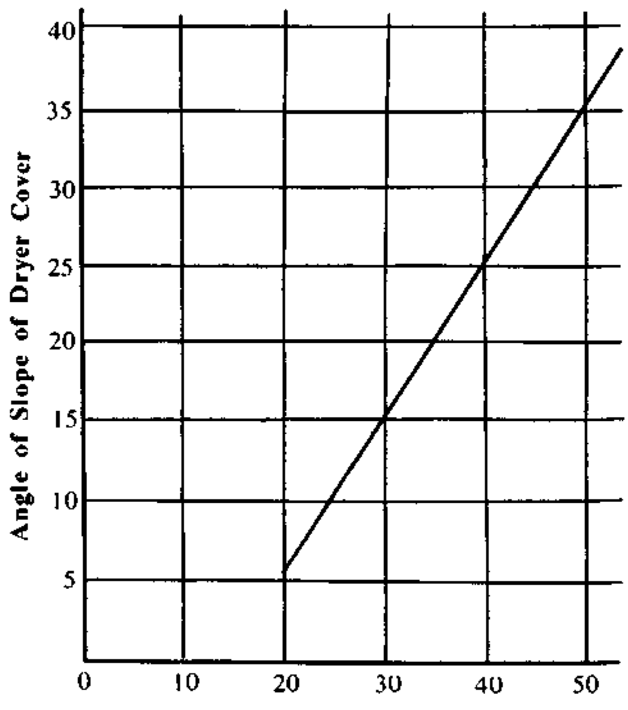


figure 2

Now is the time to drill a couple of holes in the rear and side panels to provide ventilation ports to remove the warm, moist air. The number of holes is dependent on your climate and whatever it is you wish to dry. A good method is to initiate the drying in the springtime, with a minimum of side holes and to continue drilling them so as just to prevent inside moisture condensation. This prevents drilling too many ventilation holes.

Fit the rear panel with access doors to give entry into the cabinet. Construct the trays of galvanized chickenwire or some similar material. Place them on runners about 1/2" high so as to ensure a reasonable level of air circulation under and around the drying material.

Paint the inside of the cabinet black. The outside of the side, rear and base panels should be painted with aluminum paint. If you wish to, cover the inside of the side and rear panels with a layer of aluminum foil (recycled of course) or if you have none, paint them black.

The dryer will handle about 1 1/2 pounds of produce per square foot of drying area. A small thermometer inserted into one of the ventilation holes will prove handy. Shield the thermometer bulb from direct sunlight. Temperature can be controlled by opening and closing the rear door if necessary. Practice will allow you to determine the optimal temperatures.

(reprinted from **The Mother Earth News**, no. 10)

Your produce should be perfect for drying. Use the blemished stuff for canning. Blemished or bruised fruits will not keep as well and may turn a whole tray of drying fruit bad. The smaller the pieces to be dried, the shorter the drying time. The layer of fruit should be no more than one piece deep.

Your fruit is dried when it feels dry on the outside but slightly soft inside. It should not be brittle, nor should it be possible to squeeze out any juice. After the drying is finished, store the fruit in glass or cardboard containers. For 4 successive days stir the contents thoroughly each day to bring the drier particles in contact with some that are more moist. If, at the end of the 4 days, the fruit seems too moist, return it to the drier for further treatment. Afterwards, store it in a cool place. It's a good idea to check it occasionally for molds.

This article is adapted from:

How to Make a Solar Cabinet Dryer for Agricultural Produce
by T.A. Laward.
available from:
Brace Research Institute,
Faculty of Engineering,
McGill University,
Montreal 2, P.Q.
Canada

FRUIT or VEGETABLE	PREPARATION FOR DRYING and DRYING METHOD
Beans (pod): String, Green, Snap, Wax	Wash and dry, cut or break off ends and pull strings, cut or break into one inch pieces, spread on frames or string on heavy thread, dry.
Beans (shelled): Lima, Pinto, Great Northern, Black, Soy, Kidney, Lentils, Pea (navy), Cranberry, Blackeyed peas, Cow-peas	Shell, grade if desired, spread on frames, stir daily until completely dry.
Peas: All types	Prepare and dry as for beans.
Cereal and bread grains: Barley, Corn, Oats, Rye, Buckwheat, Wheat, Rice	Spread on frames, stir daily until completely dry. Allow corn to stand on the stalks until fully mature, pick and husk, leave on cobs until grains are hard, strip from cob.
Herbaceous plants	If the plants have thick, juicy stems such as celery or rhubarb, slice thinly and spread on frames or string on heavy thread. Dry all other herbs whole, crumble when dry and separate large stems from leaves, store in air-tight containers.
Peppers: Bell, Green, Red, Cherry, Banana, Tabassco	Small peppers (Tabasco, Red) may be dried whole. Slice others in rings and spread on frames or string on heavy thread.
Tuberous root vegetables: Beets, Carrots, Parsnips, Potatoes, Salsify, Sweet potatoes, Yams, Turnips, Rutabaga	Peel or scrape skins, slice thinly and spread on frames, or cube and string on heavy thread. NOTE: When these vegetables dry, they may change color due to oxidation, but the color change will in no way harm the flavor.
Bulbous root vegetables: Onions, Leek, Kohlrabi	Peel and slice into thin rings (no more than 1/8 inch thick), spread on frames or string on heavy thread.
Apples: All types	Wash, peel, slice into rings (no need to core), spread on frames or string on heavy thread. NOTE: Apples turn brown when dried due to oxidation, but the color change does not affect the flavor.
Apricots: All types	Wash, cut in half and remove pit, spread skin side down on frames until dry. DO NOT TURN.
Berries: Blackberries, Blueberries, Loganberries, Gooseberries, Huckleberries, Raspberries, (black, red) Strawberries, Serviceberries, Mulberries, Juneberries, Shadberries, etc.	Wash, spread on frames until dry.
Cherries: All types	Wash, spread on frames until dry.
Currants: All types Figs: All types Grapes: All types	Pull from bunches (grapes), wash, spread on frames until dry.
Peaches: All types Pears: All types	Wash, halve or quarter if fruit is large, remove pit (peaches), spread skin side down on frames until dry. DO NOT TURN.
Plums: All types	Most plums do not dry well, the prune plum is best. Wash and spread on frames until dry.

SOLAR FRUIT DRYER

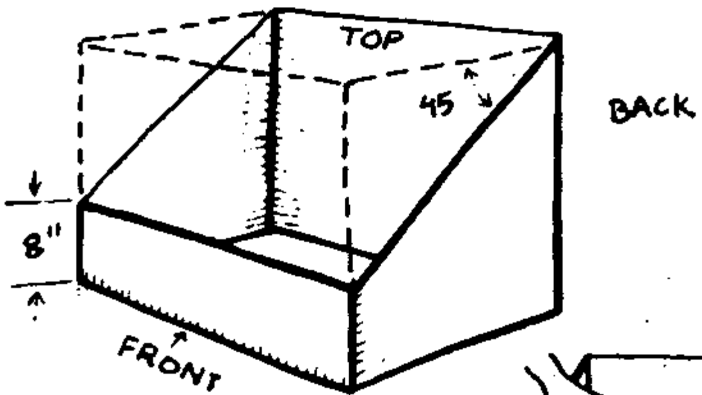
The basic principle of a solar dryer is that air is heated by the Sun in a collector and then passed over the produce which is to be dried.

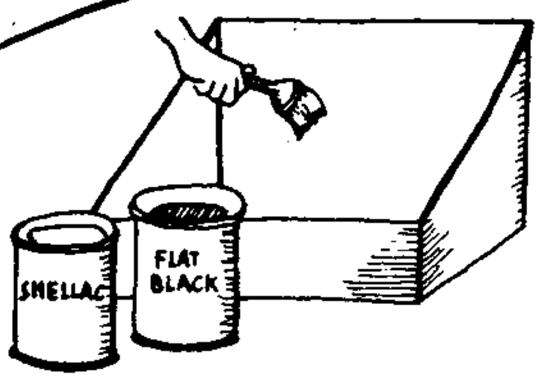
Many fruits can be dried in a Solar Fruit Dryer. Solar Dryers use the Sun's heat to evaporate the moisture in foodstuffs. When the moisture content is low, the food does not rot or go bad. This way we can preserve food and use it a long time later. Our grandmothers used to dry food for preservation by spreading it out on cloth sheets on the terrace. Perhaps your mother still makes potato chips in the same way. In the Solar Fruit Dryer, you can dry fruits, such as grapes, quite easily. And they taste especially good. If fresh grapes are Rs 20 a kilo in season, and dried grapes are Rs 200 a kilo, which is a better buy ?

You will need

- **A LARGE BOX**, such as the ones used to pack TVs
- **BLACK POSTER PAPER** or Black Enamel Paint
- **FEVICOL**
- Silver duct **TAPE**
- **NYLON SCREEN** or a piece of mosquito netting
- A wire clothes **HANGER**
- Clear vinyl **WRAP**, (transparent plastic)
- A piece of thick **CARDBOARD**

1 Find the Right Box

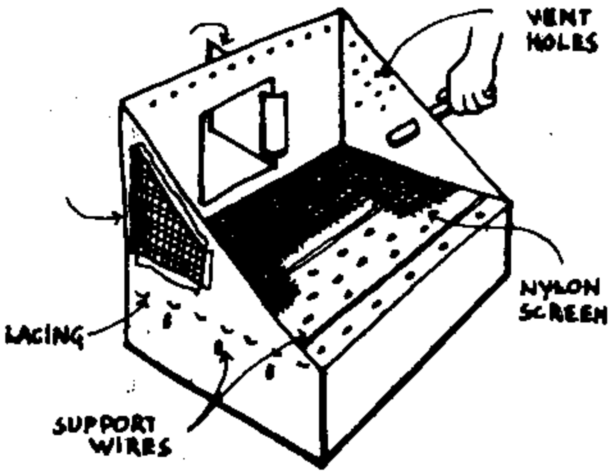




Find a box with dimensions that will leave about 20 cm in front when a 45° angle is made from the top corner.

Cut a section out of the box as shown. The entire inside of the box needs to be black. You can glue black poster paper to the inside with Fevicol. If you choose to paint, first brush on a coat of shellac, let dry for 5-7 hours, then paint with a flat black enamel paint.

2 Prepare the Box

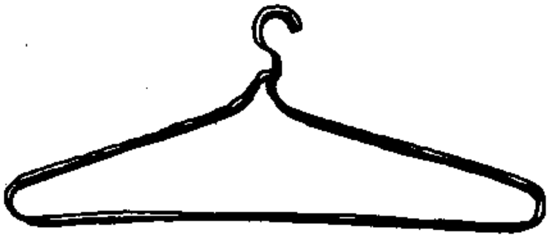


Next, cut a door in the back of the box large enough to let your hand through, plus whatever you will be putting in to dry. Reinforce the uncut, hinging part of the door with a piece of duct tape.

Poke holes in the bottom and sides, as shown, with a sharp pencil (about 30 holes). Evaporated moisture will be ventilated out through these holes.

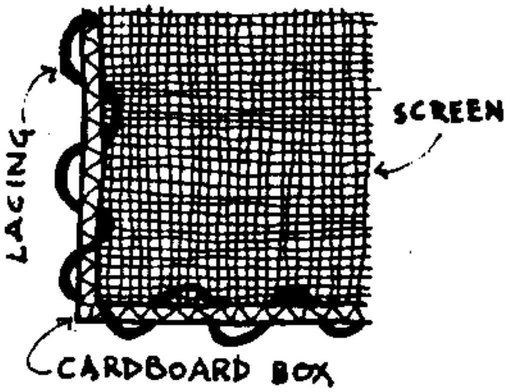
3 Make the Screen Support

Make 3 or 4 screen support wires out of a thick wire such as a coat hanger wire, and stick them through the box near the bottom as shown and bend down the ends.



4 The Nylon Screen

Get some nylon flyscreen material or mosquito netting and cut it larger than the bottom of the box, so that the edges can be turned up and laced to the sides of the box.



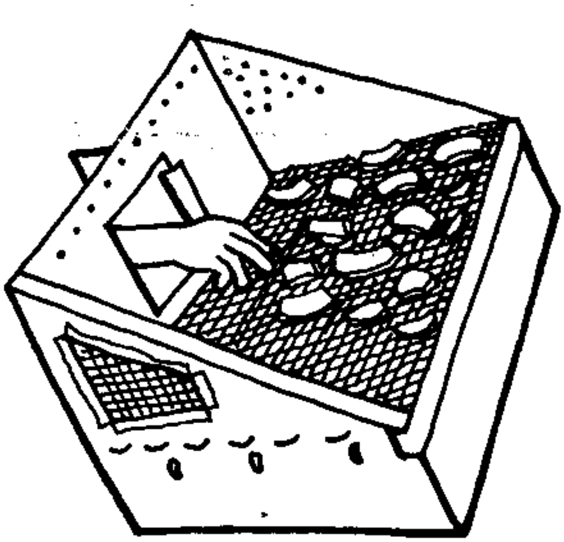
5 Glazing the Dryer Box

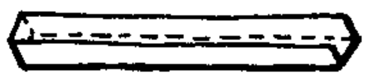
Use "Clear Vinyl Wrap" to cover the open top of the box.

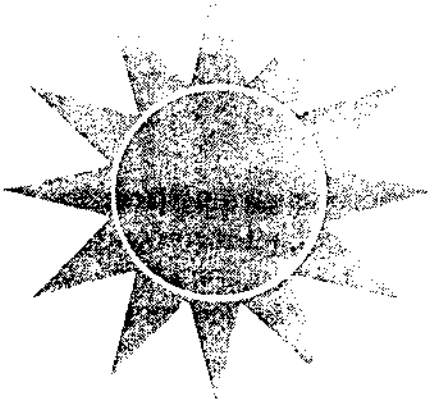
Fasten the edges down securely with tape.

Make 2 legs out of cardboard and fasten them to the bottom with duct tape as shown.

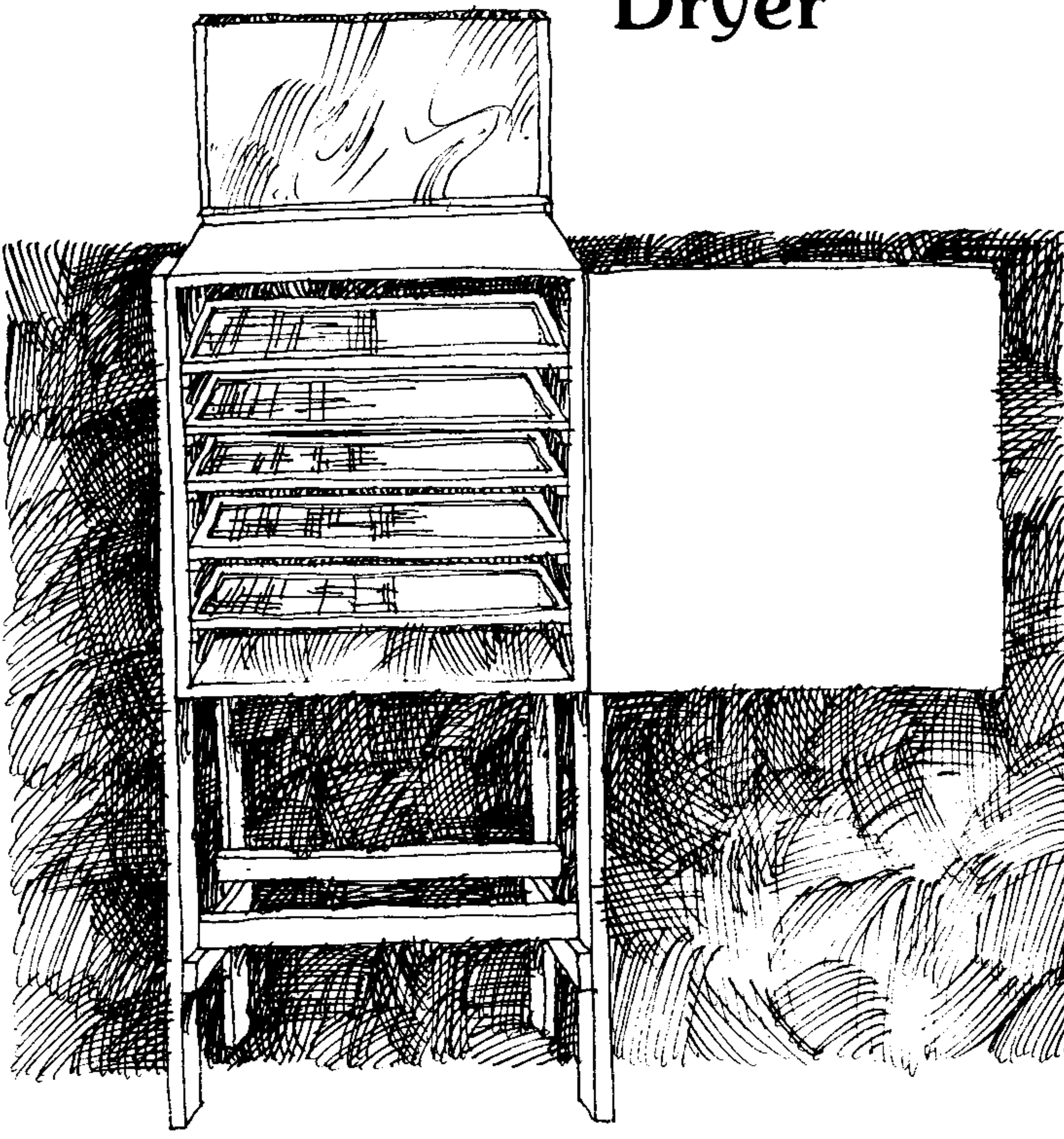
If you are worried that insects may get in, cover the vent holes with more of the nylon screen and fasten it with tape.







Food Dryer



There is nothing more satisfying than being able to chew on some tasty pieces of dried fruit in the middle of the cold winter months. This is a project that when completed will operate largely from solar power but can easily be adapted to use electrical drying should the need arise.

Fruit can be kept in your refrigerator for a few days until the weather is settled and then you can go into production; keep your fingers crossed!

The flat-plate collector heats up as direct or diffuse sunlight falls on it. Air inside the collector rises as it is heated and travels into the bottom front of the food-drying compartment. The hot moist air exits through a chimney which is blackened on the exterior to heat the air inside it and thus accelerate its elimination from the food dryer.

The food dryer is largely made from ¾-inch plywood.

Materials Required

2 4-by-8-foot sheets of ¾-inch plywood

½ 4-by-8-foot sheet of ⅛-inch hardboard

20 feet of 2-foot-wide nylon mesh screen

80 feet of ¾-by-¾-inch pine

2 2-by-3-foot used aluminum printing plates

1 24-by-18-by-3-inch light-gauge galvanized chimney

1 4-by-23¾-inch light-gauge galvanized draft controller

1 24¾-inch piano hinge

4 3-inch steel brackets

1 2-by-4-foot sheet of heavy-duty clear vinyl

1 thermometer

1 can flat black heat-resistant paint

1 quart high-gloss clear polyurethane paint

1 hook and eye

8 feet of self-adhesive weather stripping

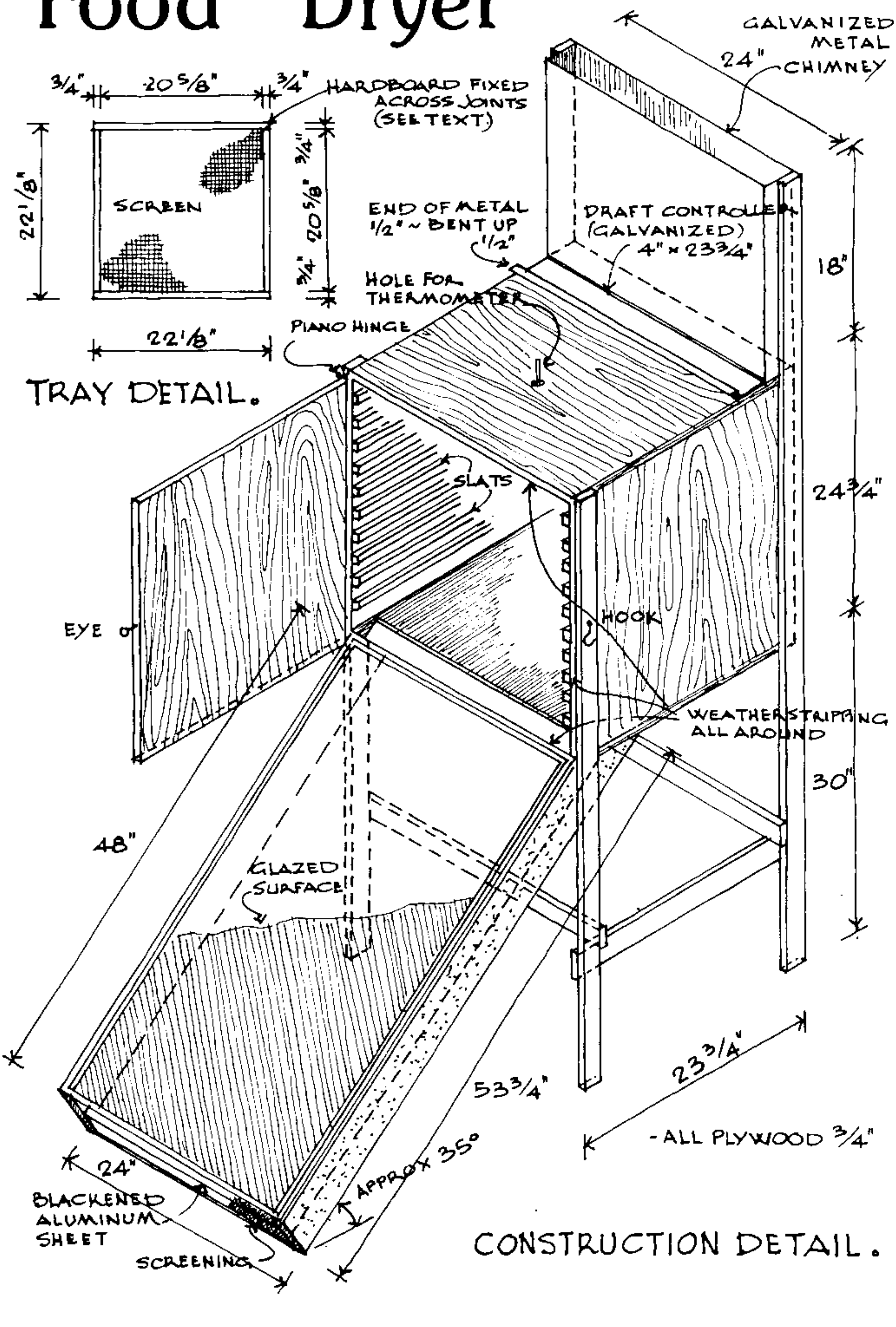
½ pound of 1½-inch galvanized finishing nails

½ pound of 1¼-inch galvanized finishing nails

paint for exterior

waterprocf glue

Food Dryer



3/4"
20 5/8"
3/4"
HARDBOARD FIXED ACROSS JOINTS (SEE TEXT)
22 1/8"
SCREEN
3/4"
20 5/8"
3/4"
22 1/8"
TRAY DETAIL.
24"
GALVANIZED METAL CHIMNEY
END OF METAL 1/2" ~ BENT UP
1/2"
DRAFT CONTROLLER (GALVANIZED) 4" × 23 3/4"
HOLE FOR THERMOMETER
PIANO HINGE
18"
SLATS
24 3/4"
EYE
HOOK
WEATHERSTRIPPING ALL AROUND
30"
48"
GLAZED SURFACE
23 3/4"
53 3/4"
-ALL PLYWOOD 3/4"
APPROX 35°
24"
BLACKENED ALUMINUM SHEET
SCREENING
CONSTRUCTION DETAIL.

Drying Compartment

The box which is to be the food-drying compartment is first constructed. Cut up plywood to the following dimensions: the door 24 by 24¾ inches; the back 24 by 24 inches; the two sides 24 by 22½ inches; the top 24 by 20 inches, and the bottom 22½ by 19¼ inches.

The two sidepieces should be glued and nailed to the back; nail through the back into the 24-inch lengths of the two sides. The top is then glued and nailed onto the top of the partially completed box, making sure to leave an opening for the chimney duct at the rear of the dryer. The bottom is then glued and nailed inside the hole left at the bottom of the dryer. Ensure that a 3¾-inch duct opening is left where the collector will later be attached.

Supporting Slats

Do not put the door on the dryer compartment until all the runner slats are attached. Cut ¾-by-¾-inch pieces of pine 22½ inches long and glue and screw these slats into place, leaving a 1-inch gap at the bottom of the dryer before the first supporting slat is put in place. Thereafter leave a 1⅜-inch gap between each of the supports; there are ten supports on either side of the dryer.

Drying Trays

Next comes the most the most tedious job—the construction of the drying trays.

Cut twenty pieces of pine ¾ by ¾ inch by 22⅛ inches long and twenty pieces of the same stock 20⅝ inches long.

Glue and nail the pieces together with the 20⅝-inch pieces fitting in between the ends of the longer 22⅛-inch pieces. Make sure that the completed frames are square. Stretch nylon mesh screen over the frames and staple it in place. Rip 20 pieces of ⅛-inch hardboard 22⅛ inches long and ¾ inch wide and 20 pieces 20⅝ inches long and ¾ inch wide. Glue and nail the 22⅛-inch-long pieces over the wooden frames, permanently sandwiching the mesh in place and also covering the joints in the underlying pine, thus giving the whole frame a lot more strength. The frames of the drying trays and the interior of the dryer may be sealed with urethane to produce a hard, washable, permanent finish.

Installing the Door

Using a piano hinge, attach the front door to the dryer. Weatherstrip the opening with self-adhesive foam weather-stripping. Screw in a hook-and-eye fastener to hold the door firmly in place.

Leg Supports

The legs are made from four pieces of ¾-inch plywood 2 inches wide; two of the legs should be 54¾ inches long and the other two 72¾ inches. Glue and nail these legs to the sides of the dryer as illustrated. Cross-brace the legs with further pieces of plywood, 2 inches wide; two being 24 inches long and the other two 25½ inches long (see illustration). Brackets may be attached to each leg and the base of the dryer if desired.

Chimney The chimney is fabricated from light-gauge galvanized sheet metal; its overall dimensions should be 18 by 3 by 24 inches. However, the back edge of the lower end of the chimney should extend an additional inch in order that the chimney may be firmly screwed to the back of the dryer. The extended legs are screwed to the chimney. A gap of 1/16 inch should be left between the chimney and the main body of the dryer to accommodate the draft controller. The chimney is then sprayed with heat-resistant flat black paint.

Collector The collector basically consists of a box which is single-glazed on the side facing the sun and contains a suspended sheet of blackened aluminum that heats up as the sun strikes it. The collector should be 4 feet in length in order to collect sufficient heat to dry the food. A 48-by-24-inch collector may be constructed as follows.

Using ¾-inch plywood, cut a base 53¾ by 22½ inches. Then cut two sidepieces, 4 inches wide and 53¾ inches long on the bottom edge, and 48 inches long on the upper edge. Glue and nail these pieces to the long sides of the base. Cut two collector plate supporting strips of pine ¾ by ¾ inch and glue and nail lengthwise so that the upper surfaces of the strips are 2 inches from the base of the collector. Obtain two 2-by-3-foot printing plates, rub them with steel wool and clean them with white spirits. Then, between the supporting strips already in place, attach four more strips, each 2 by ¾ by 1½ inches. Place one of these supporting strips at either end of the collector, and space the other two according to the exact dimensions of the printing plates you obtain. Clean the aluminum plates well and spray both sides with flat black heat-resistant paint. Then silicone and staple the plates into position after they have been trimmed to size.

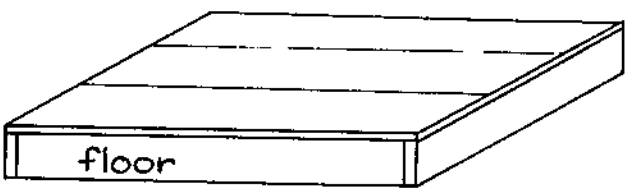
Glazing Glaze the collector with glass or plastic and hold the glazing in place with silicone and corner-profile 1-by-1-inch heavy-duty vinyl molding. Put a piece of screening across the bottom end of the collector to prevent insects from getting into your dryer. Screw the top end of the collector in position connecting it to the main body of the dryer.

You are now ready to dry up a stock of goodies for next winter's munching.

Making a Solar Drier

This drying box for fruit and vegetables works in the same way as a solar oven (see p 220).

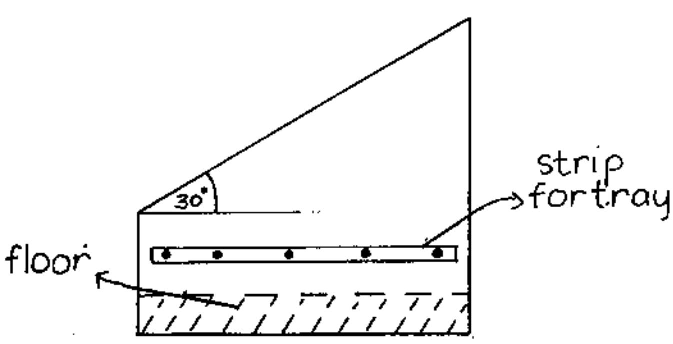
▶ The floor is a box 8cm deep and 80cm square, filled with sawdust, newspaper or dried grass so that it does not let heat out of the bottom.



▶ Cut the front piece of the box and drill the air holes

▶ Cut the side pieces of the box. They must be higher at the back than at the front so that the lid of the box slopes to face the sun.

▶ Screw on 2 strips of wood about halfway up the side pieces. These strips will hold up the drying tray.



▶ Put the box together: screw the side pieces to the floor with the wooden strips on the inside. Screw the front piece to the base and the side pieces. Fit the back cross piece in place and screw it to the side pieces. Paint the inside walls and floor with blackboard paint.

▶ Cut the cross piece for the top of the box at the back. Drill air holes in the plank and cover them with mosquito mesh to keep out fruit flies.

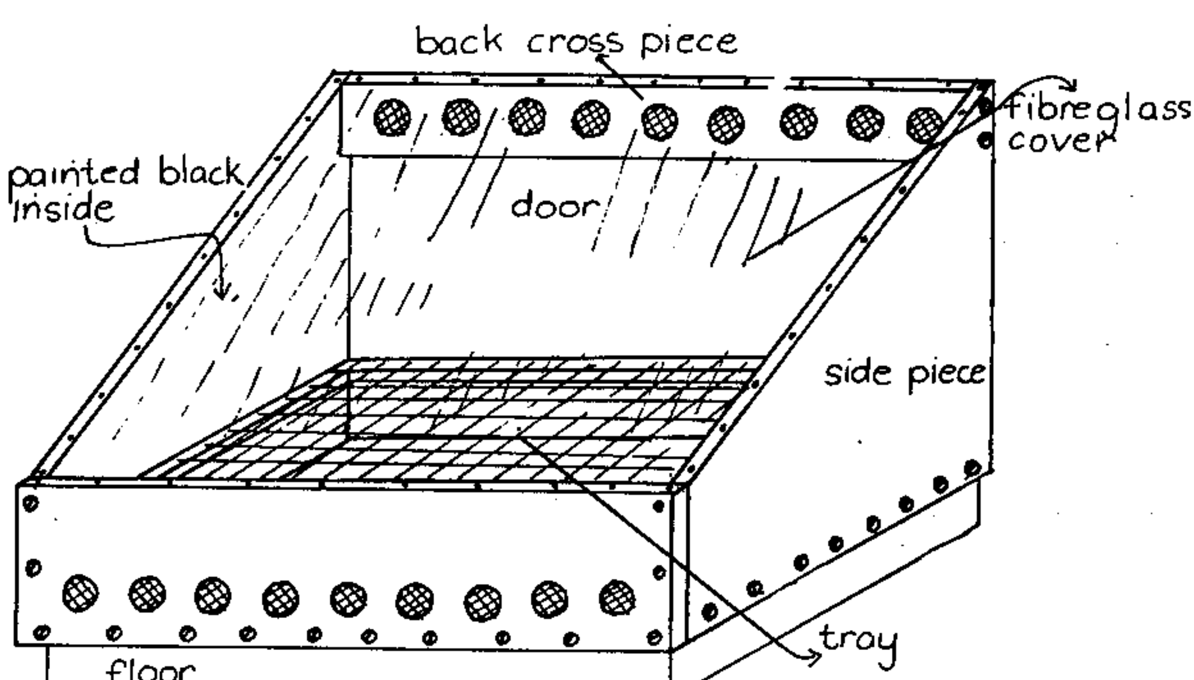
▶ Make the drying tray out of wire mesh with a wooden frame.

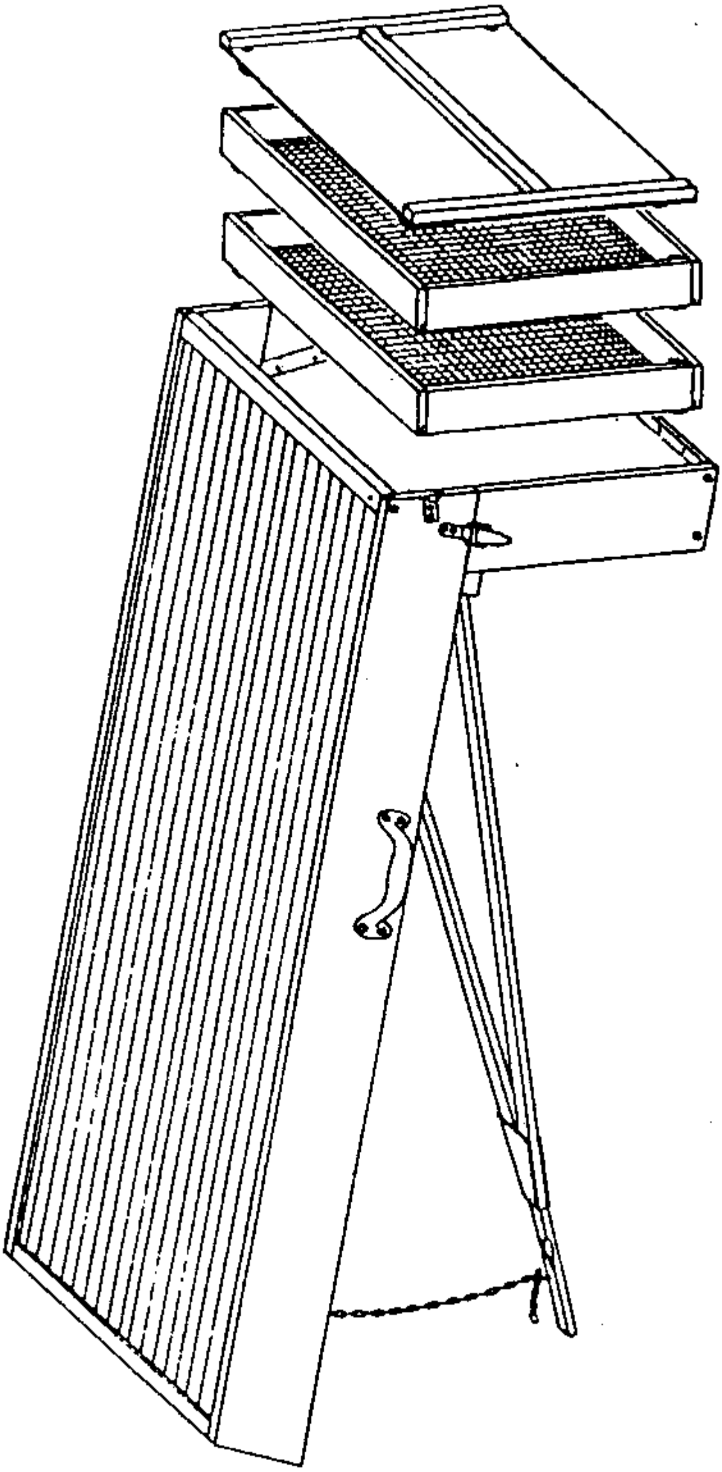
▶ Make a door for the back to fit the space between the back cross piece and the floor. The door must have hinges and fit tight to keep out fruit flies. Paint the inside of the door black.

▶ Paint the outside of the solar drier with a light coloured enamel paint.

▶ Put on the top. It is best to use fibreglass because plastic sheeting is not very strong and glass can get broken. Put rubber strips between the fibreglass and the box to stop rain getting in. A sheet of fibreglass 1m long and 50cm wide costs about R5.

To dry fruit first cut it into pieces and put it in boiling water for one minute. Put the fruit in cold water to cool, then put it into the drying box. Most fruit takes a day to dry. Peaches, apricots, pears, plums and apples are all good for drying.





SOLAR-TROCKNER ULOG

ZUM TROCKNEN VON LEBENSMITTELN

IN NICHTTROPISCHEN GEBIETEN

Anleitung zum Selbstbau

SONNENENERGIE FÜR ALLE!

Das ist das Motto der Gruppe ULOG, ein lockerer Zusammenschluss engagierter Leute in der Schweiz, die sich dafür einsetzen, die Sonnenenergie auch für die Mehrheit der Weltbevölkerung, die Armen im Trikont (3.Welt), zugänglich zu machen. Die Uebernutzung von Holz, des dort verbreitetsten Energieträgers, hauptsächlich zur Nahrungszubereitung, führt zu Bodenerosion und schliesslich zur Verwüstung weiter Gebiete. Wir haben es uns deshalb zur Aufgabe gemacht, ein einfaches, fast überall herstellbares Kochgerät bekannt zu machen, das ausschliesslich mit direkter Sonnenstrahlung auskommt und womit die meisten Gerichte zubereitet werden können. Es handelt sich dabei um den Solar-Ofen ULOG, der im Grunde nichts als eine gut isolierte, innen geschwärzte und mit einem Fenster abgedeckte Kiste ist. In der Schweiz und in vielen Ländern des Trikonts hat er inzwischen zahlreiche AnhängerInnen gefunden. Es hat sich gezeigt, dass diese einfache Technologie erst durch den Einsatz auch bei uns für den Trikont glaubwürdig wird. Mit dem Solar-Ofen ULOG lässt sich aber auch in unserem Klima auf bequeme Weise ein wesentlicher Teil der Kochenergie sparen.

Das gleiche Ziel verfolgen wir mit dem Solar-Trockner ULOG, mit dem praktisch alle frischen Lebensmittel wie Früchte, Gemüse, Kräuter, Pilze, Fleisch, Fisch und Käse auf natürliche Weise, für lange Zeit und ohne Fremdenergie haltbar gemacht werden können. In vielen Gebieten des Trikonts gehen beträchtliche Mengen an Nahrungsmitteln verloren, weil sie nicht rechtzeitig haltbar gemacht werden können. Das Trocknen an der freien Luft ist oft zu langsam und zudem unhygienisch, da die Lebensmittel vor Staub und Schadinsekten ungeschützt sind und das Trocknen über dem Feuer benötigt viel Holz. Der Solar-Trockner kann hier Abhilfe schaffen. Dieser ist ähnlich einfach in der Herstellung wie der Solar-Ofen und lässt sich in der Grösse gut den Bedürfnissen anpassen.

Es gibt im Grunde zwei Arten von Solar-Trocknern. Die einfachere Bauweise sieht ähnlich wie ein Solar-Ofen aus, nur dass die Kiste mit seitlichen Lüftungsöffnungen versehen ist. Das Trockengut wird auf Gittern hinein gelegt und, um es vor direkter Sonnenstrahlung zu schützen, abgedeckt. Das durch die Scheibe dringende und auf die schwarzen Oberflächen treffende Sonnenlicht heizt die Luft im Innern auf und entzieht dadurch dem Trockengut die Feuchtigkeit. Der wesentliche Nachteil dieser Bauweise ist, dass durch den geringen Höhenunterschied zwischen dem Luftein- und -auslass kein genügender Luftaustausch besteht. Dadurch braucht es zum Trocknen eine höhere Temperatur, die aber für wertvolle Inhaltsstoffe im Trockengut schädlich ist.

Bei der anderen Bauweise ist die Warmlufterzeugung und der Trockenraum getrennt. Sie besteht aus einem geneigten Kollektor, einem flachen, an beiden Enden offenen Kasten, der mit einer durchsichtigen Platte abgedeckt ist und in dem sich ein schwarzes Blech, der Absorber befindet. Von dort gelangt die warme Luft in eine dunkle Kammer, in der das Trockengut auf Gittern verteilt wird. Die feuchte Luft entweicht oben, häufig über ein Kamin. Dieses erzeugt den nötigen Luftzug durch den ganzen Trockner.

Das vorliegende, transportable Modell des Solar-Trockners ULOG ist für Haushalte mit relativ wenig Trockengut gedacht. Es gleicht der zweiten Bauart, doch der Kollektor ist mit 67.5° deshalb so stark geneigt, damit die warme Luft ohne Kamin von selbst nach oben strömt. Am oberen Ende befindet sich nicht eine Kammer, sondern ein Pult, auf das die Trockensiebe und zuoberst ein Deckel gelegt werden. Dabei können die handelsüblichen, runden Siebe für elektrische Trockner oder selbstgemachte, rechteckige Holzsiebe verwendet werden. Das Pult lässt sich zum platzsparenden Verstauen abnehmen. Diese Anleitung ist auf den bei uns erhältlichen Bausatz abgestimmt. Es gibt den Trockner aber auch als Fertiggerät.

STOCKLISTE

Pos.	Anz.	Benennung	Abmessungen [cm]	Material
1	1	Absorberblech	100 x 78 x 0.03	Offsetplatte
2	1	Tropfblech	30 x 70.5 x 0.03	"
3	1	Transparente Doppelstegplatte	120 x 68 x 0.45	Polycarbonat
4A	1	Seitenwand Kollektor l.	126 x 10 x 1.5	Holz
4B	1	" " r.	126 x 10 x 1.5	"
5A	1	" Pult l.	39 x 10 x 1.5	"
5B	1	" " r.	39 x 10 x 1.5	"
6	1	Rückwand Pult	67 x 10 x 1.5	"
7	2	Anschlagleiste	97 x 1.5 x 1.5	"
8	2	Verstrebungsleiste	67 x 3.5 x 2	"
9	1	"	70 x 3.5 x 2	"
10	2	"	67 x 3 x 1.5	"
11	1	"	70 x 3 x 1.5	"
12	2	Stütze	115 x 2.5 x 2	"
13	1	Rückwand Kollektor	100 x 67 x 0.3	Hartfaserplatte
14	1	Pultboden	70 x 28 x 0.3	"
15	1	Abdeckplatte Pult	70 x 35 x 0.6	Sperrholz
16	2	Abdeckleisten	67 x 2 x 0.6	"
17	2	Lamello	No. 20	
18	2	Scharnier	5 x 2.2 x 0.15	Stahl verz.
19	2	Kofferecke	3 x 3 x 0.15	"
20	1	Traggriff	14	Stahl schwarz
21	1	Kette	110	Stahl verz.
22	2	Hakenholzschraube	ø 0.3 x 3	Stahl
23	1	Halbrundholzschraube	ø 0.3 x 2	"
24	4	Senkholzschraube	ø 0.4 x 4.5	"
25	13	"	ø 0.3 x 3	"
26	6	"	ø 0.3 x 2	"
27	4	"	ø 0.3 x 1.6	"
28	18	"	ø 0.25 x 2	"
29	12	"	ø 0.25 x 1.7	"
30	4	"	ø 0.25 x 1.2	"
31	12	Senkkopfnagel	ø 0.15 x 2.5	"
32	50	Flachkopfnagel	ø 0.15 x 1.5	"
33		Anstrich Absorber	Abtönpaste schwarz	Auro Nr.338
34		Isolation		Holzwolle
35		Holzleim		wasserfest
36		Wetterschutz		z.B. Leinöl
37	2	Holzdübel	ø 0.8 x 4	
38	2	Sicherungsschnur	ø 0.2 x 8	Nylon

Trockensieb

39	2	Seitenwand	69.5 x 5 x 1.5	Holz
40	2	"	29.5 x 5 x 1.5	"
41	4	Eckleiste	5 x 2 x 2	"
42	1	Gitter	68.5 x31.5 x 0.2	Polyäthylen
43	20	Senkkopfnagel	ø 0.15 x 2.5	Stahl
44	16	Agraffen	No. 2	"

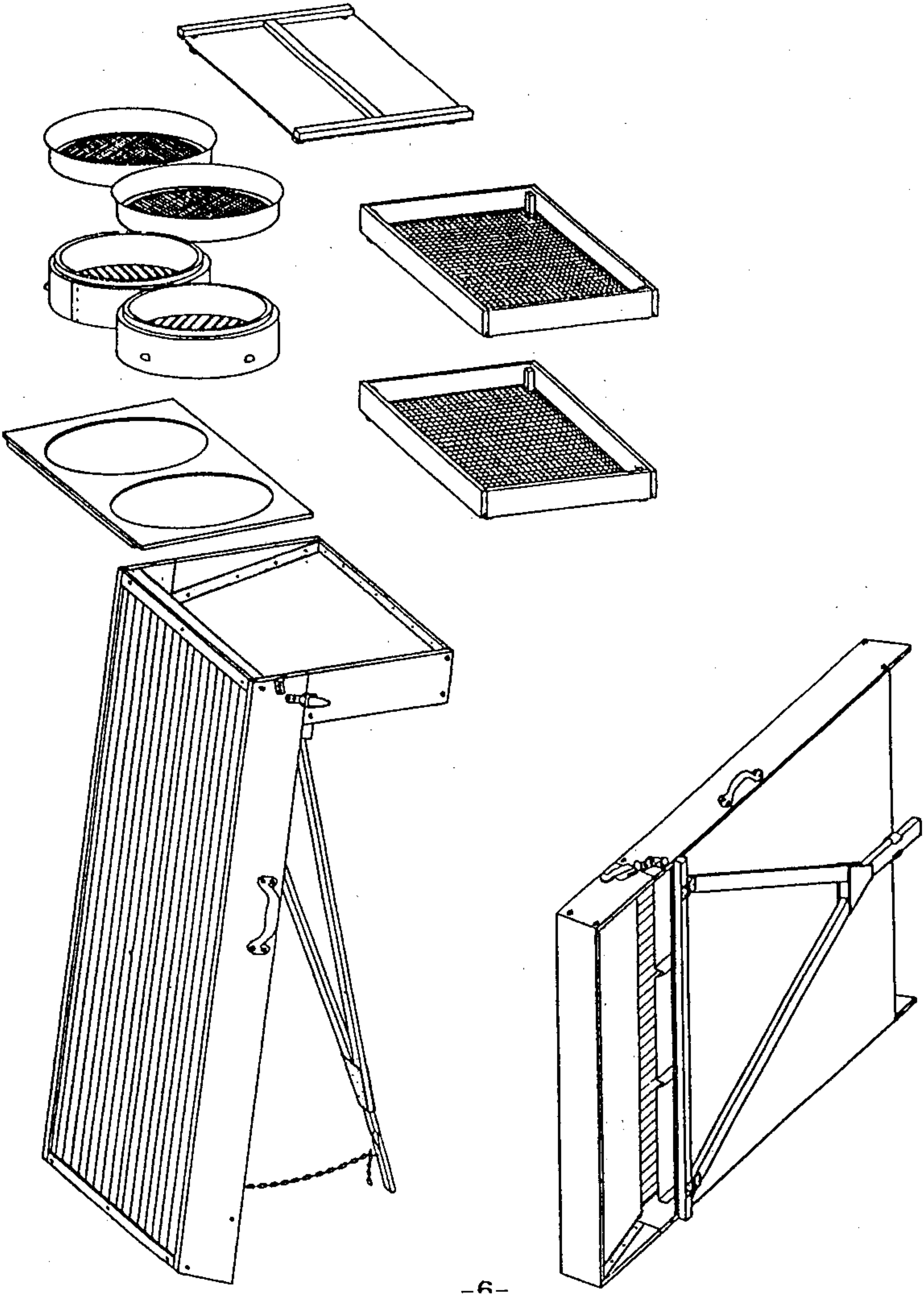
Deckel

45	1	Deckplatte	70 x 33 x 0.4	Sperrholz
46	2	Verstärkungsleiste	33 x 3 x 1.5	Holz
47	1	"	64 x 3 x 1.5	"
48	4	Distanzklotz	3 x 2 x 2	"
49	10	Senkkopfnagel	ø 0.15 x 1.5	Stahl
50	4	"	ø 0.15 x 2.5	"

VARIANTEN FÜR EINZELNE TEILE DER STÜCKLISTE

Wenn der Solar-Trockner ULOG von Grund auf selber gebaut wird, können für einzelne Teile der vorgängigen Stückliste andere Materialien gewählt und im Zusammenbau gewisse Aenderungen vorgenommen werden, die den Einsatz von Holzbearbeitungsmaschinen unnötig machen. Es ist auch möglich, die Grösse des ganzen Trockners entsprechend den Bedürfnissen zu verändern, wobei die bestehende Länge des Kollektors nicht wesentlich unterschritten werden sollte, damit ein genügender Luftzug gewährleistet bleibt.

Pos.	Variante:
1/2	Aluminiumblech von max. 0.5 mm Stärke oder Eisenblech von max. 0.2 mm Stärke (z.B. Wellblech).
3	Glasfaserverstärktes Polyester (Stärke 1 bis 2 mm) oder Glas (Stärke 2 bis 4 mm), das aber teuer, zerbrechlich und schwer ist und entsprechend eine Verstärkung der ganzen Konstruktion bedingt.
4/5/6	Bei schlechter Holzqualität grössere Holzstärke (bis ca. 2.5 cm). Anstatt der Nut in Pos. [4] für Pos. [3] kann auch eine Anschlagleiste analog Pos. [7] für Pos. [13] verwendet werden. Verbindung der Pos. [4] und [5] ohne Fälzung auf zwei Arten: Die beiden Teile können mit der vollen Holzstärke übereinandergelegt werden, wobei sich die Breite des Pults um die doppelte Holzstärke der Pos. [4] und [5] verbreitert, was eine entsprechende Anpassung der Länge der Pos. [6], [8], [14] und [15] bedingt. Diese Art eignet sich vor allem für die feste Verbindung zwischen den Pos. [4] und [5] (mit Nägeln verstärken). Bei einer losen Verbindung können die beiden Teile Kante an Kante stossen. Für den nötigen Halt sorgen auf beiden Seiten je ein in die eine Kante eingeleimter Holzdübel mit dem dazu passenden Loch in der anderen Kante und ein Kistenverschluss mit 2 Kloben, je einer für die Normal- und die gestreckte Stellung des Pults (siehe Zeichnung S. 6.)
7 - 12	Leicht geänderter Querschnitt unter Beibehaltung der Winkel.
13/14	Grössere Stärke (bis ca. 5 mm)
15	Kleinere Stärke (bis ca. 4 mm).
17	Verzapfung zwischen Pos. [5] und [6] oder 3. Schraube.
33	Anderer schwarzer Anstrich mit ungiftigen Lösungsmitteln (z.B. Wandtafellack). Aus Russ oder Eisenmanganpulver und Halböl lässt sich selbst eine Anstrichfarbe herstellen. Halböl besteht aus einem Teil Terpentin und einem Teil gekochtem Leinöl. Mischung vor dem Streichen mehrere Stunden stehen lassen.
34	Hobelspäne, Heu oder Zeitungspapierkneuel.
36	Wetterfester Farblack oder Klarlack.



BAUANLEITUNG

1. Allgemeines:

- Die Bauanleitung bezieht sich auf die in der Stückliste zusammengestellten Teile. Varianten zu einzelnen Teilen sind separat auf S. 5 aufgelistet.
- Diese Anleitung ist in erster Linie darauf ausgelegt, den Bausatz dieses Solar-Trockners ULOG zusammenzubauen, doch ermöglicht sie es auch, die Holzteile selbst herzustellen.
- Beim Anfertigen der Teile und beim Zusammenbau ist genau zu arbeiten. Ungenauigkeiten können sich negativ auf die Funktionstüchtigkeit des Trockners auswirken. Auch sind Korrekturen und Anpassungen zeitaufwendig.
- Die Positionsnummern der einzelnen Bauteile erscheinen durchwegs in eckigen Klammern, z.B. [5].

2. Absorber- und Tropfblech:

1. Schneide das Absorber- [1] und das Tropfblech [2] auf die richtige Grösse. Du brauchst dazu ein mind. 1 m langes Metallineal und ein Teppich- oder Japanmesser. Damit ritzt Du entlang der Schnittlinien, worauf diese durch mehrmaliges Hin- und Herbiegen brechen.

2. Markiere auf der rauhen Seite der Pos. [1] die Falzlinien gemäss der Zeichnung S. 14 oben und biege sie in der über der Zeichnung mit Nummern angegebenen Reihenfolge mittels des Lineals und der Tischkante, sofern diese scharf genug ist. Achte darauf, dass entsprechend ihrer Kennzeichnung die Falzlinien nach oben oder nach unten gebogen werden müssen.

3. Der Anstrich des Absorbers [33] wird am besten mit erdschwarzer Abtönpaste von Auro, eine natürliche und giftfreie Farbe mit wohlriechenden Dämpfen, mit einem Pinsel aufgetragen und zwar auf der rauhen Seite der Offsetplatte. Wegen der starken Wasserlöslichkeit des Anstrichs auch im trockenen Zustand ist das Streichen etwas heikel. Sowohl der 1. wie der 2. Anstrich sollte so dünn wie möglich aufgetragen werden. Vermeide es, beim 2. Anstrich die gleiche Stelle mehrmals zu überstreichen, da sonst die trockene Grundschicht leicht wieder aufgelöst wird und so das blanke Blech wieder zum Vorschein kommt. Sollte ein 3. Anstrich notwendig sein, darf nur an den noch hellen Stellen ausgebessert werden.
Sollten beim späteren Gebrauch des Solar-Trockners Tropfen vom Trockengut auf den Absorber gelangen, diese auf keinen Fall mit einem Lappen wegwischen, weil sonst das helle Blech wieder hervorscheint. Die Tropfen trocknen an der Sonne von selbst.

4. Pos. [2] dient nicht nur als Tropfblech, sondern auch dazu, die warme Luft aus dem Kollektor gleichmässig auf die Trockensiebe zu verteilen, indem es nach hinten schräg ansteigt. Markiere die Falzlinien auf der glatten, spiegelnden Seite gemäss der Zeichnung S. 14 unten. Vor dem Biegen müssen an den oberen zwei Ecken mit einer gewöhnlichen Schere je ein Einschnitt gemacht und die unteren beiden Ecken ganz herausgeschnitten werden.

3. Kollektor:

1. Bei den Seitenwänden des Kollektors [4] sind die linke und die rechte Seite unterschiedlich (Pos. [4A] und [4B]), genauer spiegelbildlich zueinander. Die Nut für Pos. [3] ist auf der Innenseite, die Fälzung oben zur Verbindung mit dem Pult hingegen auf der Aussenseite. Unten befindet sich ein Ausschnitt für Pos. [10]. Bohre an den in der Zeichnung S. 15 angegebenen Stellen die Löcher ø 3 mm für die Schrauben zur Verbindung mit den Verstrebungsleisten.

2. Befestige mit Holzleim und je 6 Nägeln [31] die Anschlagleiste [7] für Pos. [13] auf die Innenseite von Pos. [4] gemäss Zeichnung S. 15. Schlage die Nägel durch die Leiste in die Seitenwand, damit man sie von aussen nicht sieht. Achte darauf, dass sie gegenüber der Hinterkante der Pos. [4] um die Dicke der Pos. [13] (3 mm) nach innen verschoben sind.

3. Nun kann das Gerüst des Kollektors mit den vorbereiteten Seitenwänden [4] und den 4 Verstrebungsleisten [8], [10] und [11] zusammengebaut werden (siehe Zeichnung S. 10 /11). Zur Befestigung der Leisten [8] und [10] werden neben Holzleim je 2 Schrauben [25] und für die Leiste [11], die an den Enden vorgebohrt ist, 2 Schrauben [24] verwendet. Achte auf die Bündigkeit der Leisten gemäss der Zeichnung S. 13.

4. Befestige nun die Rückwand des Kollektors [13] mittels Nägeln [32] entlang der Pos. [7] und [10] und zwar mit der glatten Seite der Platte nach aussen. Sie kommt dabei bündig zur Unterkante von Pos. [10] und zur Unterkante der Fälzung an Pos. [4] zu liegen.

4. Pult:

1. Bohre in die Seitenwände des Pults [5] die 3 Löcher ø 3 mm für Pos. [8] und [6] gemäss Zeichnung S. 15.

2. Leime die 2 Lamellos [17] in die beiden dafür eingefrästen Nuten in der Rückwand des Pults [6]. Verbinde die Pos. [5A] und [5B] mit der Fälzung nach innen rechtwinklig mit Pos. [6] mittels der Lamellos, Holzleim und je 2 Schrauben [25]. Befestige nun die Verstrebungsleiste [8] mittels 2 Schrauben [25] und Leim mit dem Pult (siehe Zeichnungen S. 10/11 und 13).

3. Fixiere den Pultboden [14] am Pult aussen bündig zu den Wänden und der Verstrebung mittels ca. 10 Nägeln [32].

4. Nun kann das Tropfblech [2] mit der spiegelnden Seite nach oben in das Pult eingebaut werden (siehe Zeichnung S. 13). Befestige es zuerst mittels Nägeln [32] entlang Pos. [6] und zwar so, dass die umgebogene Blechkante bündig zur Oberkante der Pos. [6] ist. Bevor die anderen Seiten auch mit Nägeln [32] befestigt werden, muss im Zwischenraum von Pos. [14] und [2] mit der Isolation [34] ausgefüllt werden, wobei die Schräge der Pos. [2] berücksichtigt werden muss. Am unteren Ende wird das Blech entlang der Vorderkante von Pos. [8] befestigt.

5. Zusammenbau von Pult und Kollektor:

1. Die Verbindung des Pults mit dem Kollektor kann entweder fest verleimt sein oder so, dass das Pult zum platzsparenden Verstauen des ganzen Trockners abnehmbar ist:
   Im ersten Fall werden einfach die Fälzungen mit Leim versehen und die beiden Teile so zusammengeschoben, dass die Fälzungen vollständig übereinanderliegen und keine Absätze und Spalten mehr sichtbar sind.
   Im zweiten Fall benötigen wir die Holzdübel [37] mit ihrer Sicherungsschnur [38]. Zudem muss im Schwerpunkt der parallelogrammförmigen Fälzung in den Pos. [4] und [5] ein Loch ø 8 mm gebohrt werden (siehe Zeichnung S. 13). In dieses kann nun sowohl in der Normal- wie in der gestreckten Stellung des Pults Pos. [37] zum Sichern des Pults gesteckt werden. Fixiere Pos. [38] an einem Ende an Pos. [37] und am anderen Ende z.B. an der Stirnseite von Pos. [9]. Dadurch kann Pos. [37] nicht verloren gehen.

6. Stütze:

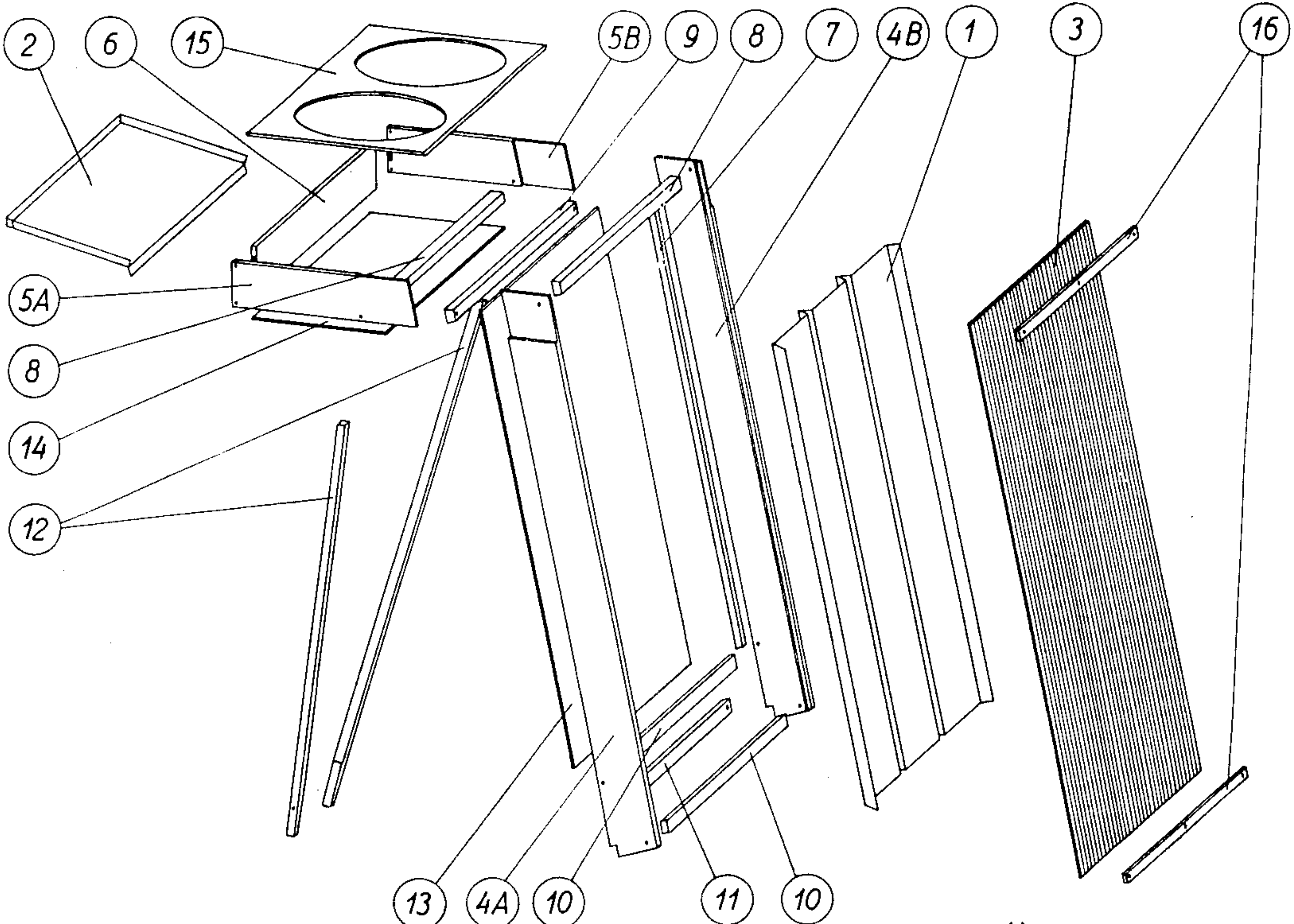
1. Befestige mittels 2 Schrauben [24] im Knick zwischen Kollektor und Pult auf der Rückseite die an den Enden vorgebohrte Verstrebungsleiste [9] (siehe Zeichnung S. 13). Die Schrauben finden dabei in der Hinterkante der Pos. [4] Halt. Nagle darauf mittels Nägeln [32] Pos. [13] an Pos. [9].

2. Wenn Du die beiden Holzteile der Stütze [12] richtig auf die Rückwand des Kollektors legst, bildet sich ein gegen Pos. [9] hin offenes V. Am unteren Ende, wo die beiden Teile zusammenkommen, müssen die angeschrägten Flächen vollständig aufeinanderliegen (siehe Zeichnung S. 15). Verbinde sie mittels Leim und einer Schraube [25]. Fixiere nun die aufgeklappten Scharniere [18] mit je 6 Schrauben [29] am oberen Ende der Stütze und an Pos. [9]. Die Scharnierachsen kommen dabei auf die Unterkante von Pos. [9] zu liegen. Achte darauf, dass bei Pos. [12] keine Ecke des Scharniers übersteht und dass bei allen 3 Löchern ein genügender Abstand zu den Kanten der Leiste besteht.

3. Befestige das Ende der Kette [21], das ein kreisrundes Loch aufweist, mittels der Schraube [23] an die Mitte der Unterkante von Pos. [10] auf der Rückseite des Kollektors (siehe Zeichnung S. 13).

4. Schraube in die Mitte der zu Pos. [13] rechtwinkligen Kante von Pos. [9] eine Hakenholzschraube [22]. Sie dient dazu, das Ende der Kette in der eingeklappten Stellung der Stütze daran einzuhängen.

5. Schraube die andere Hakenholzschraube [22] ins untere Ende der Stütze und zwar in die der Rückseite des Kollektors zugewandte Seite (siehe Zeichnung S. 13). Sie hat 2 Funktionen: einerseits kann im aufgeklappten Zustand der Stütze die Kette zur Sicherung der Stütze daran eingehängt werden und auf der anderen Seite dient sie zum Einrasten der Stütze an Pos. [11] im eingeklappten Zustand der Stütze. Pos. [22] ist also so anzubringen, dass durch leichtes Drehen der Schraube dessen vorderes Ende auf der Innenseite der Leiste einhakt.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7. Endausbau:

1. Montiere nun den fertigen Absorber [1] in den Kollektorkasten. Befestige mittels je 3 Schrauben [26] den umgebogenen, seitlichen Rand an die Seitenwand des Kollektors und zwar derart, dass der Absorber in etwa in der Mitte der Tiefe des Kollektors und bündig zur Unterkante der Rückwand zu liegen kommt, sowie das Blech das Holz der Seitenwand nicht berührt.

2. Schiebe die Transparente Doppelstegplatte [3] von oben oder unten gleichzeitig in beide dafür vorgesehenen Nuten in den Seitenwänden. Damit die Platte nicht verkantet, musst Du in der Mitte der Breitseite drücken. Falls das Einschieben nur sehr schwer geht, kannst Du die Kanten mit etwas Seife schmieren.

3. Zum Befestigen der Platte dienen die 2 Abdeckleisten [17] mittels je 3 Schrauben [28] durch die Platte hindurch an die obere und untere Verstrebungsleiste [8] bzw. [10] (siehe Zeichnung S. 13).

4. Zum Schutz der hinteren Ecken des Kollektors, die beim Gebrauch des Trockners auf dem Boden stehen, dienen die Kofferecken [19]. Schraube sie mittels je 2 Schrauben [30] an die entsprechenden Ecken, nachdem Du sie etwas abgefeilt hast.

5. Schraube den Traggriff [20] mittels den 4 Schrauben [27] so an Pos. [4A] oder [4B], dass der Trockner beim Tragen ausbalanciert ist.

6. Die Abdeckplatte des Pults [15] (siehe Zeichnung S. 16 oben) wird nur benötigt, wenn die runden, handelsüblichen Trockensiebe aus Metall oder Kunststoff verwendet werden. Bei fester Verbindung von Kollektor und Pult schraube Pos. [15] rundum mit 12 Schrauben [28] bündig zur Aussenkante fest. Bei loser Verbindung von Kollektor und Pult darf Pos. [15] nur entlang Pos. [6] und Pos. [5] bis zur Fälzung mittels total 7 Schrauben [28] befestigt werden.
Wenn neben den runden auch rechteckige, gemäss Pos. [39] bis [44] selbst gemachte Siebe zum Einsatz kommen, schraube Pos. [15] nicht fest auf das Pult. Mit Arretierleisten auf der Unterseite versehen kann sie einfach auf das Pult gelegt werden.

7. Zum Schluss wird der ganze Solar-Trockner aussen mit dem Wetterschutz [36] angestrichen.

8. Trockensiebe und Deckel:

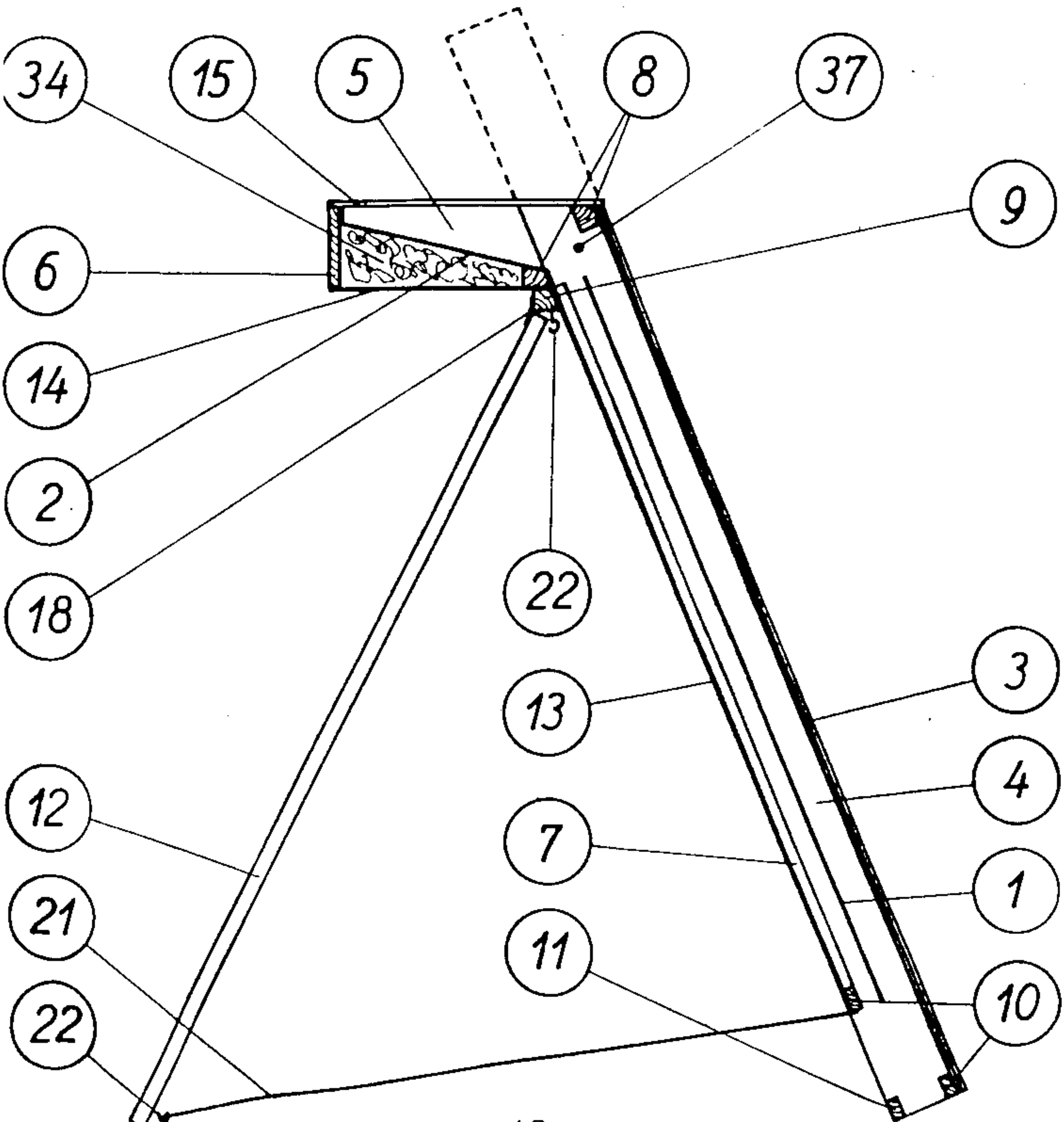
1. Schräge die 4 Kanten an einem Ende der Eckleisten [41] mit einer Feile leicht an. Befestige an beiden Enden der kurzen Seitenwände [40] auf die Innenseite mit Leim und je 2 Nägeln [43] bündig zur Aussenkante eine Eckleiste. Das angeschrägte Ende sollte dabei 1 cm gegenüber der einen Längskante von Pos. [40] vorstehen (siehe Zeichnung S. 17).

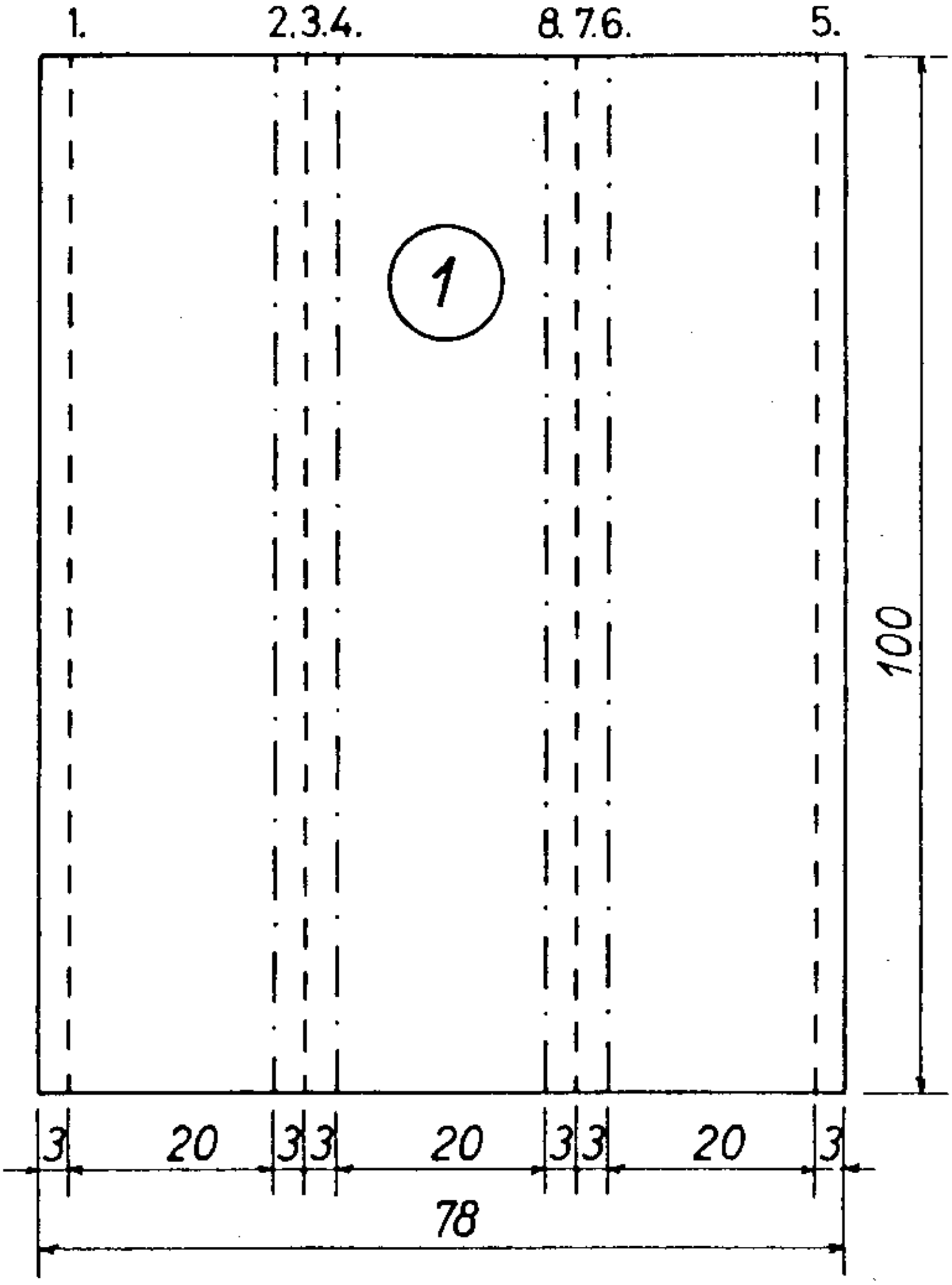
2. Setze den Rahmen des Siebes rechtwinklig zusammen, indem Du die langen Seitenwände [39] mittels Leim und pro Ecke 3 Nägeln [43] (2 in Pos. [40] und 1 in Pos. [41]) aussen bündig an die vorbereiteten kurzen Seitenwänden.

3. Das Gitter [42] wird nach dem Ausschneiden der 4 Ecken für Pos. [41] mittels den Agraffen [44] auf die Seite des Rahmens befestigt, wo die Pos. [41] vorstehen.

4. Schräge an einem Ende der Distanzklötze [48] die 4 Kanten analog Pos. [41] an. Befestige nun die 4 Pos. [48] auf die Unterseite der Deckplatte [45] mittels Leim und je 1 Nagel [50] gemäss Zeichnung S. 17. Auf die Oberseite der Pos. [45] werden die Verstärkungsleisten [46] und [47] mit Leim und den Nägeln [49] befestigt.

5. Beim Deckel für runde Siebe ist die Form und die Anordnung der Pos. [48] anders. Damit der Deckel auf den 2 nebeneinanderliegenden Sieben hält, braucht es an den vorstehenden Enden einen Absatz, der auf dem Siebrand aufliegt (siehe Zeichnung S. 16 unten).





Falz nach:

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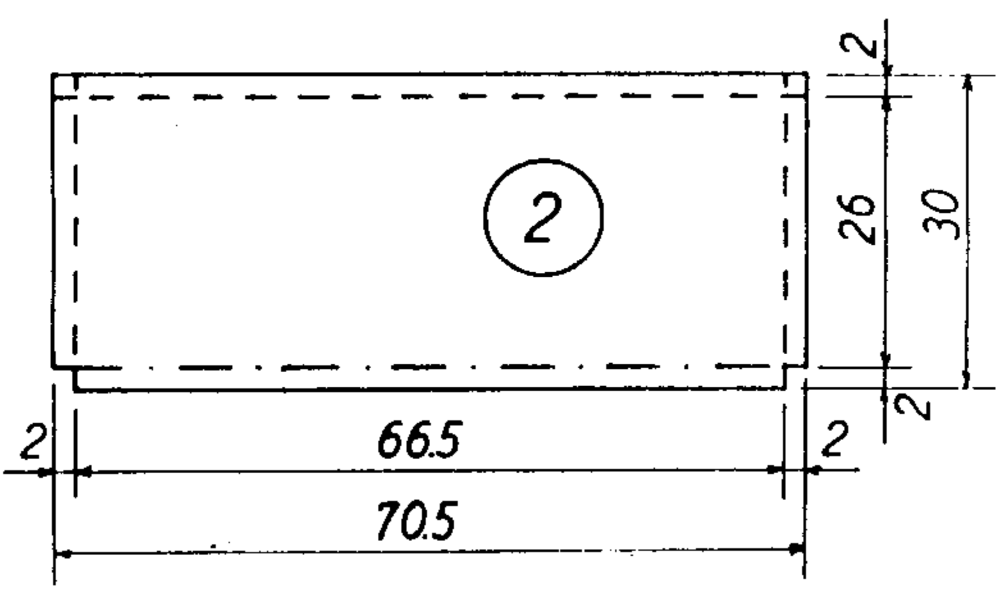

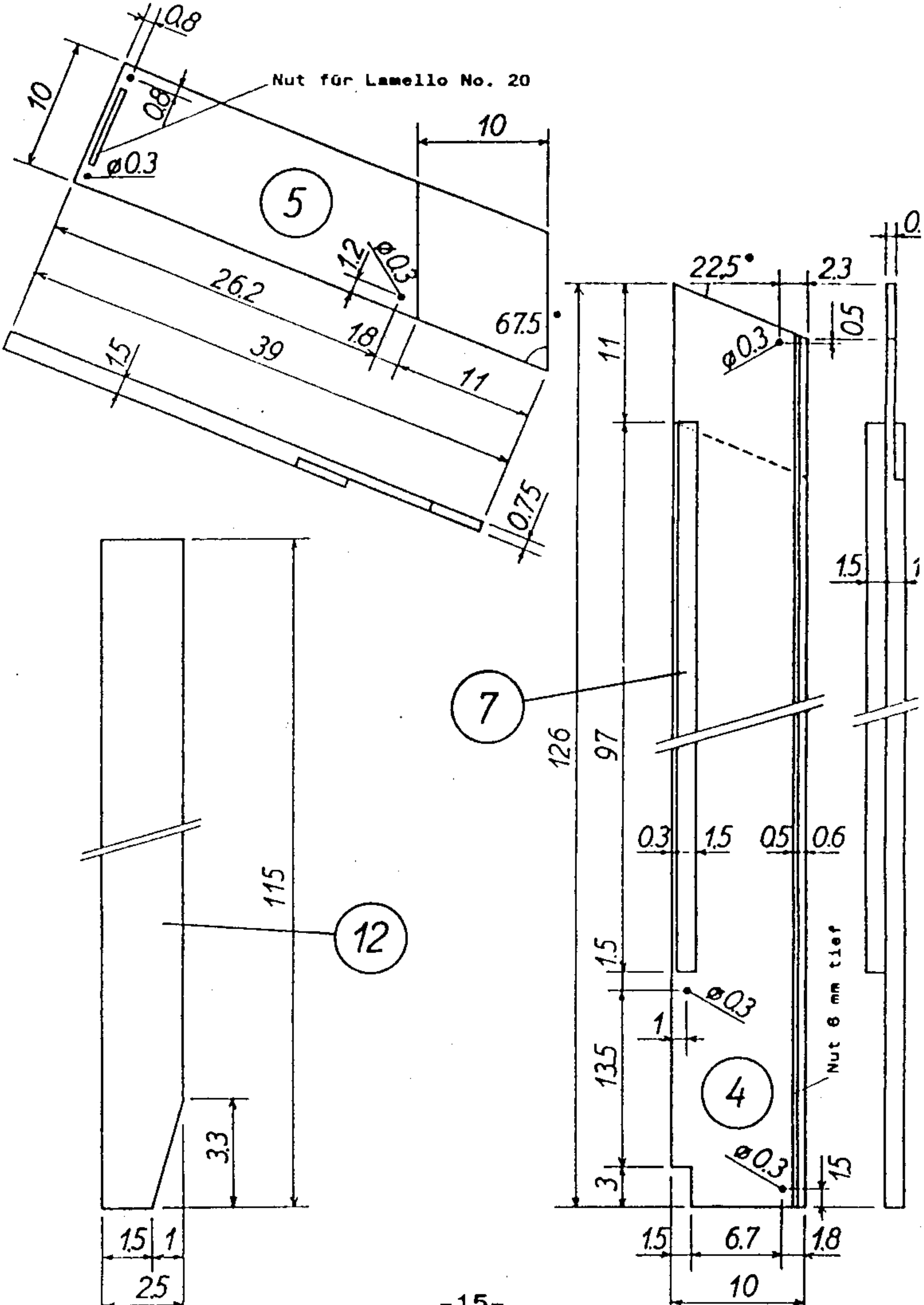
Nut für Lamello No. 20
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11
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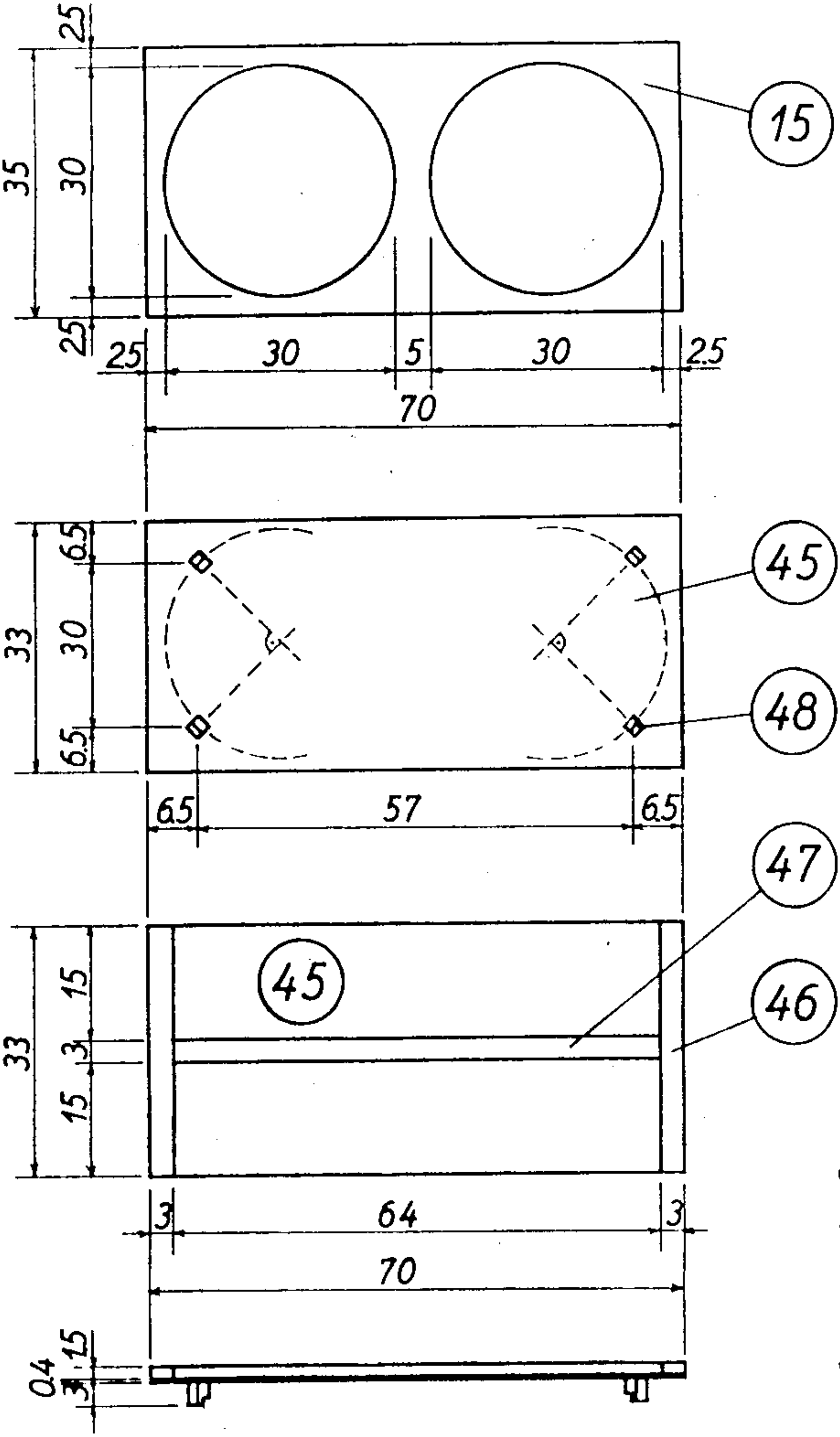
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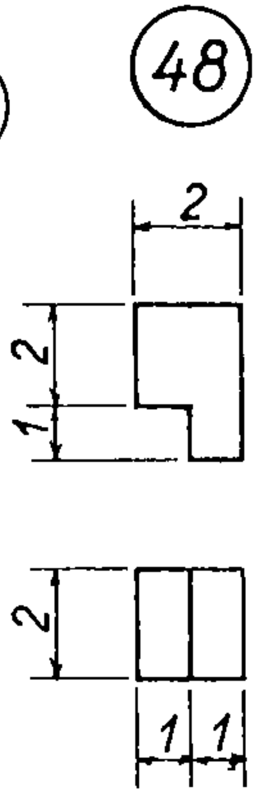
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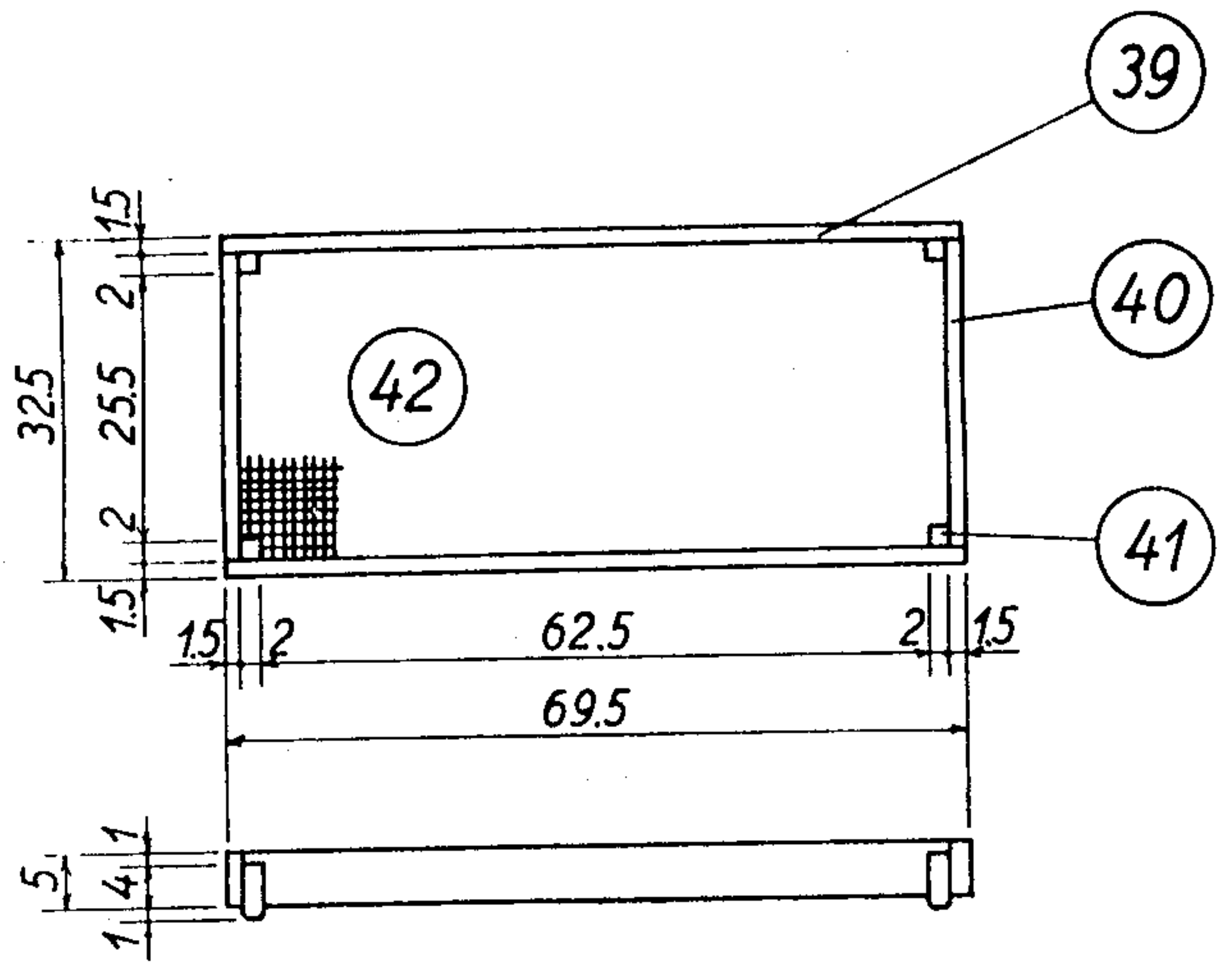
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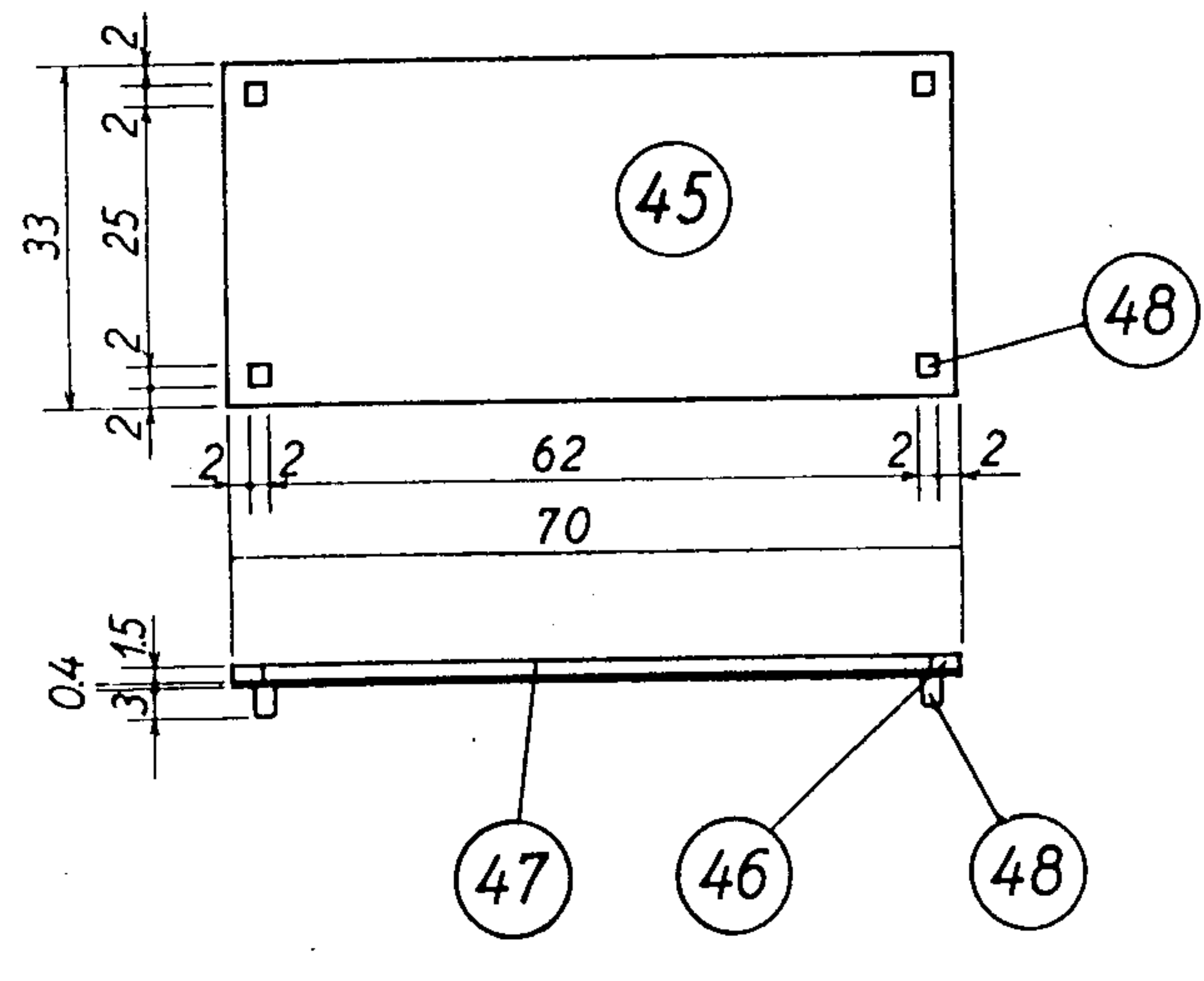
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EINIGE WICHTIGE TIPS ZUM GEBRAUCH DES SOLAR-TROCKNERS (ST)

- Der ST funktioniert nur bei direkter Sonnenstrahlung. Das durch die durchsichtige Abdeckung des Kollektors dringende Licht wird auf der schwarzen Oberfläche des Absorbers absorbiert, wodurch er sich erwärmt. Diese Wärme wird unmittelbar an die Luft im Kollektor abgegeben. Sie beginnt zu steigen (warme Luft ist bekanntlich leichter als kalte), und durchströmt darauf die auf dem Pult gestapelten Trockensiebe. Durch die untere Oeffnung des Kollektors strömt entsprechend Umgebungsluft nach. Durch diesen stetigen warmen Luftstrom wird dem Trockengut die Feuchtigkeit entzogen.

- Beim Aufstellen des ST ist darauf zu achten, dass das Pult einigermassen waagrecht ist. Je nach Neigung des Untergrunds kann mit der Kette die Stütze in verschiedenen Stellungen fixiert werden. Wähle einen Untergrund, bei dem die Luftzufuhr des Kollektors nicht behindert wird.

- Der ST braucht nicht regelmässig der Sonne nachgeführt zu werden. Ein- bis zweimaliges Verstellen pro Tag genügt.

- Die Trocknungstemperatur sollte 45°C möglichst nicht übersteigen, da sonst wertvolle Inhaltsstoffe zerstört werden können. Bei hoher Umgebungstemperatur und starker Sonneneinstrahlung kann sich die Luft im ST auf bis zu 70°C erhitzen. Durch teilweises Abdecken des Kollektors oder durch Drehen des ST aus der optimalen Stellung zur Sonne kann eine Ueberhitzung verhindert werden.

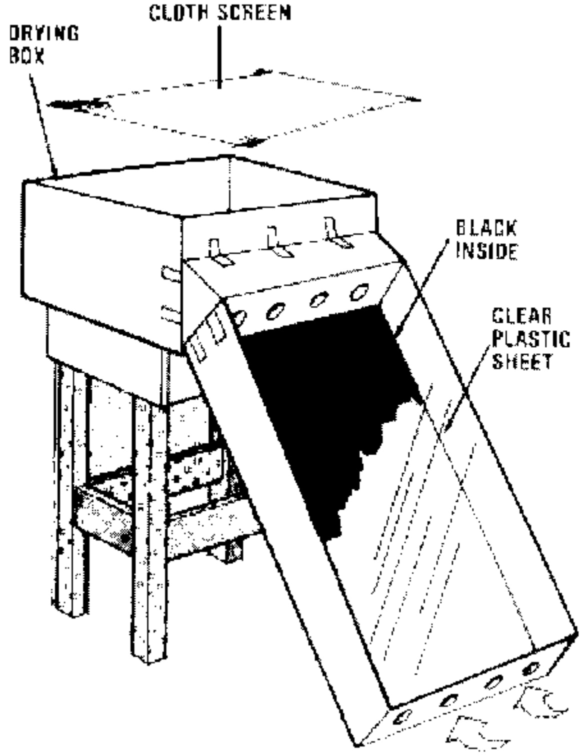
- Decke das oberste Trockensieb ab, damit das Trockengut nicht der direkten Sonnenstrahlung ausgesetzt ist. Das Licht kann das Trockengut verfärben, sowie Nährstoffe und Vitamine zerstören. Als Abdeckung eignet sich der in der Bauanleitung beschriebene Deckel, der einen Spalt als Luftauslass freilässt, oder allenfalls eine grobmaschige Gaze. Bei starkem Wind empfiehlt es sich, den Deckel z.B. mit einem Gummiriemen festzubinden.

- Das Unterbrechen des Trockenvorgangs in der Nacht kann durchaus wünschenswert sein. Vor allem bei stark wasserhaltigen Früchten kann sich durch das Trocknen aussen eine harte Kruste bilden, die die Feuchtigkeit von Innen nur noch schlecht durchlässt. Bei der nächtlichen Unterbrechung weicht sich diese Kruste wieder auf. Anderntags geht dann der Trocknungsvorgang ungehindert weiter.

- Genaue Angaben über das Vorbereiten und Trocknen der verschiedenen Lebensmittel geben "Das Trockenbuch" aus dem Oase-Verlag und das Buch "Dörren" aus dem Ulmer-Verlag, die beide bei der Gruppe ULOG aber auch im Buchhandel erhältlich sind.

- Lasse den ST trotz des Wetterschutzes nicht im Regen stehen. Dies ginge unweigerlich auf Kosten seiner Lebensdauer. Sein geringes Gewicht macht es einem ja leicht, ihn zu verräumen. Für den Unterhalt genügt es, die transparente Abdeckung und das Tropfblech von Zeit zu Zeit zu reinigen. Tropfen auf dem Absorber solltest Du bei Verwendung der schwarzen Abtönpaste von Auro auf keinen Fall abwischen, da sonst das helle Blech wieder zum Vorschein kommt. Lasse sie einfach trocknen.

Solar Dehydrator



Made from two cardboard boxes, some clear plastic wrap, and a little tape. You can build a nearly free solar dehydrator. Set it on a stool or chair and face it's solar collector towards the sun, and you have a functional food preservation machine for little work and even less money.

The above picture almost says it all. Using a long thin cardboard box for the collector and a taller, nearly square, cardboard box for the drying box. Boxes could be made to size by cutting and taping together small cardboard pieces. Line the bottom of the collector box with a black plastic garbage bag or paint the bottom with black, water based, poster paint, (lamp black or soot mixed with a little vegetable oil would work as well). ***If you use spray paint or other toxic paints, let the collector bake in the sun for a day or two before use.*** Cover the top of the collector with clear plastic wrap or window glass, etc. Tape it together as shown.

To increase the efficiency, you may want to cover the sides and bottom of both boxes with fiberglass or styrofoam insulation.

Drawing courtesy of: **Mother's Energy Efficiency Book** Copyright 1983 ISBN 0-938-43205-2

Solar Food Dryers

Larisa Welk and Lucien Holy

A request from a reader for an inexpensive solar food dryer spurred much response from our readers. Here are two types of solar food dryers we would like to share. One is for humid climates, two others for drier climates.

Solar Food Dryer for Humid Climates

Larisa Welk

We dehydrate nearly all our food from our 1/4 acre garden except tomato sauce, salsa, pickles, sauerkraut, juices, and some fruit sauces. We also put spuds, roots, and squash in a root cellar. Who needs a freezer? Our pantry is crammed with organic, nourishing foods for our simple, a la Nearings cuisine.

For years I tried about every solar dryer design imaginable. The only common factor in all those attempts was their very limited usefulness here in the humid upper Midwest. None of them could reliably turn food into a non-moldy finished product. Some didn't work at all if not tracked periodically during the day. It was with this background that the "idea light" came on in my head.

Cat on a Hot Tin Roof Theory

One day I needed to dry a bunch of greens and the current solar dryer was full (a couple of handfuls was all it could handle). I had an old window screen lying around and a corrugated metal roof built over our old trailer-house. Using a ladder to get to the roof, I put the screen down first and put the food on it. I wanted to keep the sun off the food itself so I covered it with a piece of black cloth. Then, to keep everything from blowing away or being bothered by flies, I covered it with a storm window that I had on hand.

Later that afternoon I thought I'd see how it was doing. The greens in the "dryer" were still quite limp when I crawled up the ladder to take a look at the stuff on the roof. Much to my surprise, the roof-top greens were crispy dry! It looked as if I had finally stumbled on something that worked. I tried several other foods on the roof before I was convinced enough of the design to build a unit at ground level for easier access.

The Basic Design Principles

I found through experimenting that the primary ingredients for this dryer were: corrugated, galvanized metal roofing, screen, black porous cloth, glazing, and slope.

The sun shines through the clear glazing onto the black cloth, heating up the air space under the glazing. The corrugated metal provides air spaces under the screen for the warm, moisture laden air to move. The air moves passively upward along the slope, carrying away the moisture from under the trays of food. The galvanized metal also gets hot and reflects heat back onto the food. This combination really gets the job done.

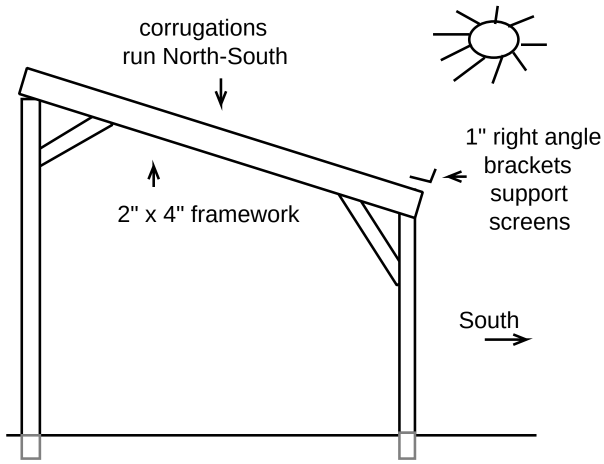
The Deluxe Super Dryer

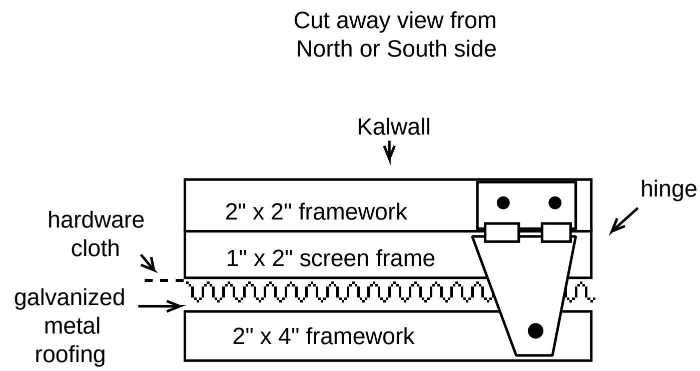
Using these basic principles, I built a 4 foot x 12 foot, waist high "shed" (I store extra wood under this roof). The 4 foot width enables me to reach easily from either side. You could make this wider if you wanted. The roof pitch is approximately 15 degrees. The legs are treated wood and stick into the ground about 6 – 8 inch. Next I built twelve 2 foot x 2 foot screens made from 1 inch x 2 inch pine and $^{1}/_{4}$ inch hardware cloth. This size of screen is easy to handle. They were 2 foot x 4 foot and I cut them in half.

The glazing is Kalwall® Sunlite® and is the most expensive part of the system (it holds up better than glass in hail storms and weighs less). My neighbor has since built a dryer and used acrylic glazing. It was much cheaper but time will tell which material lasts longer. The framework for the glazing is attached to the dryer with T-strap hinges on both the north and south sides. These were made into loose pin hinges so you can open the dryer from either side by pulling the pins and lifting the lid. A prop stick holds the lid open.

For cloth I've found polyester double knits resist fading better than natural fibers (at last, a worthwhile use for this stuff). Be sure to hem the edges so you won't end up with fuzz or fibers in your food.

I use fiberglass screen on the trays to keep the food from contacting the galvanized hardware cloth and also over the top of the food to keep it from sticking to the black cloth. I cut the screen double the size of each tray so it can be folded over the food. Stainless steel screen would be the best but I don't know of an economical source. If I used it I would still probably use hardware cloth





underneath for rigidity and because having removable screen facilitates pouring food into containers and makes cleanup easier.

What It Can Do
Even in Minnesota the sun can dry all of these foods easily: apples, green beans, peas, corn, cabbage, broccoli, cauliflower, peppers, kale or any greens, herbs, melon, fruit leathers, strawberries & other berries, plums, beets, onions, mushrooms, squash, eggplant, tomatoes, asparagus, celery, bananas, etc. The dryer can also be used to crisp bean pods for threshing, small grains before storing, and to dry corn before shelling and grinding. When using the dryer this way, I do not use the black cloth since I do not want these items to get too hot (I save seed from my beans and corn).

Techniques
When using a solar dryer, an accurate weather forecast to ensure proper timing is essential. Really wet foods (corn, melon, strawberries, etc.) will take at least two good days of full sun. The first day is the most critical. The food needs to get dry enough to coast through the night before finishing off the next day. Sometimes food will not be finished until the third day or longer, depending on the weather. If food is nearly dry, a raining spell will only postpone the process but the food won't spoil. Greens and herbs will be done in one day. My definition of "dry" is crispy for all vegetables, though fruits can remain somewhat pliable.

Foods need to be cut in uniform pieces for best drying. For example, you'll need to dry celery stalks separately from the leaves. Placement in the dryer is important also since the warm, moist air rises. Foods entering their second day in the dryer should be below freshly cut up foods. Herbs can always go lower where it is not quite as hot. Foods dry faster if stirred once or twice although this isn't absolutely necessary. Melons and other sticky foods should be peeled from the screens when partially dry and flipped before they become permanently bonded.

The only foods I steam blanch are sweet corn, peas, green beans, and asparagus. Because of the length of time it takes to pick and prepare the 18 to 24 dozen ears of corn we normally do in one batch, we pick it in the evening and steam blanch it immediately. I spread the ears out all over the kitchen counters to cool for the night. Early the next morning I cut the already somewhat shriveled kernels from the cobs and have it all out into the dryer before the sun starts it work. If I started in the morning with picking, it would take until about 1:00 pm for all the corn to be blanched, cut, and into the dryer – too late for corn in this humid climate.

Be sure to put away your dried goodies before the evening dew has remoistened them, but do allow the foods to cool off if you bring them in during the heat of the day. Store dried foods in airtight containers (a good use for all those extra canning jars you won't be needing) in a cool, dark place.

Improvements
In eight years of use, there are a couple of improvements I would make. I would build all the trays and glazing framework out of cedar instead of pine. Half of the original dryer has been rebuilt so far since the pine didn't hold up, even though the wood was painted with linseed oil.

Furthermore, I would make the slope of the unit adjustable so it would work better later into the fall when the sun is lower in the sky. Other than that, this dryer has been a real workhorse. Some of my neighbors use the dryer on my off days so it is often filled to capacity. With nearly 48 square feet of tray space, it can preserve enough food for a very large family or a group of smaller families.

Solar Food Dryer for Hot Climates

Lucien Holy

Some older books on food dehydration recommend sulfiting even though it is now known to be very bad for asthma sufferers. Besides, another name for sodium bisulfite is "Sani-flush" toilet bowl cleaner! Yummy! Another treatment is sulphur dioxide created by burning sulphur. That is very polluting and breathing the fumes can damage your respiratory system. Treatment with ascorbic acid (Vitamin C), citrus juice, or nothing is more to my taste.

The problem with many solar food dryers is that they are often solar ovens with vents. One design even has reflectors. If it looks like an oven, then on a good day it will become an oven. A solar oven is compact, tightly sealed and reaches up to 300°F. Even simple box ovens go over 200°F. In contrast, the requirements for food dehydration are a constant change of air, roomy interior, and a temperature of under 120°F (the temperature at which nutrient loss begins) with little or no chance of reaching cooking temperature. After all, food drying is a long process, and you don't want to constantly monitor and adjust the unit to avoid ruining the food through excess heat. Direct sunlight on the food is undesirable as it tends to bleach out color and flavor, and dry unevenly.

TAP

The solar device that does these things is not a solar oven, but a Thermosyphon Air Panel (TAP), which is a vertical solar air heater. My final designs are based on a separate TAP collector and dryer box. A box is the ideal shape for the dryer section, and is easily modified. Oven-like designs result in cramped space, poor ventilation, uneven temperatures, and odd shelf arrangements.

Most old solar dryer plans require 50 or more hours of work, a shop, and money. Worse yet, they work well for someone, somewhere, but I have found that dehydrators must be designed for a particular conditions and uses.

You can quickly make a simple mockup with cardboard boxes and Saran Wrap® glazing (staple or tape on). Using a thermometer, you can quickly arrive at a new design that works under your conditions. You can, for example, enlarge your collector in a few minutes with a razor, tape, and cardboard. Cardboard solar ovens, popularized by Joseph Radabaugh's book "Heaven's Flame" proves the practicality of this technique.

Collector

I use a collector about twice the size of my dryer section. One advantage of using a separate TAP is that the area ratio can be anything you need.

Insulation

In a hot climate you don't need insulation because the temperature difference between the 110° – 120° inside air and the outside in the sun is very little. In a cool sunny area, insulation will improve performance. You can use corrugated cardboard or use a double box with the space filled with wadded newspaper. Since the insulation is on the outside you may also use hard foam.

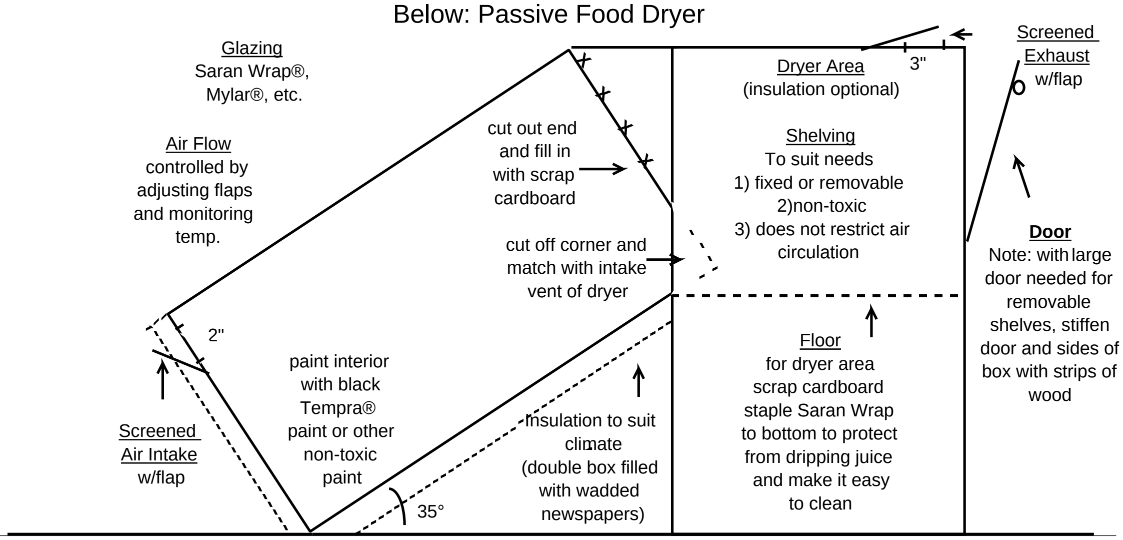
Glazing

I use Saran Wrap® glazing for my experiments because it costs 2¢ per sq. ft., is easy to apply, heat resistant, and food safe. Just tape or staple it to your collector. Oddly enough, it worked so well that it became my standard glazing, even for box ovens at 220°F! It is very thin and very clear and passes more light than the usual glass, Plexiglas®, Kalwall® and Sunlite®, etc. For oven use apply it with a loose fit because it shrinks when heated, Saran Wrap's® "cling" quality makes it unnecessary to tape the 11 $^1/_2$ inch wide sheets together, just overlap them one inch.

Air Flow

Moving air by the thermosyphon method requires a vertical layout. If you want a really large collector, like 4

Below: Passive Food Dryer



foot x 8 foot, then it can get rather awkward. If I were to go to a really large unit I would use a horizontal collector with positive air flow provided by a solar-powered fan. These are available in several sizes and are not expensive. Solar vents are perfect because they produce airflow in direct proportion to sunlight. I have built a small unit of that type because, stored vertically, it only takes up 1 sq. ft. of area in my apartment

Tape
The best tape for solar use is aluminum duct tape like Reflectex®. By the way, this tape makes quick, easy, durable reflectors. Just apply rows to the backing until it is covered.

Shelving
I'll leave the shelves up to you, to suit your needs. If you use the usual aluminum screen, then you don't need a frame for most sizes. Do not use lemon juice on your food to be dried if you use aluminum screens. Use non-toxic materials, wood dowels or strips, netting or cheese cloth, etc. Remember, it must allow air flow.

Passive Food Dryer
This passive design uses two L=23 inch W=13 inch D=10.5 inch cardboard boxes with dryer dimensions of L=13 inches W=10.5 inches D=10 inches. The one disadvantage of corrugated cardboard construction is that it deteriorates when exposed to the elements, especially moisture. I brush on 50/50 polyurethane varnish and thinner. This not only water proofs and preserves the cardboard, but saturates it, bonding the fibers together for a very durable material. Cure well in the sun before using.

Active Solar Food Dryer
This unit is based on a gadget from "Northern Hydraulics" catalog. A solar powered fan with built-in solar cells for $9.99. It's too feeble for its claimed purpose (but that is what makes it so cheap!). It is just right to provide a steady, gentle air flow in a small food dehydrator. This style lends itself to very large units.

Access
Larisa Welk & Bob Dahse, RR3 Box 163-A, Winona, MN 55987

Lucien Holy, 8015 Spencer Hwy. Apt. #58, Deer Park, TX 77536

Northern Hydraulics, POB 1219, Burnsville, MN 55337-0219

Reader Response
We would like to thank all the wonderful readers who sent in information on different solar food dryer designs. It was hard to choose which ones to publish. There is definitely interest in this subject! Kathleen Jarschke- Schultze.

List of Books on food drying:
Dry It, You'll Like It by Gen MacManiman, Fall City, WA 98024

How to Dry Foods by Deanna DeLong, HP Books, POB 5367, Tucson AZ 85703 • 602-888-2150

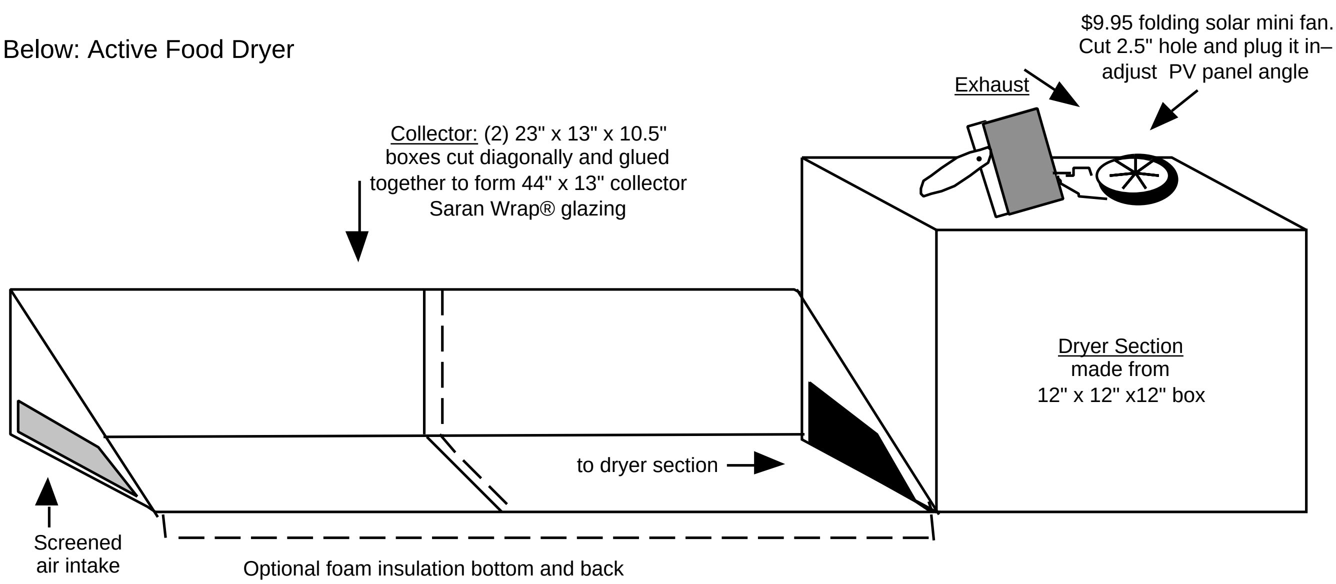
Understanding Solar Food Dryers by Roger G. Gregoire, P. E., VITA, 1600 Wilson Blvd., Ste. 500, Arlington, VA 22209 • 703-276-1800

Food Drying at Home by Bee Beyer, JP Tarcher, Inc., 9110 Sunset Blvd, Los Angeles, CA 90069

Solar Drying: Practical Methods of Food Preservation International Labour Office, CH-1211 Geneva 22, Switzerland

Solar Food Dryer by Ray Wolf, Rodale Plans, Rodale

Below: Active Food Dryer



Press, 33 East Minor St., Emmaus, PA 18049

A Handbook for Solar Food Drying State Energy Office; 335 Merchant St., Ste 110. Honolulu, HI 96813 • 808-548-4080

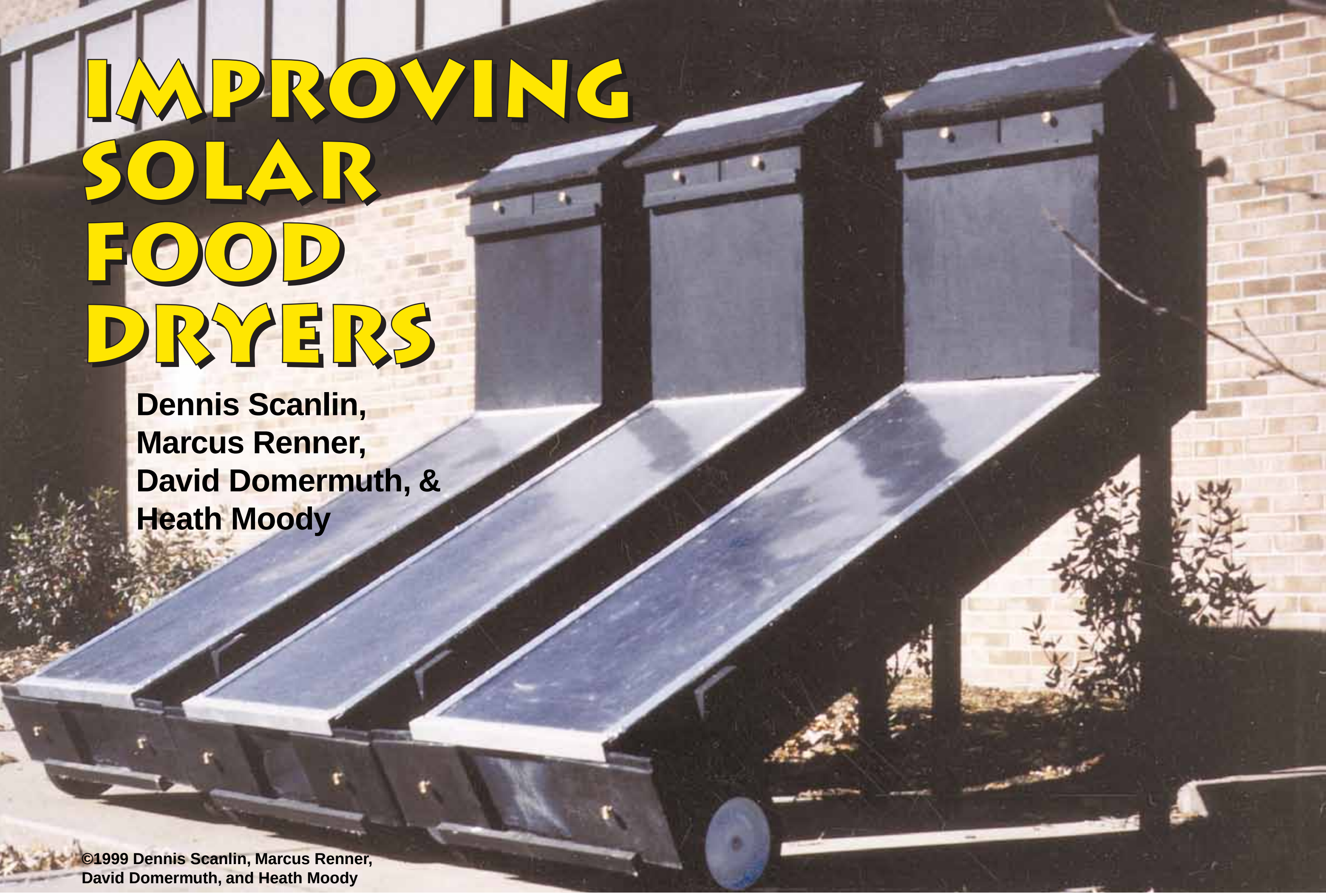
Healthy Environments
Camera-ready

Abraham Solar
camera-ready

12 Volt Products
camera-ready
leave border in layout

IMPROVING SOLAR FOOD DRYERS

Dennis Scanlin,
Marcus Renner,
David Domermuth, &
Heath Moody



Above, Photo 1: Three identical solar food dryers for testing against a control.

This article describes a series of experiments conducted over the last year and a half with three solar food dryers. The food dryers were constructed at Appalachian State University (ASU) using plans published in *HP57*. The goal of this research program was to improve the design and to determine the most effective ways to use the dryer.

Figure 1: Cutaway View of the Appalachian Solar Food Dryer

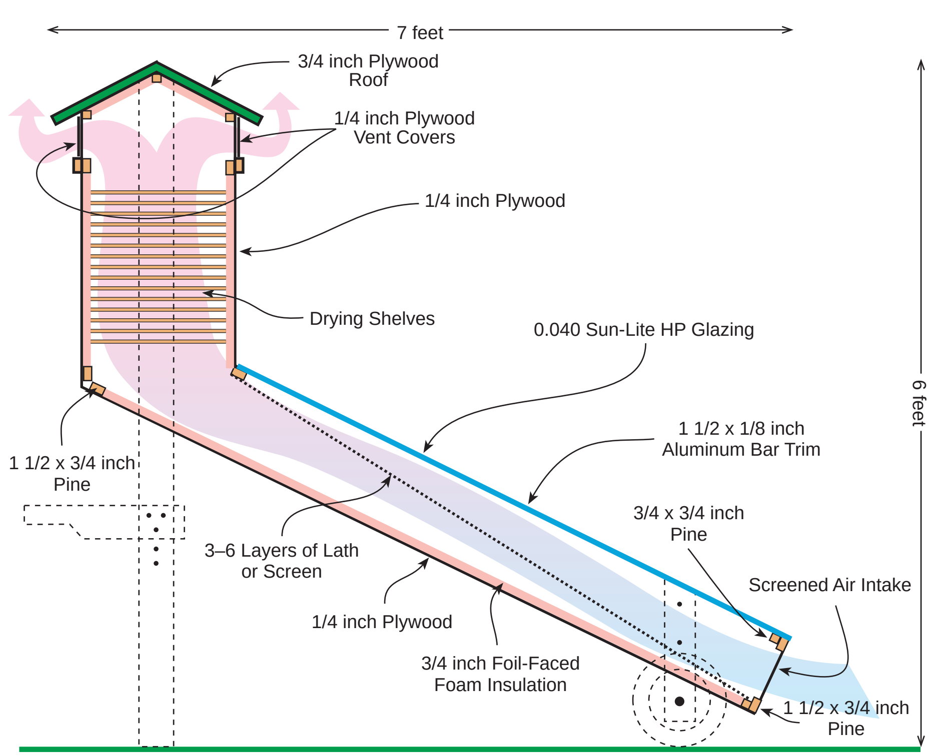
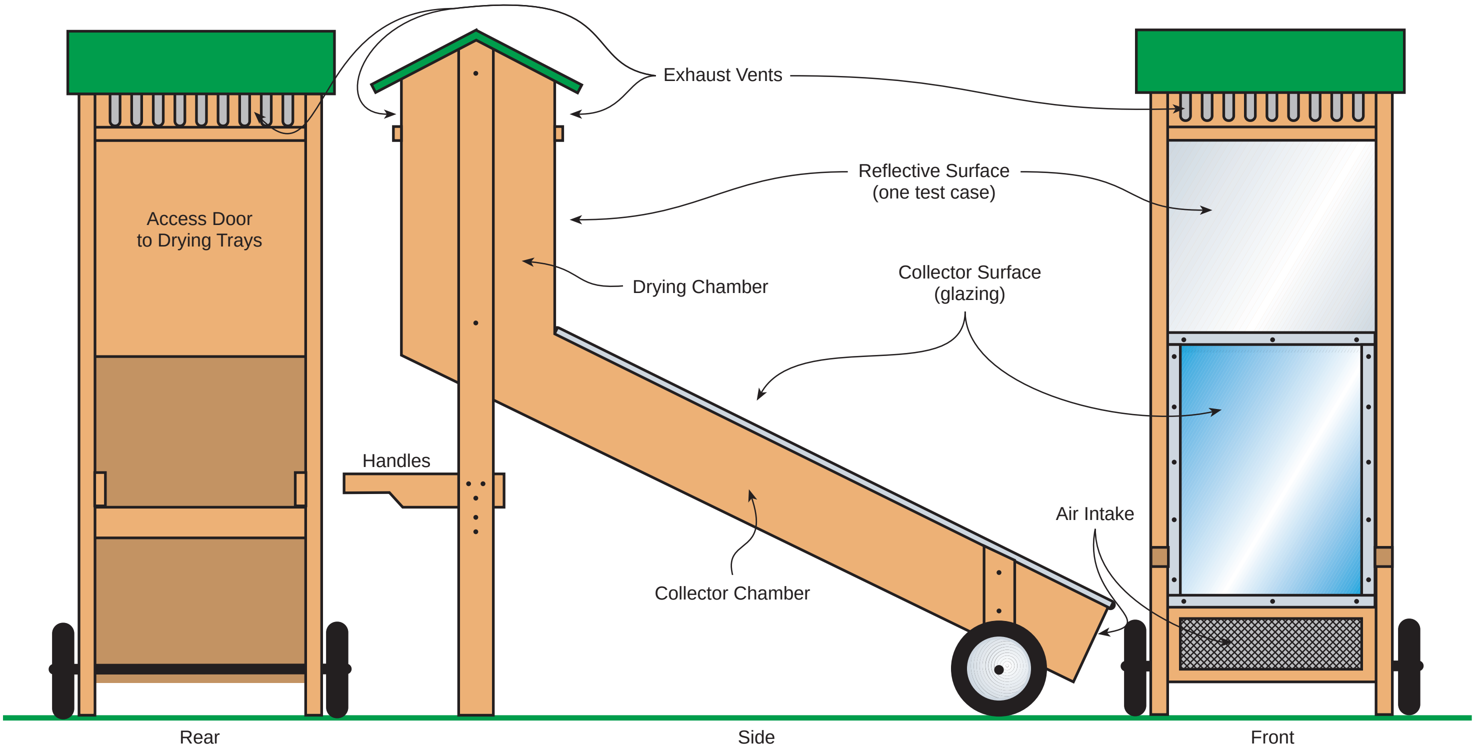


Figure 2: Multiple Views of the Appalachian Solar Food Dryer

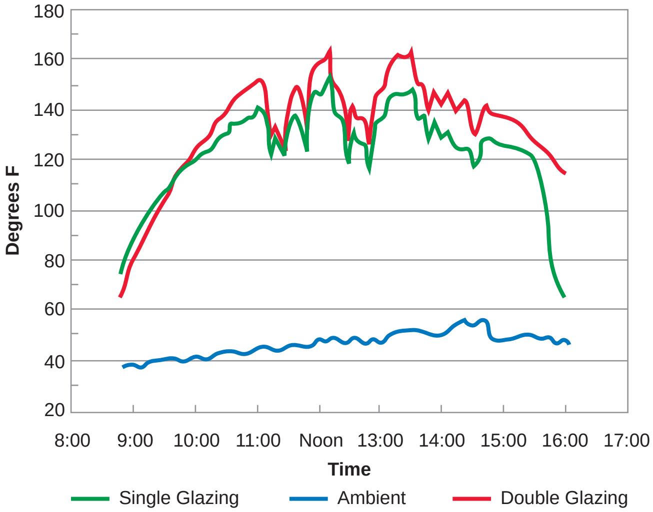


These solar food dryers are basically wooden boxes with vents at the top and bottom. Food is placed on screened frames which slide into the boxes. A properly sized solar air heater with south-facing plastic glazing and a black metal absorber is connected to the bottom of the boxes. Air enters the bottom of the solar air heater and is heated by the black metal absorber. The warm air rises up past the food and out through the vents at the top (see Figure 1). While operating, these dryers produce temperatures of 130–180° F (54–82° C), which is a desirable range for most food drying and for pasteurization. With these dryers, it's possible to dry food in one day, even when it is partly cloudy, hazy, and very humid. Inside, there are thirteen shelves that will hold 35 to 40 medium sized apples or peaches cut into thin slices.

The design changes we describe in this article have improved the performance, durability, and portability of the dryer, and reduced construction costs. This work could also help in designing and constructing solar air heaters used for other purposes, such as home heating or lumber drying. Most of our experiments were conducted with empty dryers using temperature as the measure of performance, though some of our experiments also involved the drying of peaches and apples. We have dried almost 100 pounds (45 kg) of fruit in these dryers during the past year. Graduate students in the ASU Technology Department constructed the dryers, and students taking a Solar

Above, Photo 2: Setting up the solar simulator.

Graph 1: Single vs. Double Glazing



Energy Technology course modified them for individual experiments.

Methodology

We began by constructing three identical food dryers. Having three dryers allowed us to test two hypotheses at one time. For example, to examine three versus six layers of absorber mesh and single versus double glazing, Dryer One might have three layers of black aluminum window screening as an absorber with single glazing; Dryer Two, six layers of the same absorber screen with single glazing; and Dryer Three, six layers of the same absorber screen with two layers of glazing. Once we set up an experiment, we collect data. This lasts from several days to a couple of weeks until we are confident that the data is reliable. Then we try something different.

Using three food dryers also allows us to offer more students hands-on experiences with solar air heaters. Each semester, students take apart the dryers' solar collectors and rebuild them using different materials or strategies. This classwork was supplemented with experiments set up and completed by several graduate students.

Equipment for Data Collection

We have two systems for measuring temperature. The first system uses inexpensive indoor/outdoor digital thermometers. One temperature sensor is placed inside the dryer and the other one outside. Different locations are used for the sensor inside the dryer. If food is being dried, we normally place it under the bottom tray of food and out of direct sunlight. This temperature data is recorded on a data collection form every half hour or whenever possible.

The other system uses a $600 data logger from Pace Scientific to record temperature data. It is capable of measuring temperature, relative humidity, AC current, voltage, light, and pressure. The logger does not have a display, but it's possible to download the data to a computer. The software that comes with the logger allows us to see and graph the data. The data can also be exported to a spreadsheet for statistical analysis.

We measure air flows with a Kurz 490 series mini-anemometer. We weigh the food before placing it in the dryer, sometimes during the test, and at the end of each day. We use an Ohaus portable electronic scale, purchased from Thomas Scientific for $111. We measure humidity with a Micronta hygrometer purchased from Radio Shack for about $20.

Solar Simulator

In addition to outdoor testing with the actual food dryers, we use a solar simulator (see Photo 2) built by David Domermuth, a faculty member in the Technology Department at ASU. With the simulator, we can do more rapid testing and replicate the tests performed on the dryers, even on cloudy days. The simulator also lets us control variables such as ambient temperature, humidity, and wind effects. The unit can be altered quickly because the glazing is not bolted on. The simulator was constructed for $108. It was built in the

Below, Photo 3: This dryer has both a vertical wall reflector and side reflectors.

same way as the food dryer, but without the food drying box at the top.

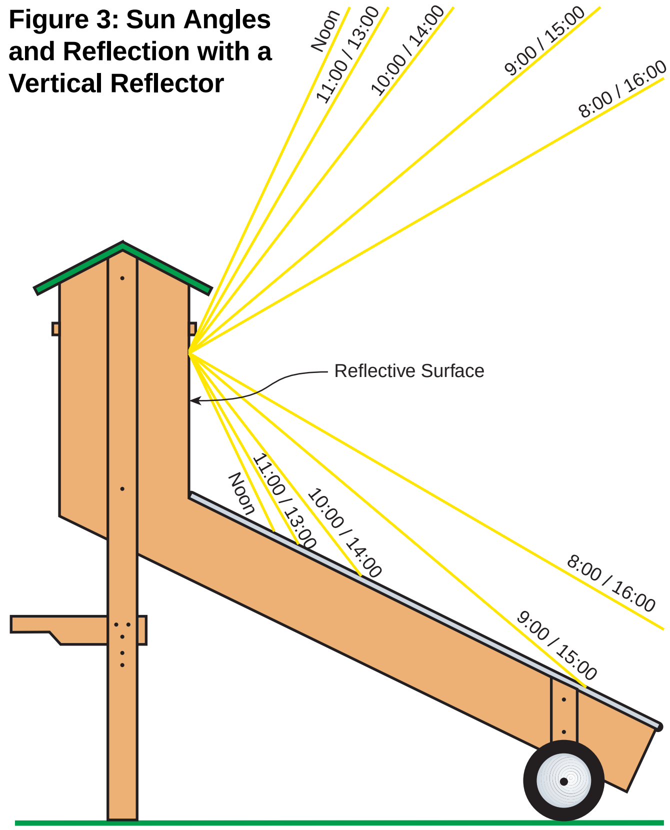
The simulator uses three 500 watt halogen work lights to simulate the sun. The inlet and outlet temperatures are measured with digital thermometers. The temperature probes are shaded to give a true reading of the air temperature. We conducted the simulator tests inside a university building with an indoor temperature of 62–64° F (17–18° C). As we changed variables, we noticed significant differences in outlet air temperatures. The simulator did produce temperatures comparable to those produced by the food dryers out in the sun. However, we did not always achieve positive correlations with our food dryers' outdoor performance. We may need to use different kinds of lights or alter our procedures somewhat.

Experiments
We have done at least twenty different tests over the last year and a half. All were done outside with the actual food dryers and some were also repeated with the solar simulator. The dryers were set up outside the Technology Department's building on the ASU campus in Boone, North Carolina. We collected some additional information at one of the authors' homes. Every test was repeated to make sure we were getting consistent performance. We tried to run the tests on sunny to mostly sunny days, but the weather did not always cooperate. The dips in many of the charts were caused by passing clouds.

Single vs. Double Glazing
The original design published in *HP57* used two layers of glazing separated by a 3/4 inch (19 mm) air gap. We used 24 inch (0.6 m) wide, 0.040 inch (1 mm) Sun-Lite HP fiberglass-reinforced polyester plastic for the outer layer. For the inner layer, we used either another piece of Sun-Lite, or Teflon glazing from Dupont. Sun-Lite glazing is available from the Solar Components Corporation for about $2.40 per square foot ($25.83 per m^2). These two layers cost over $50, or about one-third of the total dryer cost. We wanted to see if the second layer helped the performance significantly and justified the added expense.

We set up two dryers with six layers of steel lath painted flat black. One had single glazing and the other had two layers of glazing. The outer glazing was Sun-Lite HP on both dryers. The dryer with double glazing used Teflon as the inner glazing. The two dryers were identical except for the number of glazing layers. The tests were run on nine different days between February 17 and March 26, 1998. We opened the bottom vent covers completely and the top vent covers to two inches (51 mm). The ambient temperatures were cool and no food was being dried.

Figure 3: Sun Angles and Reflection with a Vertical Reflector

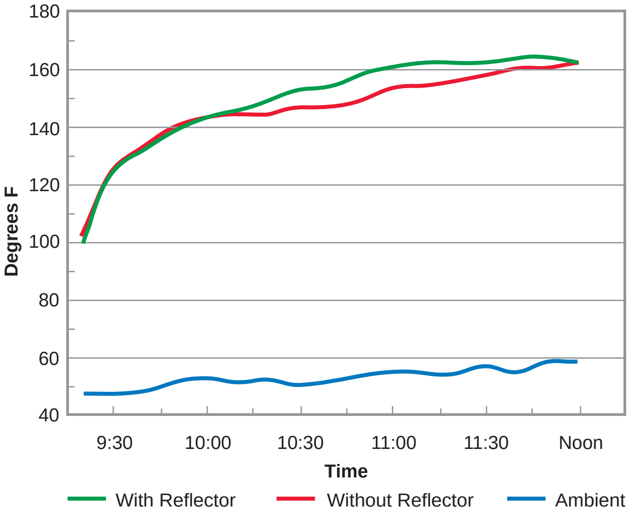


As Graph 1 shows, the double glazing did result in higher dryer temperatures. This was on a sunny day with clear blue skies and white puffy clouds, low humidity (30%), and light winds. The temperatures throughout most of the day were slightly higher with double glazing. However, the single glazed dryer works well and routinely reached temperatures of 130–180° F (54–82° C). When this test was replicated with the solar simulator, the double glazing also produced slightly higher temperatures.

Our conclusion is that double glazing is not necessary for effective drying. It does reduce some heat loss and increases the dryer's temperature slightly, but it increases the cost of the dryer significantly. Another problem is that some condensation forms between the two layers of glazing, despite attempts to reduce it by caulking the glazing in place. The condensation detracts from the dryer's appearance and may cause maintenance problems with the wood that separates the two layers of glazing.

Reflectors
One possible way to improve the performance of these dryers is to use reflectors. We tried several strategies: making the vertical south wall of the dryer box a reflective surface, hinging a single reflector at the bottom of the dryer, and adding reflectors on each side of the collector.

Graph 2: Vertical Wall Reflector vs. No Reflector



Look at the temperatures recorded on Graph 2. A slight increase in dryer temperature was recorded in the dryer having the south-facing reflective wall. The reflected light covers the collector most completely at mid-morning and afternoon. As the sun gets higher, the light is reflected onto a smaller area of the collector.

Single Reflector

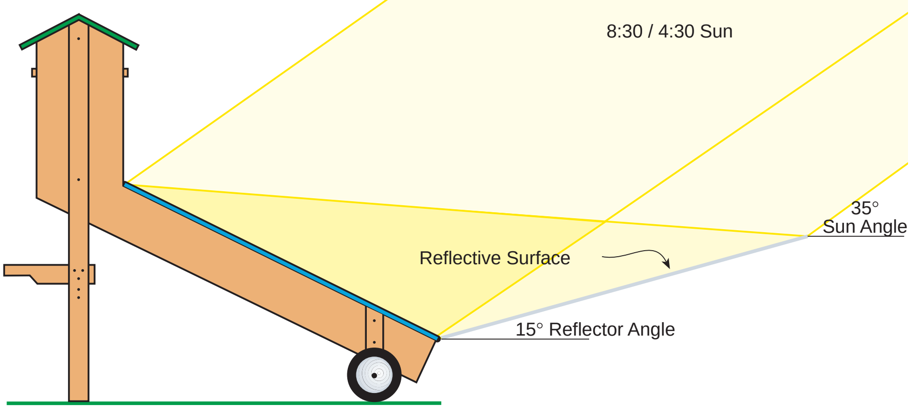
A single reflector was hinged to the bottom of the collector (see Photo 4). This reflector was supported with a string and stick arrangement, similar to one used by Solar Cookers International. With all reflector systems, the dryer has to be moved several times throughout the day if performance is to be maximized. This allows it to track the azimuth angle of the sun. The altitude angle of the reflector also needs to be adjusted during the day from about 15° above horizontal in the morning and evening to 45° above horizontal around noon (see Figures 4 and 5). The reflector added 10–20° F (2.4–4.8° C) to the temperature of the dryer and removed slightly more moisture from the food than a dryer without a reflector.

Vertical Wall Reflector

We realized that the vertical south wall of the dryer box could be painted a light color or coated with aluminum foil, a mirror, or reflective Mylar (see Photo 3). A vertical south-facing wall reflector would reflect some additional energy into the dryer's collector, protect the wood from cracking, and prevent deterioration from UV radiation. Considering the fact that the angle of reflection equals the angle of incidence, we were able to model the performance of this reflector, using a protractor and a chart of sun altitude angles (see Figure 3). If the dryer is moved several times throughout the day to track the sun's azimuth angle, then the reflector concentrates some additional solar energy onto the dryer's collector during most of the day.

Above, Photo 4: Setting the front reflector angle.

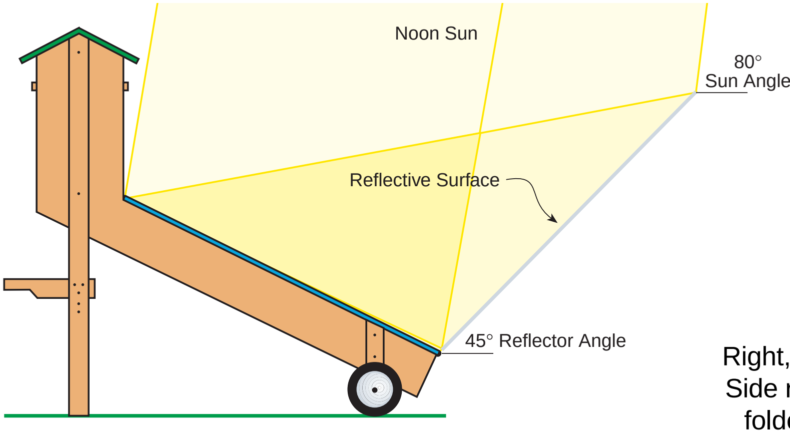
Figure 4: Single Reflector at Low Sun Angle



Side Mounted Reflectors

A third strategy was to add reflectors to both sides of the collector. This captures more solar energy than the

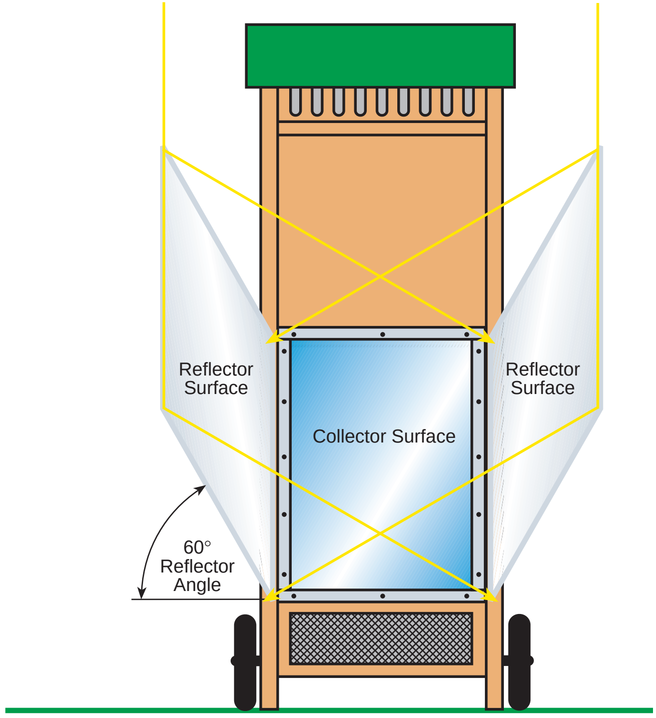
Figure 5: Single Reflector at High Sun Angle



other two strategies. We determined that the ideal reflector angle would be 120° from the collector surface (see Figure 6). This assumes that the dryer is pointing toward the sun's azimuth orientation.

We performed an experiment to compare a dryer with two side reflectors and a vertical wall reflective surface with a dryer having no reflectors (see Photo 3). Both dryers were moved throughout the test period to track the sun. The reflectors were mounted with hinges and could be closed or removed when transporting the dryer (see Photo 5). Graph 3 shows the significant increase in temperatures attained by using these reflectors. The problem with this design was that if the dryer could not track the sun for one reason or another, one of the

Figure 6: Ideal Angle for Side-Mounted Reflectors



Right, Photo 5: Side reflectors folded onto glazing for transportation.

reflectors would shade the collector in the morning and the other in the afternoon.

We concluded that the vertical wall reflector and the single reflector mounted to the bottom of the collector are the best ways to add reflectors, since tracking is not crucial in these applications. However, these dryers routinely attain temperatures of 130–180° F (54–82° C) without reflectors, which is hot enough for food drying and for pasteurization. Based on our work so far, reflectors just don't seem to be worth the trouble.

Absorbers

All low temperature solar thermal collectors need something to absorb solar radiation and convert it to heat. The ideal absorber is made of a conductive material, such as copper or aluminum. It is usually thin, without a lot of mass, and painted a dark color, usually black. The original dryer design called for five layers of

Graph 3: Vertical Wall & Side Reflectors vs. No Reflector

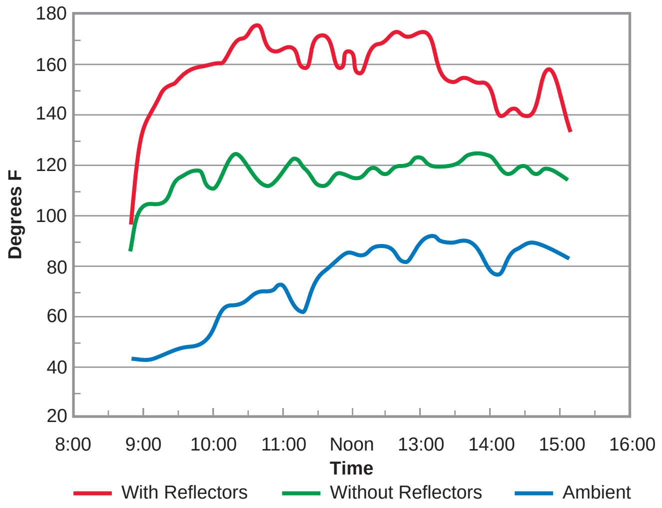
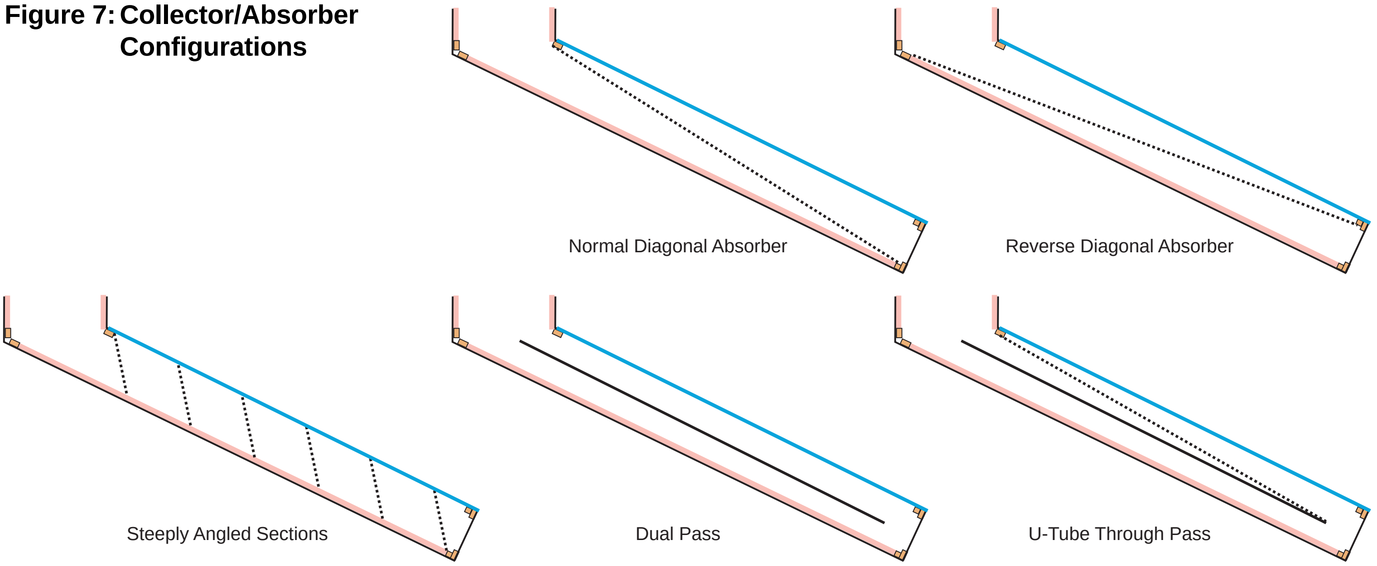


Figure 7: Collector/Absorber Configurations

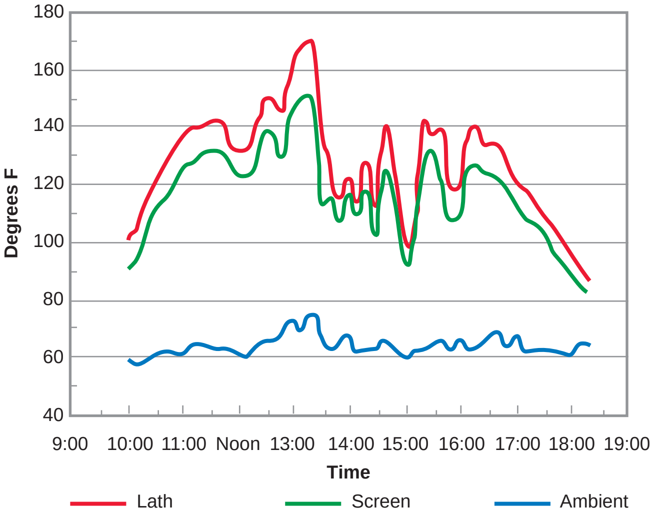


black aluminum window screening, which had proven to work well in other air heating collectors we had constructed. Other designs call for metal lath, metal plates such as black metal roofing, or aluminum or copper flashing. We decided to try some different materials and approaches to see if we could come up with a better absorber.

Plate vs. Screen

First, we compared five layers of black aluminum window screen placed diagonally in the air flow channel to one piece of black corrugated steel roofing placed in the middle of the channel (see Figure 7). We found that the mesh produced temperatures about 7° F (3.9° C) higher than the roofing in full sun. Other experiments have shown that mesh type absorbers are superior to plate type absorbers. These differences might be reduced if we used a copper or aluminum plate instead of the steel roofing.

Graph 4: Lath vs. Screen Absorber



Lath vs. Screen

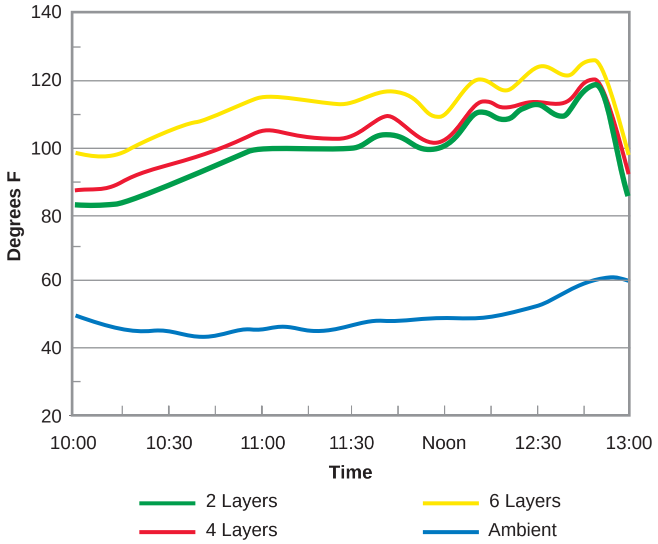
Next, we compared three layers of pre-painted black aluminum window screening to three layers of galvanized steel lath painted flat black. We found that the lath produced temperatures as much as 15° F (3.6° C) higher than the screen in our outdoor solar food dryer tests. We got the same results when we compared six layers of screen to six layers of lath (see Graph 4). While we found that the lath produced slightly higher temperatures, it was harder to work with, needed to be painted, and cost slightly more than the screen.

When these tests were replicated with the solar simulator, we had slightly better results with the screen than with the lath in both the three and six layer tests. We were disappointed by the lack of positive correlation between our outdoor tests with the actual food dryers and our indoor tests with the solar simulator. But there are many variables to control and quite a few people involved in setting things up and collecting data, so our control was not as tight as we would have liked. Despite these problems, we are confident in concluding that there is not a great deal of difference in performance between lath and screen—both work effectively.

Layers of Absorber Mesh

We then compared three layers of lath to six layers of lath, and three layers of screen to six layers of screen. Obviously the more screen used, the greater the expense. The literature on solar air heaters recommends between five and seven layers. We arbitrarily picked three and six layers. In our outdoor tests, we found that six layers of screen produced temperatures 5–10° F (1.2–2.4° C) higher than three layers. Likewise, when we repeated these experiments outdoors with lath, we found that six layers outperformed both two and four layers (see Graph 5).

Graph 5: Two vs. Four vs. Six Layers of Absorber

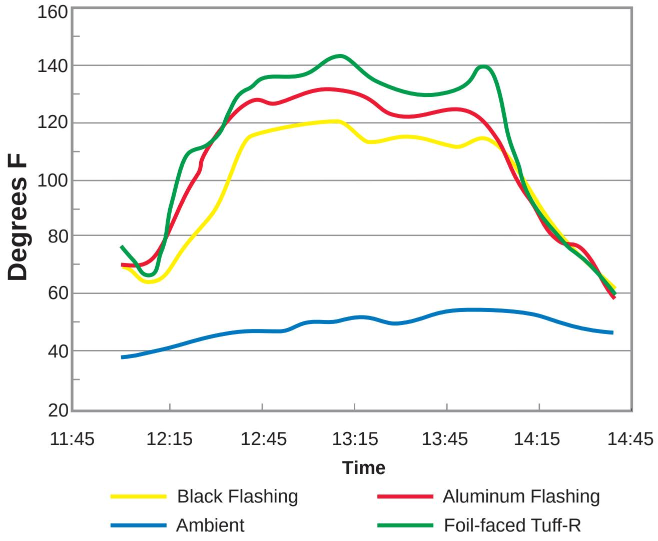


Tests performed in the solar simulator showed very little difference between three and six layers. We used the simulator to test one and two layers and no absorber. With no absorber, the temperature decline was over 60° F (33° C), dropping from 153 to 89° F (67 to 32° C) . The temperatures for one, two, three, and six layers of lath after one half-hour were 145, 155, 159, and 160° F (63, 68, 70, and 71° C). Based on our work, we feel that two or three layers of screen or lath are adequate for effective performance, but adding a few more layers will produce slightly higher temperatures.

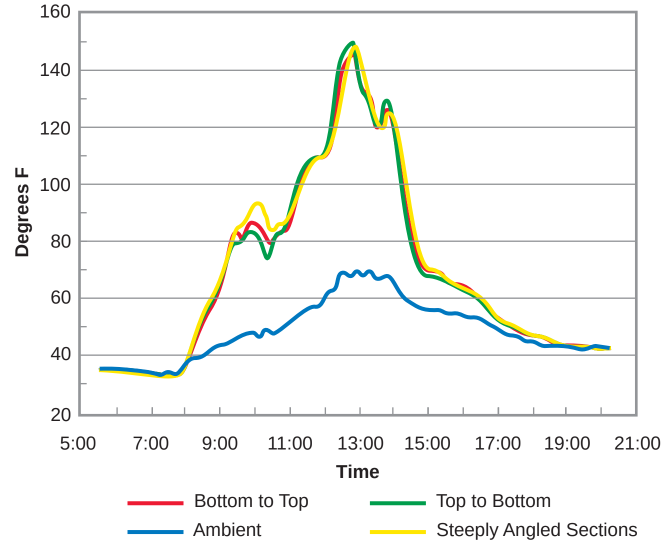
Reflective Is Effective

When constructing a solar air heater, you must decide what to do with the bottom of the air flow channel, below the absorbing material. In the next part of our research, we placed aluminum flashing in the bottom of the air flow channels of two of the three dryers, on top

Graph 6: Collector Bottom Material Comparison



Graph 7: Absorber Installation Comparison



of the 3/4 inch (19 mm) foil-faced insulation (Celotex Tuff-R, polyisocyanurate). The flashing in one of the dryers was painted flat black. The third dryer was left with just the reflective insulation board on the bottom of the air flow channel. This test was done with both the actual dryers and the solar simulator. In both cases, the highest temperatures were attained with the reflective foil-faced insulation. The differences were substantial, with the reflective insulation showing readings as much as 25° F (14° C) higher than the dryer with the black aluminum flashing (see Graph 6).

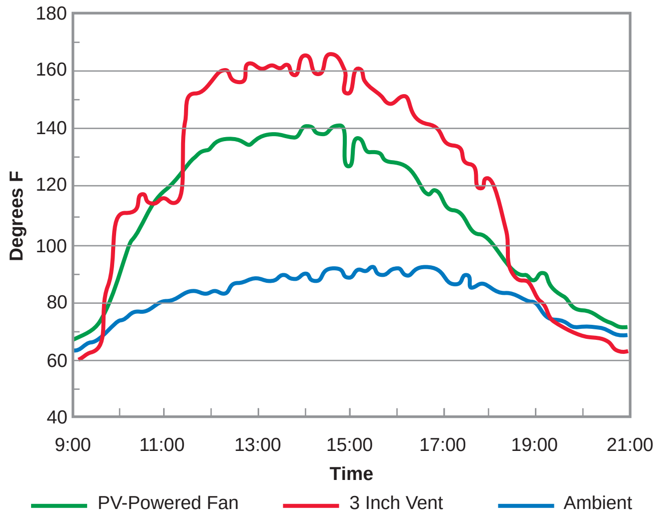
Mesh Installation

The original design called for the mesh to be inserted into the collector diagonally from the bottom of the air flow channel to the top (see Figure 7). This seemed the best from a construction point of view. In this test, three configurations were compared: from bottom to top as originally designed, from top to bottom, and a series of more steeply angled pieces of mesh stretching from the top to the bottom of the air flow channel. The differences in temperatures attained were very small (see Graph 7), and we concluded that there was not much difference in performance.

U-Tube vs. Single Pass

Another characteristic of the original design is the U-tube air flow channel. In addition to the air flow channel right below the glazing, there is a second air flow channel right below the first one, separated by a piece of insulation board (see Figure 7). We compared a dryer with this U-tube design to a dryer with just a straight shot single channel and found no significance difference in temperatures. We removed the insulation board from our dryers and have completed all the experiments detailed in this article without the U-tube setup.

Graph 8: PV Exhaust Fan vs. Vent

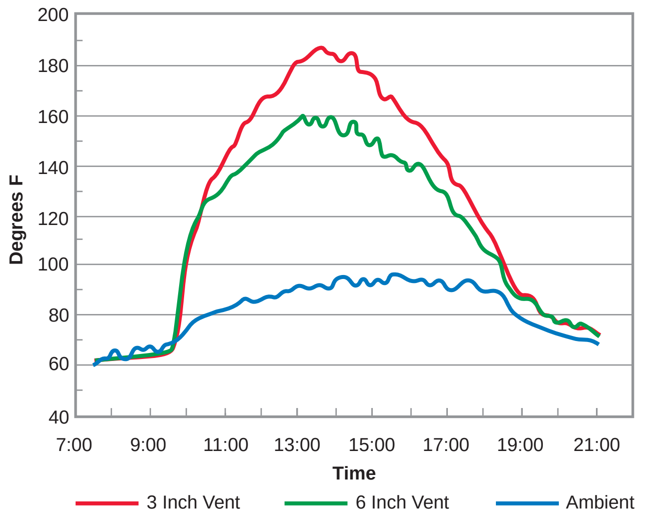


Active vs. Passive

We experimented with several small, PV-powered fans to see if they would generate higher air flows and possibly accelerate food dehydration. We tried three different sizes: 0.08, 0.15, and 0.46 amps. We placed the fans in the exhaust area of the dryer. Of the three, the 0.15 amp fan seemed to work the best. It increased the air flow from about 25 to 50 feet per minute (8 to 15 meters per minute), but decreased temperatures significantly (see Graph 8). The larger fan did not fit in the exhaust vent opening, and the smallest fan did not significantly increase the air flow.

Even with the fans in use, the drying performance did not improve. In every trial, the passive dryer either matched or outperformed the active dryer. Each morning during a five-day experiment, we placed exactly the same weight of fruit in each dryer. We used one to three pounds (0.4 to 1.4 kg) of apple or peach slices. Each afternoon between 2:30 and 5 PM, we removed and weighed the fruit. On all five days, the fruit dried in the passive dryer weighed either the same or less than the fruit dried in the active dryer.

Graph 9: Three Inch vs. Six Inch Exhaust Vent



Vent Opening

The dryers have vent covers at the top which can be adjusted to regulate the air flow and temperature. The smaller the opening, the higher the temperatures attained. We wanted to know how much the vents should be opened for maximum drying effectiveness. We tried a variety of venting combinations while drying fruit. For most of our experiments, we filled five to seven of the thirteen shelves with 1/8 inch (3 mm) fruit slices. We cut up, weighed, and placed an identical quantity and quality of fruit in each of two dryers in the morning. Sometime between 2 and 6 PM, we removed the fruit from the dryers and weighed it again. We compared openings of different measurements: a one inch (25 mm) to a seven inch (178 mm), a 3/4 inch (19 mm) to a five inch (127 mm), a three inch (76 mm) to a six inch (152 mm), a three inch (76 mm) to a nine inch (229 mm), and a three inch (76 mm) to a five inch (127 mm). During these experiments, the bottom vents were completely open.

We found that higher temperatures were attained with smaller vent openings, but that drying effectiveness was not always maximized. The best performance was observed when the vents were opened between three and six inches (76 and 152 mm), and temperatures peaked at 135–180 °F (54–82° C) (see Graph 9). With the one inch (25 mm) and smaller openings and the seven inch (178 mm) and larger openings, less water was removed from the fruit. There was no difference in the water removed when we compared three inches to five inches (76 mm to 127 mm) and three inches to six inches (76 mm to 152 mm).

Based on this work, we would recommend opening the leeward exhaust vent cover between three and six inches (76 and 152 mm), or between ten and twenty square inches (65 and 129 cm^2) of total exhaust area. The exact size of the opening depends on the weather conditions. With the vents opened between three and six inches (76 and 152 mm), we have been able to remove as much as sixty ounces (1.75 *l*) of water in a single day from a full load of fruit and completely dry about three and one-half pounds (1.5 kg) of apple slices to 12–15% of the fruit's wet weight.

Construction Improvements

As we experimented with the dryers, we came up with some design improvements to simplify the construction, reduce the cost, and increase the durability or portability of the unit. To simplify the construction and eliminate warping problems caused by wet weather, we decided to eliminate the intake vent covers during our experiments. The vent covers at the top, if closed at night, would prevent or reduce reverse thermosiphoning and rehydration of food left in the dryer.

The redesigned air intake now has aluminum screen secured to the plywood side pieces with wooden trim. We also redesigned the top exhaust vent cover to eliminate the warping problem caused by leaving the vent covers opened during wet weather. The new exhaust vent cover works very well (see Photo 6). It spreads the exhaust air across the dryer's width rather than concentrating it in the center. This should improve convective flows and performance. However, the vent cover makes it more difficult to calculate the exhaust area, and as a result, we mainly used the old design for our research this past year.

We added wheels and handles to the unit, as it is heavy and difficult to move around. It's now easier to maneuver, although it is still difficult to transport in a small pickup truck. We purchased ten-inch (254 mm) lawnmower-style wheels for $6 each. The axle cost $2. With the wheels on the small legs at the bottom of the collector, one person can move the dryer.

The original design specified thin plywood for the roof of the dryer. We replaced that with 3/4 inch (19 mm) plywood and covered the peak of the roof with aluminum flashing. We also used 1/2 inch (38 mm) wide by 1/8 inch (3 mm) thick aluminum bar stock and stainless steel screws to attach the glazing to the dryer's collector. Each collector used fourteen feet, eight inches (4.5 m) of aluminum bar at a cost of $23. The 1/4 inch (6 mm) plywood strips used in the original design were adequate and less expensive, but would have required more maintenance.

Conclusions and Recommendations

The dryer described in *HP57* has worked well in our tests. It produces temperatures of 130–180° F (54–82° C), and can dry up to 15 apples or peaches—about 3 1/2 pounds (1.6 kg) of 1/8 inch (3 mm) thick slices—in one sunny to partly sunny day. The best performance in our outdoor tests was attained with six layers of expanded steel lath painted black, although aluminum screen works almost as well and is easier to work with. We also found that two or three layers of screen or lath would produce temperatures almost as high as six layers. The surface behind the absorber mesh should be reflective, and for best performance the exhaust vent covers should be opened three to six inches (76–152 mm). The cost of the dryer and the time to construct it can be reduced by eliminating the U-tube air flow channel divider, the second or inner layer of glazing, and the intake vent covers, and by reducing the number of layers of screen or lath to two or three.

Above, Photo 6: The new vent design.

We made the unit more portable by adding wheels and handles, and improved the durability by fastening the legs with nuts and bolts, using aluminum bar to hold the glazing in place, and using 3/4 inch (19 mm) plywood for the roof. We would also like to take the insulation board out of a dryer to see if it significantly impacts the performance. This would further decrease the cost of the dryer. Soon, we hope to compare this design to direct solar dryers, which a *Home Power* reader has recently suggested can outperform our design. Thus far, we have avoided direct dryers because of concerns about vitamin loss in foods exposed to direct solar radiation.

We have tried to carefully explore all of the significant variables affecting this dryer's performance. We have been able to increase drying effectiveness with higher temperatures of approximately 30° F (16.6° C), while decreasing the cost by about $30. We have demonstrated the best vent opening for drying effectiveness, and seen the impact that variables such as double glazing, fans, reflectors, and absorber type have on performance. We have also developed and demonstrated a low cost solar simulator that can be used to test solar thermal collectors indoors.

Access

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Solar Cookers International (SCI), 1919 21st Street, Sacramento, CA 95814 • 916-455-4499 Fax: 916-455-4498 • sci@igc.org

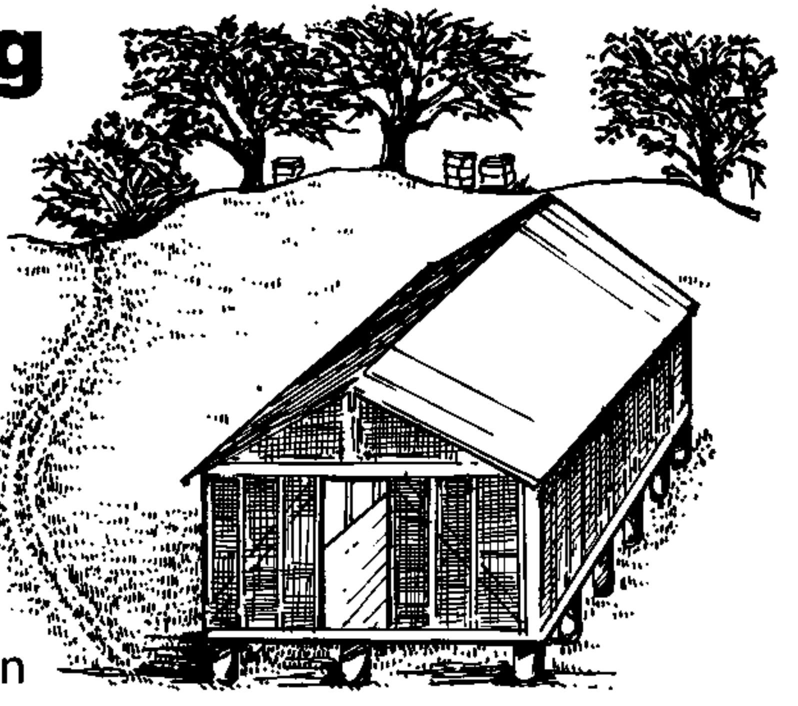
Sun-Lite HP glazing was purchased from Solar Components Corporation, 121 Valley Street, Manchester, NH 03103-6211 • 603-668-8186 Fax: 603-668-1783 • solar2@ix.netcom.com www.solar-components.com

Scales, anemometers, and other data collection equipment were purchased from Thomas Scientific, PO Box 99, Swedesboro, NJ 08085 • 800-345-2100 609-467-2000 • Fax: 800-345-5232 value@thomassci.com • www.thomassci.com

Data logger was purchased from Pace Scientific, Inc., 6407 Idlewild Rd., Suite 2.214, Charlotte, NC 28212 704-568-3691 • Fax: 704-568-0278 sales@pace-sci.com • www.pace-sci.com

Constructing a Large Fruit Dryer & How to Use It

by Lee & Robert McPhadyen



The Dryer Construction

We were called on to construct and operate a fruit drying unit as a pilot project on very short notice. We did not have an opportunity to accumulate a supply of recycled material and (regretfully) had to buy fairly expensive new lumber.

The materials used in the construction of our structure cost approximately one thousand dollars but this we are convinced could be reduced by 1/2 to 2/3 by someone with the time and access to good used wood.

The structure we decided on had base dimensions of 12' x 24'. We felt a dryer this size would allow the processing of enough fruit to provide a reasonable supplement to the income of a small family farm or survival collective. The size or dimensions of the structure are not as important as consideration of its function.

First, we chose a location where prevailing wind or breezes (which carry off the moisture) would blow along the longest dimension of the building (Fig. 1).

The second consideration was to locate the building where it would benefit from the longest period of sunshine not only during each day but during the drying season.

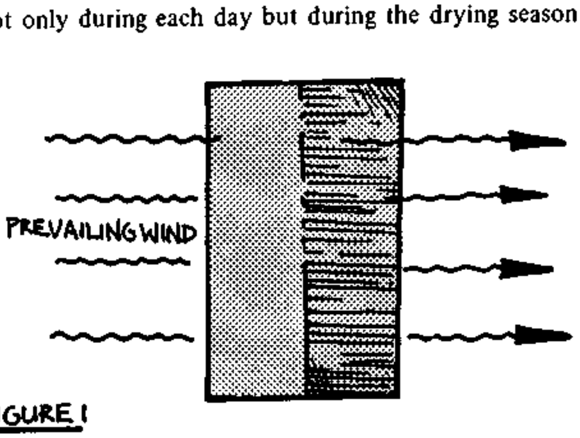
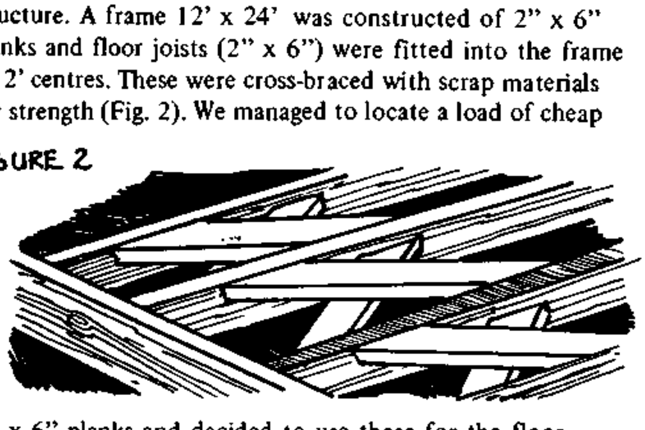


FIGURE 1

Thirdly, we chose a slight elevation, and then used foundation posts or cribbing to elevate the structure even more. This meant a free flow of air around the entire structure. A frame 12' x 24' was constructed of 2" x 6" planks and floor joists (2" x 6") were fitted into the frame on 2' centres. These were cross-braced with scrap materials for strength (Fig. 2). We managed to locate a load of cheap

FIGURE 2



2" x 6" planks and decided to use these for the floor decking instead of more expensive ¾" plywood. Anything sturdy could be used. By this time, we were ready to raise the walls. Our floor was good and level so we fabricated the walls flat on the deck using 2" x 4" lumber. The studs were cut to 7' lengths; this could be shortened by a few inches but should not be shorter than 6½'. There is no advantage of studs longer than 7'. The studs were placed on 24" centres which would allow simple application of standard fly screen of 24" or 28" widths later on. A provision was made in one end wall for a 36" door frame for unloading fruit from a truck plus one space between studs on a side wall for alternative access to the structure. As each wall was assembled it was raised into place and braced to secure it in position. When all four walls were raised 2" x 6" planks were cut into 12' lengths and placed in position on the upper plate off the walls. Two inch by four inch lumber spacers were spiked to the plate between each plank and the plank in turn was spiked (3" nails) to the

FIGURE 3

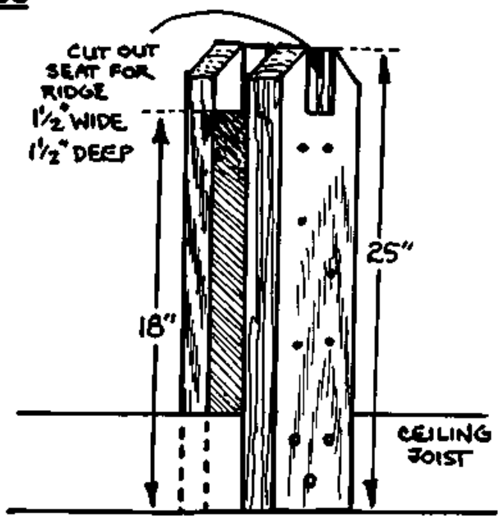
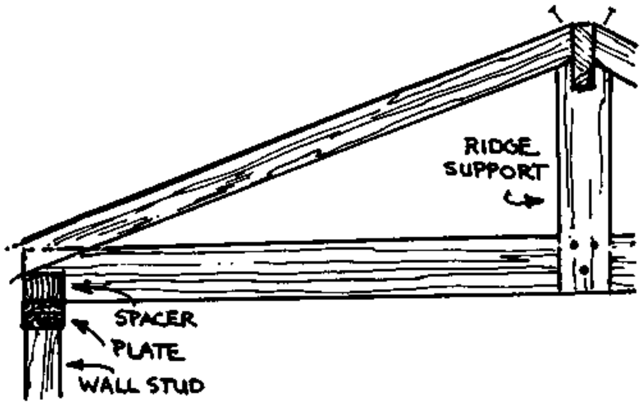


FIGURE 4



ends of the spacers to provide 2' centres for the 2" x 6" planks (Fig. 4). Walls are plumbed and squared as the planks are spiked to the spacers. We planned the roof to provide extended eaves to prevent direct sunlight from hitting the drying fruit at any time. On the other hand the eaves should not extend to a point that might inhibit the flow of air through the structure. The roof was constructed by mounting a ridge board of 2" x 6" plank mounted on supports fastened to the ceiling joists as in Fig. 3.

To make the support, cut two pieces 2" x 6" plank 25" long and one piece 18" long. Nail them together with a shorter piece sandwiched in between the longer two. This creates a slot at one end 5½" deep allowing you to set the support over the ceiling joist to form centre of roof. Cut a slot on the opposite end 1½" wide x 1½" deep to carry the roof ridge. For a strong roof, one support should be made for each ceiling joist. Our roof withstood a 70 m.p.h. windstorm last December. Next we took 12' long 2" x 4"s and cut the ends to fit to the roof ridge, using the first one as a pattern to mark the rest. Nail the top end of each 2" x 4" to the roof ridge, and the bottom ends to the 2" x 6". The bottom ends will be resting on the spacers. This will provide an adequate overhang for shade.

We then applied an overall roof of 5/16" unsanded sheathing plywood followed by the cheapest 50 lb. rolled roofing (using plenty of lap cement and allowing a fairly generous overlap for a little extra strength). If the budget hasn't been exhausted the walls can be closed in with fly

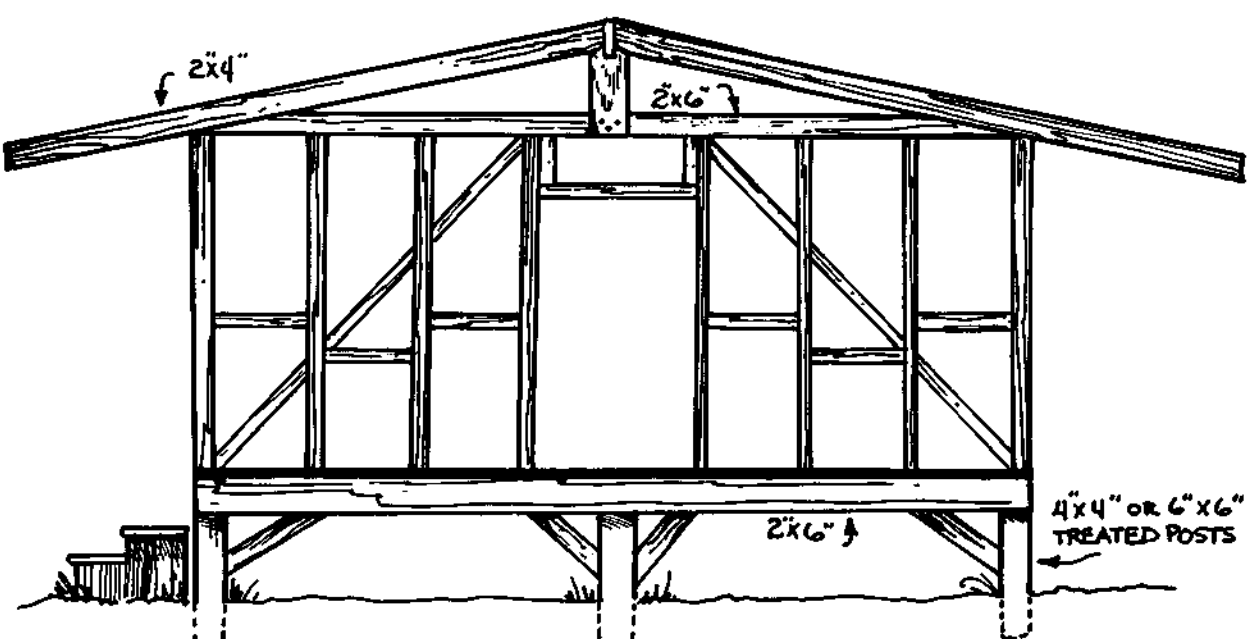


FIGURE 5

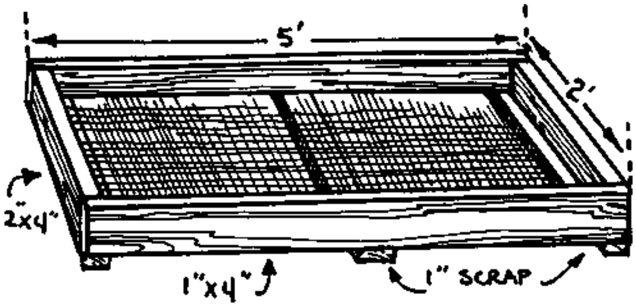


FIGURE 6

screen stapled to the studs and then further secured with plaster lath. Screen doors can be made for the two entrances. For drying racks, we made frames 2' x 5' using 1" x 4" strapping lumber on the sides and 2" x 4" scrap on the ends. Fly screen was stapled to the bottom with end runners and the centre support was made from 1" scrap (Fig. 6)

Spaces between studs should be cross-braced for extra rigidity and overall strength.

Drying Fruits

In the drying of fruits, we used only the natural elements, providing the previosuly described shed to protect the fruit from the direct rays of the sun, as these destroy the vitamin A content. The shed also provided a cover from rain. We had some rain while certain fruits were drying, and while the high humidity slowed the drying process, so long as the fruit was not wetted by the rain, we could detect no ill effects from the wet weather. We used no sulphur and found that with the exception of very ripe pears, the colour remained very good for all fruits. We were drying large quantities and were not able to harvest the fruit as I have stated in the following recipies. However, each day we would pick over the trees, taking only the ripest fruit. With cherries and prunes, we were able to wait until the fruit was withering from the stems. If you are buying your fruit, it is impossible to get it this ripe, but the fruit can still be satisfactorily dried; it just won't be quite as sweet.

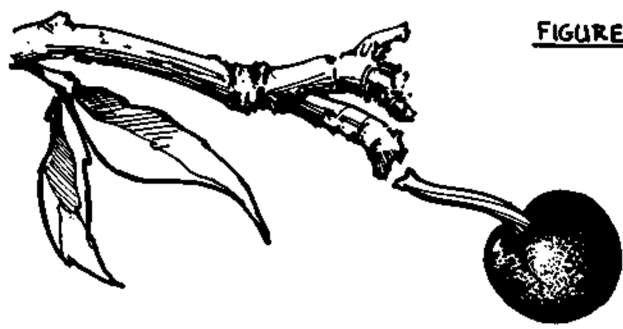
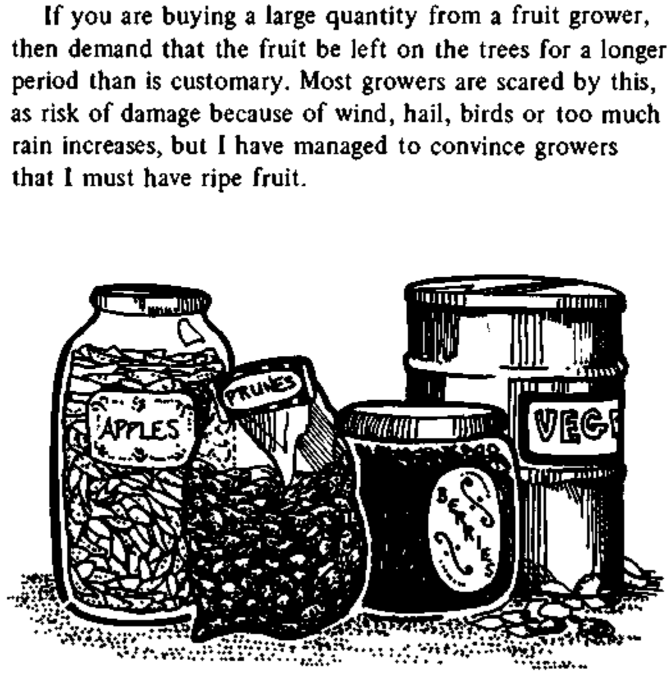


FIGURE 7

When picking your fruit (pears, apricots, peaches, nectarines) the stem should come off the tree when you touch it. If you have to pull to get fruit off, I do not feel that this is ripe enough for proper development of nutritional factors in fruit, and for the flavour potential to be realized.

If fruit is too green when picked, and stored to colour, as is the case with most commercial fruit sales, then you sadly miss out on flavour and can end up with a bitter taste. When picked too green, the fruit does not really ripen; it simply changes colour. The sugar content does not increase from the time it is picked; just what little sugar that was there concentrates.

If you are buying a large quantity from a fruit grower, then demand that the fruit be left on the trees for a longer period than is customary. Most growers are scared by this, as risk of damage because of wind, hail, birds or too much rain increases, but I have managed to convince growers that I must have ripe fruit.



Packing & Storing Dried Products

Once dry, pack your fruit immediately in containers such as tins, jars, plastic bags, etc., that will not allow the reabsorption of moisture and contamination by eggs of insects etc.

Dried fruits are not readily susceptible to spoilage by moisture absorption, but will deteriorate more quickly if not stored properly. Once packed, store in a dark cool place.

Preparation of Dried Fruits

Restoration: Soak the product in cold water for 1-3 hrs.; no longer. Use only enough water to restore to original size.

Cooking

Place the product on your stove in the water used for restoration; simmer, do not boil. As soon as it is tender cease cooking as the fruit will overcook quickly and the texture and flavour will be spoiled.

Eat As Is

Wonderful candy for the kids! Use home dried fruits in place of commercial ones usually called for in recipes. Cherries substitute for raisins very well.

Occasionally concentrations of sugar in the fruit will carmalize, or burn. This does not happen very often but when it does you end up with a dark brown mark on dried fruit. It seems to occur when very ripe fruit has been badly bruised. I prefer to put aside bruised fruit and make juice from it. This occurs most often with apricots.

Grapes – Method 1: If you can buy or produce a type of grape that will stay on the stems, pick the bunches and hang them to dry under eaves on a string.

Method 2: Submerse ripe fruit in boiling water for 2 minutes to check *the skin. Place it on racks and dry.

Method 3: Remove the grapes from their stems, place them on racks and dry. This method takes longer than method 2.

Sun Cooked Preserves: Wash and hull strawberries, raspberries or other berry fruits. Place them in shallow enamelled pans. Drizzle honey over the fruit and mix well. Cover the pans with sheets of glass and place in the sun. Let stand for several days until fruit is a jelly-like consistency, stirring several times each day. Pack in hot clean jars and sterilize in hot water bath 2-3 minutes. Enjoy them on cold snowy days. Open a jar of summer and eat.

Apricots: For small quantities, if you are fortunate enough to have your own trees, let the grass grow as apricots ripen and dry the fruit as it falls to the ground. The grass is a perfect cushion and very little fruit is damaged. This degree of ripeness creates the perfect dried apricot. Collect the fruit as it falls, split, place on racks open side up and allow moisture to escape. If the weather is very hot, they should be ready in 2-5 days. When adequately dry they will separate from each other when several are balled together in your hand. If they overdry, no harm is done, they keep very well but may need some moisture before being eaten. Better to overdry than leave too much moisture in them as they mould if too wet.

Honey Apricots: Prepare solution of 1 part honey to 2 parts water. Bring to 200° F. Split the apricots, place them in a wire basket, submerge in honey mixture and count to 20. Take out and place apricots on racks and let dry. A more extravagant method is to drizzle some pure honey over the apricots once they are on the racks. It's time consuming but gives some very special eating for winter. Fruit done this way will be a little more tacky when dry. There is no need to turn apirctos while drying.

Cherries: Best picked when the fruit is beginning to shrivel from the stem.

Method 1: Dip whole cherries into boiling water for 2 minutes. The same water can be used several times. It may have honey added to it if desired. Place on racks and dry.

Method 2: Pit the cherries. It's time consuming and tedious, but it's nice to have no pits in some fruit. I have not found this method allows the fruit to dry any quicker. Place pitted cherries on racks, let dry. There is no need to turn.

Method 3: Wash whole fresh fruit, put on racks and let dry 3 to 5 days and longer if needed (up to 4 weeks).

Pears – Method 1: Pick ripe but firm fruit. Wash, stem and cut unpeeled and uncored into very thin slices. You can purchase machines that do this chore quickly and evenly. Place slices on racks but do not turn. They will be dry in 24 to 36 hours.

Method 2: For a darker but very sweet treat, allow your fruit to ripen till ready to fall or let it fall on thick grass. Wash, stem, cut in quarters, remove core if desired, and place the skin on racks. This method takes longer to dry and fruit oxidizes more but makes delicious eating. If you wish, fruit may be peeled but if very ripe, is likely to stick to the screens.

Peaches: Harvest peaches as late in the ripening process as allows them to be handled without becoming badly bruised. I did not peel mine. However, if you have a slip skin type available to you, do so. The skin once dry, is reduced, and is hardly noticeable. Halve the peaches, pit, and place in racks. They may take up to 7 days to dry.

Nectarines: Do the same as for peaches.

Plums & Prunes: Harvest when the fruit begins to wither from the stems.

Method 1: Dip the whole fruit into boiling water for 2 minutes, to check the rather tough skins. Do not immerse too many at once as the water must boil around the fruit to achieve desired checking. Place on racks and dry. They may take up to 3 weeks to dry as these fruit are late in the season. I found this method not as satisfactory as the 2nd method. The fruit skins did not check evenly and some fruit simply did not dry as moisture could not escape.

Method 2: Split the fruit, remove pip or stone, lay open side up on racks, do not turn, and let dry. They can take up to 2 or 3 weeks to dry.

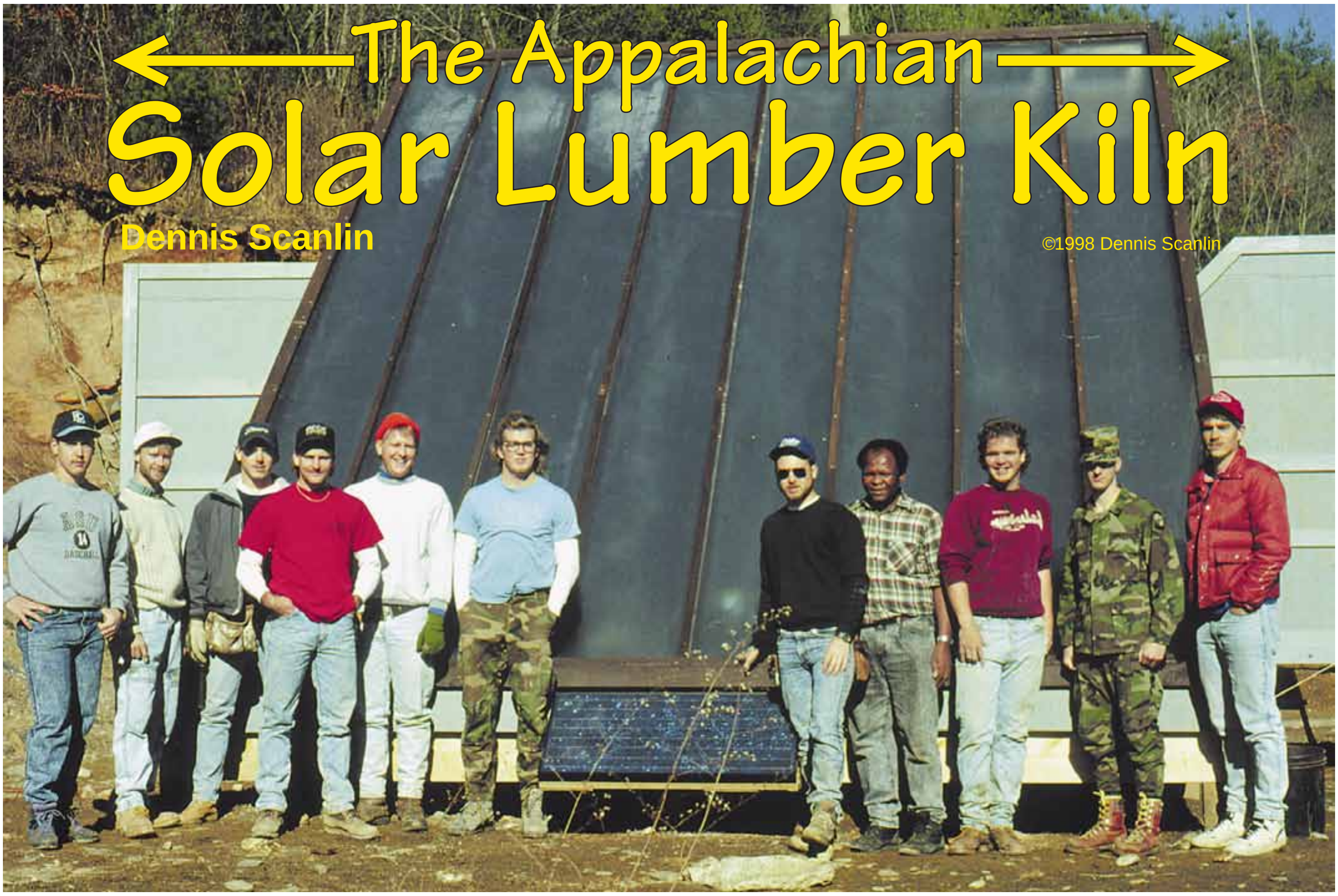
We were able to do all of our drying with the sun's heat and the breeze evaporating. Some geographic areas may have to supplement this with artificial heating etc. – but this would be a whole other subject.

In this past season all fruit took much longer to dry, but with equally good results. However, with the longer time on racks, the racks need rotating and checking, as some pieces of fruit are more likely to mould. Discard any of these. Allow a lot of space, 18" between racks and as much space as possible between stacks of racks, to allow a really good air flow. This is particularly important during periods of cool, cloudy, or rainy weather. Fruit is also more likely to collect dust during extra time on the racks. If desired, this can satisfactorily be removed before storing your fruit. Fill a large pot with water, allowing a 2" headspace. Bring the water to a boil. Place your fruit in a wire basket that will fit in the pot and not allow the fruit to escape through the holes in it. Submerse the fruit in boiling water for 10-15 seconds, shaking it up and down as you do so. Remove the basket from the water and tip the fruit, one layer deep, onto racks to dry off. A warm sunny day with a breeze is the ideal day for this procedure. Within 2 hours the fruit is quite dry, soft, clean and ready for immediate storage before further dust can settle on the fruit. This process does not cook the fruit in any way. The plunge is too short in time. In 2½ hours, you can process at least one hundred pounds of dry fruit.

*check means to cage or make small breaks in the skin, by shrivelling it a little. This allows moisture to escape more readily.

The Appalachian Solar Lumber Kiln

Dennis Scanlin



Above: Students from Appalachian State University with the Solar lumber kiln.

The drying of lumber is essential before it can reliably be used indoors. Drying consumes an enormous amount of energy. Each year (in the United States) lumber drying consumes 10 trillion BTUs, the equivalent of 1.7 million barrels of oil (*Fine Woodworking*, 1986). Two-thirds of all the energy used in producing lumber is for drying, adding 40 to 75% to lumber's value. Green 4 by 4 FAS cherry currently costs $1.27 per bd. ft. and kiln dried is $2.20, a 73% increase. Edwin Culbreth, the former owner of General Hardwood Products in Deep Gap, North Carolina, for whom the 3000 bd. ft. capacity kiln described in this article was constructed, spent as much as $0.08 per bd. ft. drying lumber in a dehumidification kiln. The initial cost of a kiln is also significant. An all electric 2,000 bd. ft. kiln with a small electric boiler can cost over $30,000.

Solar Drying

Lumber drying can be successfully accomplished with solar energy. The temperatures desired for lumber drying are between 100 and 180° F (the same as for food drying) and these can be obtained with a low temperature solar thermal collector. A solar kiln can operate all year long and during good solar periods can dry lumber in virtually the same amount of time as could a fossil fuel powered kiln. The quality of solar dried lumber is also as good or better than lumber dried in conventional kilns. Solar kilns can be constructed for much less than the cost of conventional kilns. The kiln described in this article was designed and constructed by students and faculty at Appalachian State University in the Department of Technology's Appropriate Technology Program. It has been in continual operation for 6 years. The inspiration for the design came from the "Oxford Kiln," a lightweight, portable, inexpensive, but not very durable kiln designed at Oxford University in England (*Fine Woodworking*, 1986). The 3,000 bd. ft., PV controlled, solar kiln described in this article was constructed for $3800. I have also constructed a smaller 600 to 1000 bd. ft. kiln in West Virginia for about $1000.

Wood Drying
Wood absorbs water, and swells and shrinks with changes in moisture content. This characteristic can make wood difficult to predictably use. The goal of wood drying is to remove moisture until it reaches the level present in the environment where the wood will ultimately be used. This keeps the swelling and shrinking to a minimum. Wood will release or absorb moisture until it is in equilibrium with the surrounding air. This state is called the equilibrium moisture content (EMC). If the wood will be used outside, then wood could be stacked outside and will eventually reach equilibrium with the environment. No kiln is necessary. The speed of drying will be affected by the thickness and density of the wood and the relative humidity of the surrounding air. Thin, low density wood placed in a low humidity environment will dry most quickly. If the lumber is for furniture to be used in a lower humidity environment inside a house, then the wood should be dried until it has the same moisture content (MC) of that environment. Usually 6 to 8%. This involves removing water from inside the cell walls (bound water), as well as the "free" water in between the cells.

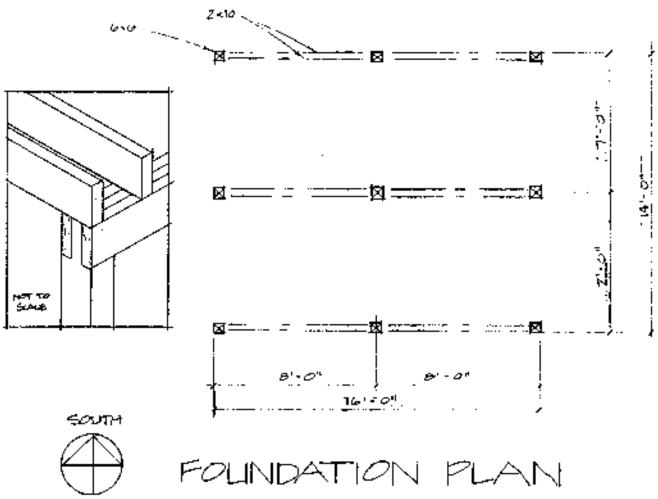
The bound water is more difficult to remove. It could be removed by stacking the lumber inside the space where it will eventually be used. However this could take a year or more and most of us are not interested in living with stacks of lumber. Indoor drying can also proceed too quickly, because of the low humidity indoors, and cause surface checking. More commonly, lumber for furniture is dried in a kiln. The wood is exposed to 100° to 180° F air until it reaches the moisture content comparable to the relative humidity of the end use environment. In general the higher the temperature and air flow and the lower the humidity, the faster the drying. The goal is to speed up the drying process but keep it slow enough by controlling the humidity and temperature to prevent uneven shrinkage and the resulting defects. Most conventional kilns operate with air velocities of between 200 and 500 CFM through the lumber pile. The humidity is normally kept high during the early phases of drying and lowered as the drying proceeds.

Above: Installing exhaust vents.

Above: Installing the dark aluminum screen used for solar absorption.

Components of a Solar Kiln
A solar kiln is basically a low temperature solar thermal collector, usually an air heating collector, connected to an insulated and tightly constructed building. A stickered lumber pile is placed inside. A solar kiln has the same basic components as most solar thermal technologies: south facing glazing to admit solar energy; an absorbing material, often metal, to absorb solar energy and convert it to heat; insulation and tight construction to reduce unwanted heat loss; an air intake, flow path and exhaust area; and an area for lumber pile. A reflector could be added to increase performance.

Glazing Options
Glazing is the material that allows solar energy to enter the solar collector. It can be glass or plastic. An ideal glazing would have a high solar transmittance, over 90% and a low terrestrial infra-red (IR) or heat transmittance. It would let a lot of solar energy in but not much heat radiate out. Glass is an ideal material having as high as 91% solar transmittance and as low as 1% IR transmittance. But it is heavy, breakable, and is not normally available in long lengths. Sun-Lite HP plastic or Kalwall is also a good material with properties similar to glass (86% and 4% transmittances), with the added advantage of coming in rolls which can be cut any length desired (manufacturer recommends no longer than 16 feet). This eliminates horizontal seams



which can be problematic. It is also light weight and non-breakable. If properly maintained it can last a long time, maybe 25 years. Maintenance involves coating every 10 years with "Kalwall weatherable surface," a 2 part resin. The Sun-Lite HP glazing for the solar kiln described here is 0.040 inches thick by 49 1/2 inches wide. The cost is $1.85 per sq. ft.

Thinner plastic glazing can also be used. Many have very high solar transmittances over 95%, but also have high IR transmittances, over 50%. They are not as durable as glass or Sun-Lite. But some resist UV degradation and can be good options for a second inner glazing. There are a variety of products on the market. The kiln depicted has an inner, second layer of glazing separated from the Sun-Lite by a 3/4 inch air space. The inner glazing is Teflon FEP film. Wengert and Oliveira (1987) have indicated that collector performance can be improved by 35% or so when a second layer is used.

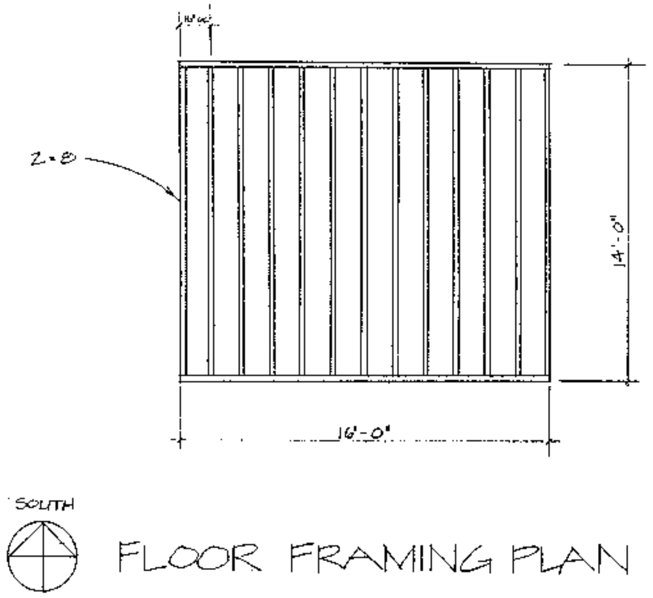
Other Glazing Issues

Other glazing decisions include: what angle should the glazing be above a horizontal plane or the ground (altitude) and what direction should the glazing face (azimuth)? Assuming the kiln would be used all year round, the glazing angle should be the same as one's latitude. This would provide the greatest number of BTUs over a year. Latitude plus 10 to 15° would result in slightly better performance during the shorter days of winter while still providing good summer performance and more usable interior space. This is the strategy we pursued. The Appalachian kiln is located at 36° N LAT and has a glazing angle of 45°.

Above: Laying out foundation and floor.

The azimuth angle for the kiln's collector should be due south for best performance in northern latitudes, although slight variations won't significantly affect the performance. Make sure the sun can strike the collector all day long or at least from 9 to 3 solar time.

A final consideration is what size the glazing needs to be. Wengert and Oliveira (1987) recommend 1 sq. ft. of glazing for each 10 bd. ft. of dryer capacity. All successful designs surveyed have this much or more glazing. The Appalachian kiln has a 3,000 bd. ft. capacity (1,000 cubic feet) and 320 sq. ft. of glazing, a little more than 1 sq. ft. per 10 bd. ft. (0.32 sq. ft. per

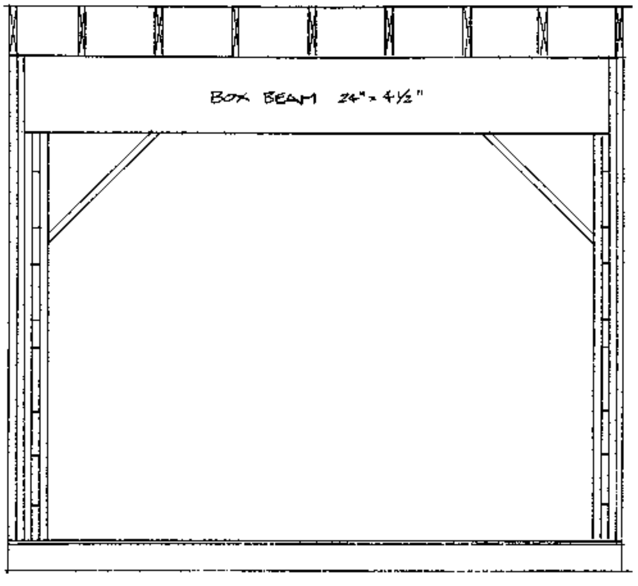


Above: Bracing the north wall.

cubic ft.). This ratio performs well, although two recently published kiln designs have higher ratios of around 1 to 3 sq. ft. per cubic foot and are capable of producing higher temperatures and faster drying (Kashihara, 1989; Kavvouras, M. and Skarvells, M.A., 1996). They also cost considerably more to build.

Absorbers

A good absorber will be a dark color, thin, and have good conductivity. Most absorbers are made of black metal. Copper and aluminum are often used because of their excellent conductivity. The Appalachian dryer uses 6 layers of dark gray aluminum window screening. 5 to 7 layers has been suggested in articles and books on solar air heating. We have not explored the difference in performance with different numbers of layers. Others have used metal or wire lathe painted black instead of window screening. When we compared the lathe to the screening in small test collectors we found no significant difference in performance. The screening cost less, \$0.22 vs. \$0.28 per sq. ft., and did not have to be painted. The screen is diagonally positioned in the air flow channel. This through-pass mesh type absorber has been proven to be a superior configuration in our tests. Other published reports have come to the same conclusion. The air must pass through the warm metal mesh, resulting in good heat transfer.



NORTH WALL FRAMING PLAN

Insulation and Tight Construction

The floor of the dryer is insulated with 8 inch unfaced fiberglass insulation (R25). The east, west, and north walls are insulated between the studs with 3 1/2 inch faced fiberglass insulation (R11) and are sheathed with 1/2 inch Tuff-R polyisocyanurate insulation board (R3.5). The exterior surface is 3/8 inch T111 sheeting and the interior was sheathed with 3/8 inch plywood. A layer of polyethylene was caulked and stapled to the interior surface of the studs before the 1/2 inch plywood was installed. Caulking and weather stripping made the structure as tight as possible.

Air Intake, Flow Path, and Exhaust

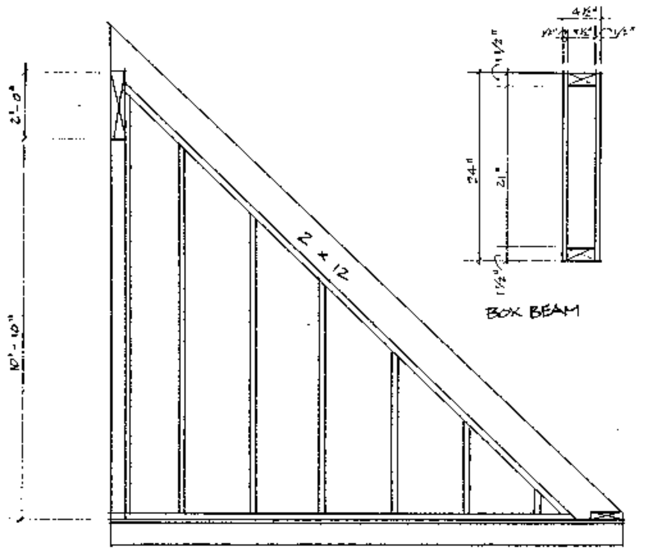
The air flow path through the collector was created using the south facing framing members. They are 2 by 12's on 24 inch centers. On the bottom of the 2 by 12's, 1/2 inch plywood was glued and screwed in place. Then 3/4 inch by 3/4 inch absorber mesh support strips were positioned diagonally up the air flow channel on the faces of the 2 by 12's and screwed in place. The inside of the air flow channel (the 2 by 12's, absorber mesh support strips, and the top or south side of the plywood) was painted a dark brown (black was not available at the time). Then the 6 layers of dark gray aluminum screening were stapled in place and the glazing layers fastened to the top, south facing surface.

The depth of the air flow channel, determined by the 2 by 12's, was selected by computing 1/20 of the length of the collector which was approximately 20 feet or 240 inches (1/20 or 0.05 x 240 = 12 inches). The 11.25 inch depth of a 2 by 12 was as close as we could get using stock lumber.

Above: Setting up 2 by 12 south wall rafters.

of the south facing 2 by 12's. The air is pulled down through the absorbing mesh and into the air plenum. The fans then blow the air into the lumber pile. A row of eight exhaust vents was placed below the intake vents just above the doors. Covers hinged at the top of the vents permit regulation of air intake, exhaust, temperature, and humidity inside the kiln. These can be controlled by ropes and pulleys operated from the ground. Another set of eight vents was constructed inside the kiln at the top of the north side. These can be opened when the other two sets are fully or partially closed to permit the recirculation of the kiln air for further heating. This permits greater control of temperature and humidity.

Air is drawn into the kiln by three 1000 CFM, 12 VDC, 1.1 Amp fans, powered by a single MSX-60 Solarex PV module. The fans are 16 inches in diameter, with a three wing aluminum blade. An air plenum for the fans was constructed in the bottom south corner of the drying chamber. The PV module is connected directly to the fans, which are connected in parallel. No controls, regulators, or batteries are used. When the sun is shining the fans are turning. They have done so now for 6 years with no maintenance. The fans draw air into eight 8 inch by 16 inch soffit vents placed in the top of the north wall. These vents were placed between each



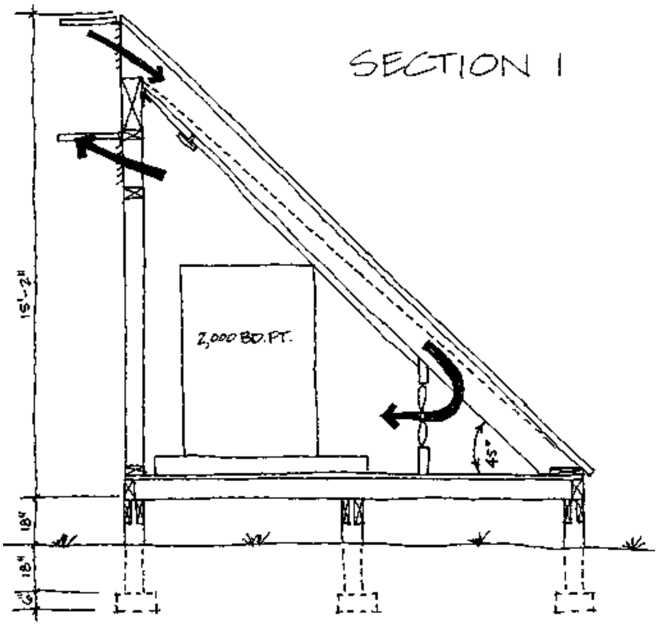
EAST/WEST FRAMING PLAN

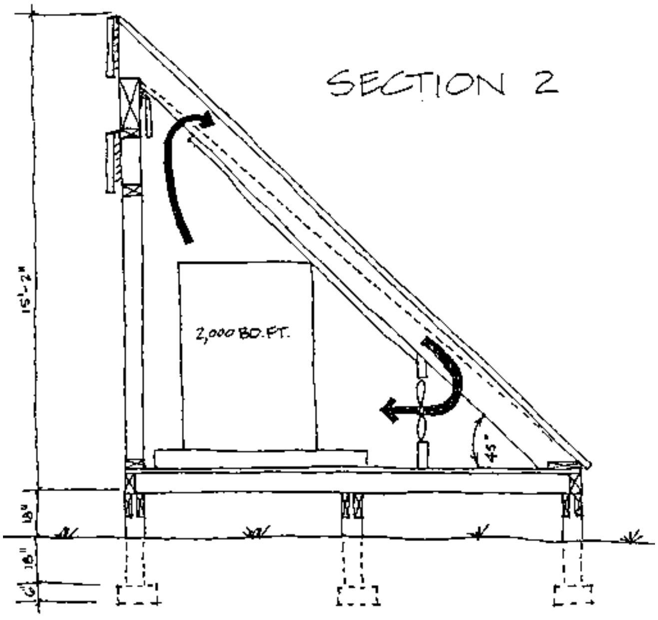
Area for the Lumber
The kiln will accommodate up to 3,000 bd. ft. of lumber, up to 14 feet long. It has two large doors on the north side to facilitate loading with a fork lift. Baffles were installed inside the kiln on the east and west interior walls to force the warm air through the lumber. They are 1/4 inch plywood panels hinged to the sides and controlled with string and cleats.

Other Construction Details
Except for the glazing, the kiln was constructed of common building materials. The kiln is 16 feet long east to west, 14 feet wide north to south, and approximately 15 feet tall. The drawings provide most of the construction details. The foundation is nine 6 by 6 locust posts positioned in three rows. Three posts are 8 feet apart in each row and the rows are 7 feet apart. Two 2 by 10's are bolted to each of the rows to form three 16 feet long girders. The floor is 2 by 8 joists, 16 inches o.c., with 1 by 8 boards nailed diagonally to the joists. A 1/4 inch plywood air barrier was fastened to the underside of the joists after the insulation was installed.

After the floor, the north wall was constructed. This required a 24 inch by 4 1/2 inch by 15 1/2 foot box beam, constructed of a 2 by 4 frame with 1/2 inch plywood glued and screwed to each side. The beam permitted the large opening for loading with a forklift. The beam and north wall were constructed, plumbed, and braced in place.

Next came the 2 by 12's for the south framing, the east and west framing, and collector construction. Insulation, vent detailing, door construction and installation, painting, and all the other details followed.





Kiln Operation

As soon as possible after cutting the lumber, the ends should be sealed with aluminum paint, paraffin, glue, latex paint, or urethane varnish to reduce rapid drying at ends. This helps avoid cracking. The lumber should also be stacked and stickered as soon as possible after cutting. Shelter furniture grade lumber from direct sun and aim the end of the stack into the prevailing wind. This also helps avoid overly rapid drying and cracking. Build the pile about 1 foot off the ground and place stickers (1 inch by 1 inch) at the ends and every 18 to 24 inches. Cover the top of pile with scrap boards or plywood and put some rocks or cinder blocks on top. Lumber can be air dried outside to about 20%. To compute moisture content, use an electronic moisture meter or use an oven and 1 inch cubes from a board about 2 feet from the end. Weigh a cube and put it in the oven at about 220° F until it no longer loses weight. Subtract the oven dry weight from the sample's wet weight, divide by the oven dry weight, and multiply by 100.

$$\frac{W - D}{D} \times 100 = MC$$

where

W = Sample wet weight
D = Sample oven dry weight
MC = Moisture content in percent

The air dried lumber can then be kiln dried down to 6 to 8%. Green lumber can also be placed into the kiln. The normal operation of a dry kiln is to maintain low to moderate temperatures (120° F) until the wood drops to about 30% MC then increase the temperatures to 160 to 180° F in several steps. Most solar kilns do not permit as much adjustability as in a conventional powered kiln. However, it is possible to adjust the temperature and humidity by controlling the air vent covers. The temperature will drop at night. This temperature drop allows the lumber MC and temperature to equalize. Some (Wengert and Oliveira, 1987) have suggested that this reduces cracking and bending.

In the initial phases of drying green lumber keep the inner vent cover open and the outer vent covers closed to keep the humidity high. The temperature will automatically be depressed by the mass of all the

Below: A Solarex MSX-60 powers three 1000CFM fans.

Above: Setting up vent control lines.

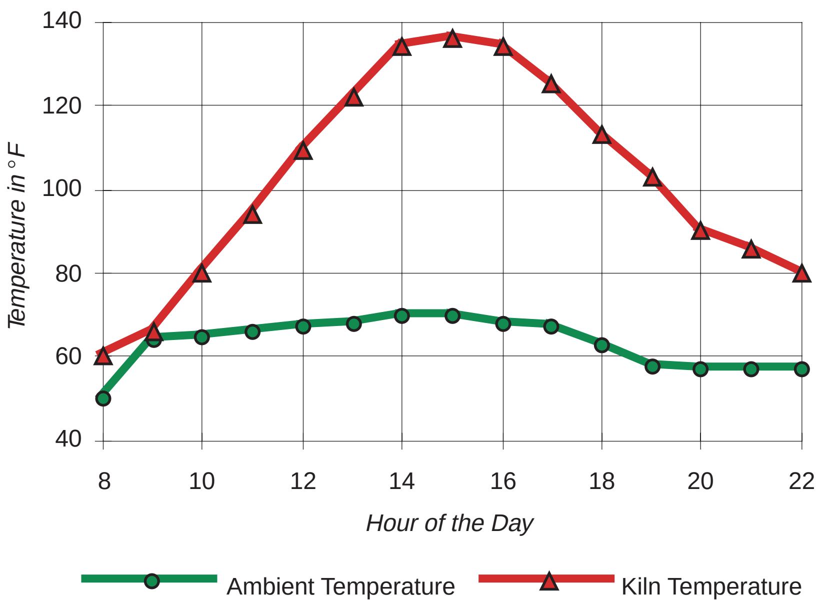
moisture. Some moist air will still escape and after the moisture content drops to around 30% or the temperature rises over 130° F, the outer vent covers should be opened a little and the inner vent cover closed. Adjust the exterior vent covers to regulate the temperature. They normally won't need to be opened very much. Gradually close them to increase the temperature as much as possible at the end of the drying cycle for maximum drying. Keep taking MC measurements and closing vent covers until wood gets down to about 6% MC. The operators of the Appalachian kiln found that it dried well by keeping the interior vent covers open and the exterior vent covers almost closed. A reflector would probably improve the kiln's performance but add to the cost and complexity. We have not experimented with one on this kiln, but a reflector added to solar food dryers has increased temperatures by about 20° F and reduced drying time.

After drying to below 6 to 8% remove lumber from kiln if you have a dry place to store it. Lumber will reabsorb moisture after being dried if left in an environment having a higher moisture content. Stack the lumber tightly without stickers.

Kiln Performance

The kiln has been in continual use for 6 years and has successfully dried many loads of lumber down to 6 to 8% MC. The maximum temperature observed in this kiln is about 150° F. The graph shows the kilns typical performance on a sunny day in September midway through a drying cycle. It dries more quickly in the spring, summer, and fall than in winter. The first load of lumber placed in the kiln was about 2150 bd. ft. of 4 by 4 basswood. It was put in on December 13 and was down to 38% by December 28, 28% by January 12, 15% by February 5, and 7% by March 13. There were a lot of cold, cloudy days throughout the period. During most of the year, air dried lumber with a moisture content of about 25% placed in the kiln takes 2 to 4 weeks to reach 6 to 8% MC. During one summer, 4 by 4 cherry dried from 39% to 15% in 2 weeks. After 4 more weeks the wood had an average MC of 8%. Ash, oak, cherry, poplar, and cedar have all been successfully dried. The largest load dried at one time was 3,880 bd. ft.

Solar Lumber Kiln — September 22



Solar Kiln Costs

Basic framing, sheathing and foundation	$1,800
Insulation	$279
Absorber mesh	$480
Glazing (FRP)	$635
Air distribution system (PV module, 3 fans)	$665
Total	$3,859

Access

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Fans and module: Alternative Energy Engineering, PO Box 339, Redway, CA 95560
800-707-6609.

Sun-Lite HP: Solar Components Corporation, 121 Valley Street, Manchester, NH 03103 • 603-668-8186.

Teflon FEP film: DuPont Company, Electronics Department, High Performance Films Division, Wilmington DE 19898 • 800-441-9494.

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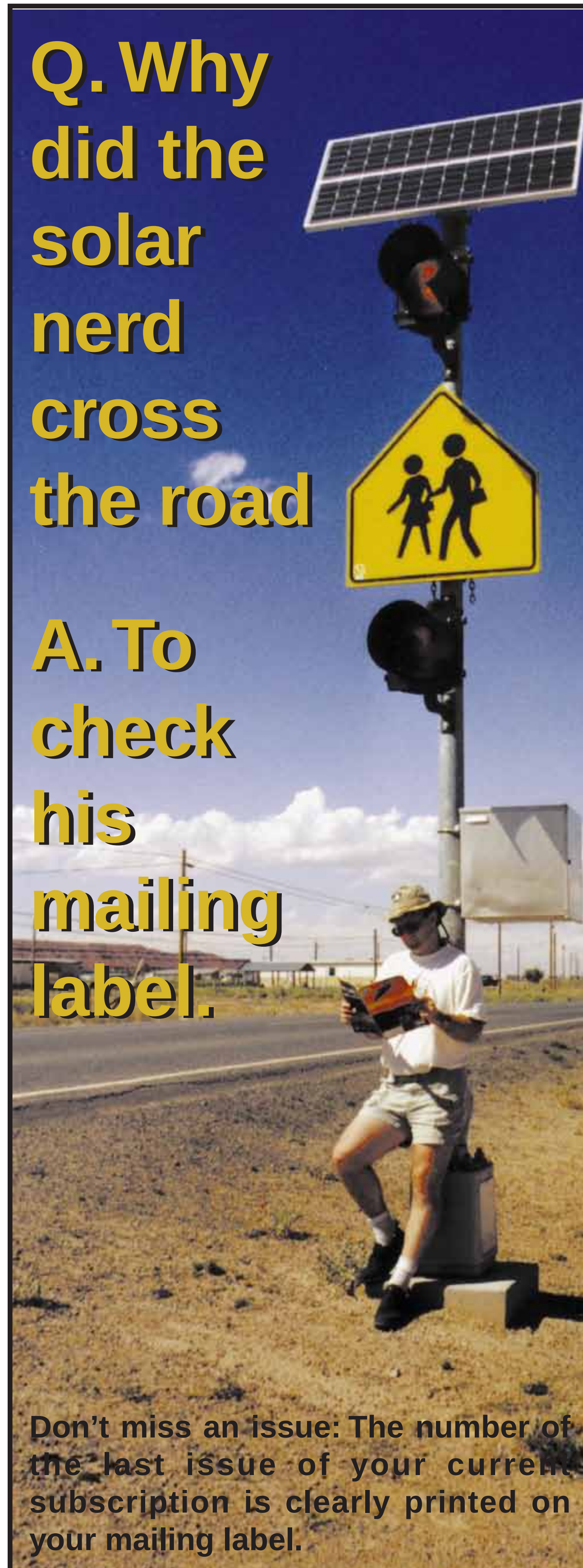


Chapter 10: APT solarware. Making cookers, fruit dryers and hot boxes from corrugated card and junk car glass.

Using APT solarware and recipes

The topic of APT solarware is specialized. Therefore, a separate chapter is devoted to it. Making the solarware described here requires no new skills, although some techniques are modified slightly.

APT solarware is probably unknown to most readers. To use it effectively requires understanding and the ability to adapt to unconventional ways of food processing and cooking. Therefore, the second part of this chapter describes ways of using APT solarware effectively, without knowledge of which you may contravene the second rule of APT and produce an APT article that is not useful.

The terms solar oven or cooker are used interchangeably. A water heater is a cooker adapted to accommodate water containers. A fruit dryer is a ventilated cooker with a movable single glass top.

Although APT solarware is marvellously useful it demands attention during the day. Stoves must be turned to follow the sun. At the first onset of rain and at nightfall they must be protected by a covering of plastic. A clear plastic cover may be left permanently on the stove. You cannot just go out all day and leave your slow cooker to look after itself.

Solar ovens and heat conservation

Solar ovens embody the principles of heat conservation. The ovens are boxes with glass tops, constructed and decorated to receive and conserve maximum heat from the sun.

Solar ovens catch the sun because:

- They have glass tops which must be kept clean
- The top is set at the most effective sun-catching angle (which varies according to latitude), and
- The stove is rotated to follow the sun.

Solar ovens conserve the sun's heat because:

- They are absolutely air-tight
- The walls and bottom of the box are made of very thick carton card
- The little pipes of imprisoned air in the card help to make them heat-proof. The heat cannot escape
- The top consists of two layers of glass with about 1cm between them so they also hold air motionless and let very little heat through
- The walls and bottom of the box are lined with black paper, and, if it is available, with film wrapping paper that is black on one side and aluminium coated on the other. The effect

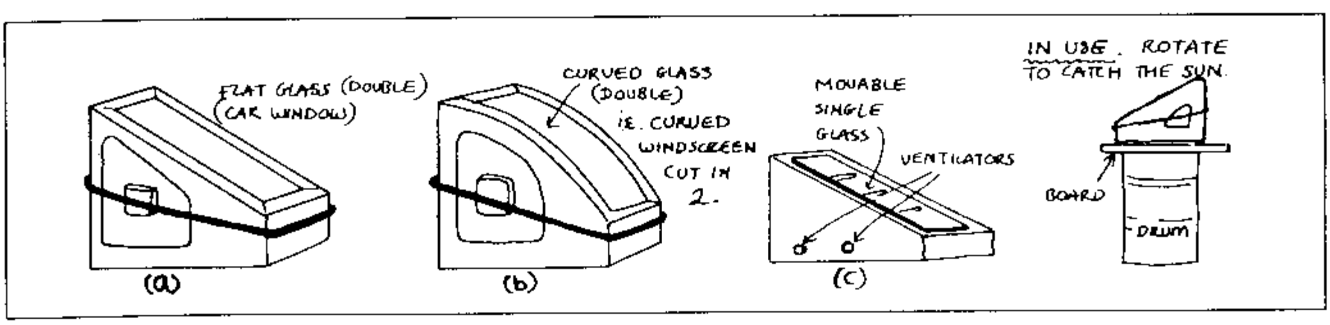


Figure 10.1 *Cookers or water heater (a and b) and a dryer (c)*

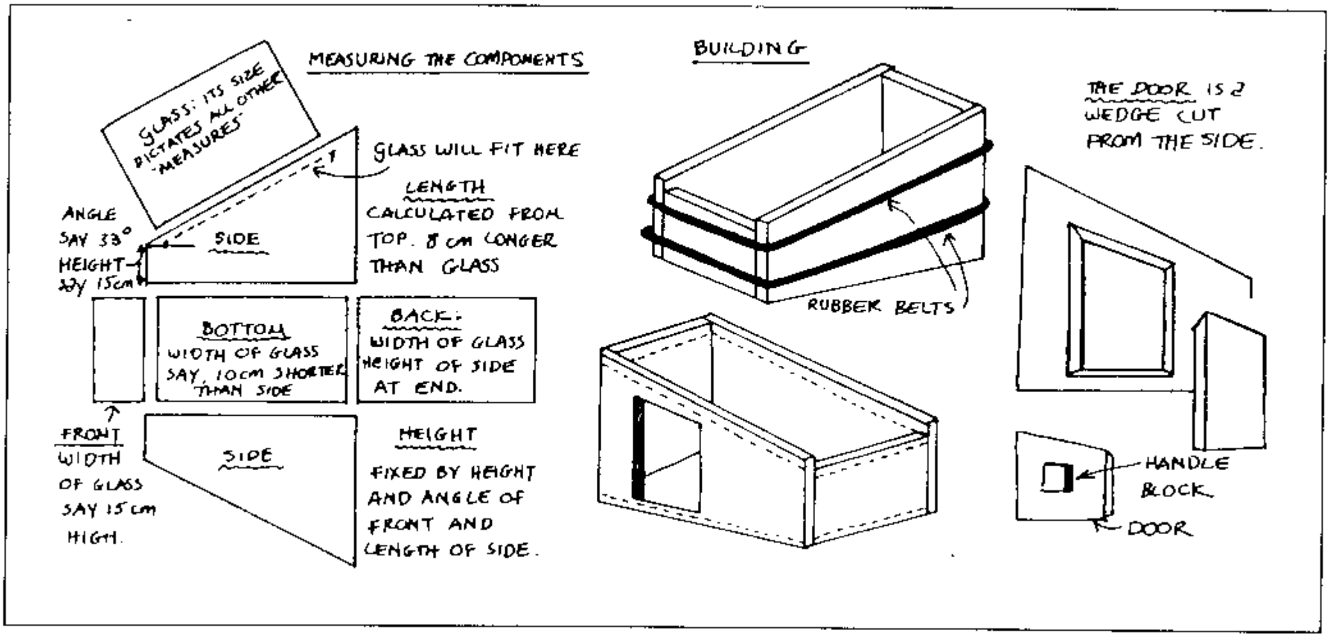


Figure 10.2 *An APT cooker or water heater*

of the black is to absorb the heat while the aluminium reflects what has been absorbed

- The door is a tightly fitting bung, held in place by an elastic strap, and
- One or two pieces of metal, for example flattened tin which is painted black, are used as hot plates either on the stove floor or as shelves that lift containers into the hottest area of the stove.

Making a solar oven

The following are not step-by-step instructions. They should make your objectives clear and enable you to carry out the various processes in the order and way that seems right in your
* case. (Refer to Chapter One: 18 and Chapter Four: Utility approach three, boxes.)

First, get two pieces of glass as nearly the same size as possible. Old cars are the best source of supply. The glass, unlike normal window glass, is tough. Car breakers are often glad to get rid of old cracked windscreens. These are usually of laminated glass which can be cut with an ordinary cutter. Make identical cuts on both faces of the glass. Car windows are also sometimes given away. Being flat they are easier to use, but their glass is usually uncuttable. The size and shape of the glass dictates the size and shape of the stove you can make, which can lead to some odd-shaped but still efficient cookers.

Make templates for the sides and bottom of the box in the following order:

- The two sides – take a fairly long piece of card. At one end mark the height of the front (about 12 to 15cm). At that point draw a line about 33° from the horizontal to mark the angle at the top. To mark its length lay an edge of your (shorter) piece of glass along that top edge and add another 8cm to it. From that point you can drop a perpendicular to the bottom edge to mark the length and shape of the side pieces
- The bottom piece – make it the width of the glass, and about 8cm shorter than the side pieces. The hottom will be enclosed by four sides
- The front and hack pieces – these will be he same width as the hottom and will get their respective heights from the two ends of the side pieces
- Make the boards – about 4cm thick (that may be 10 to 12 layers of carton card). If you have the option make pipes run horizontally to improve the insulation. Let them dry, and
- Do a mock assembly testing your box against the glass. Then, make any necessary adjustments by rubbing or cutting or adding to the boards. With the box still assembled decide which side the door will be and plan the door. If it will not weaken the board you

* P. A. and B.

could cut it now. Otherwise cut it when the box has been properly assembled.

Specifications for the door are: edges cut at an angle, to fit tight (wedged); near the back; and near or level with the bottom (to facilitate cleaning) and as high and as wide as possible (to accommodate tall bottles and wide pots). Corners may be angular or round.

Making the oven door
Make the oven door now or later. To construct the door:

- Cut the door out in one piece as cleanly as possible. Do this only when the board is really dry. Use any suitable tool that you can find, a thin saw knife or a pruning saw is ideal
- Paste the cut edges of the door and the hole. Rub them smooth with a rough tool, for example with a stone. Lay some soft slightly pasted paper on the edges, all around, to provide padding. Then, layer them and bind strongly with paper, building edges up where necessary to make them fit
- Wrap the door in a thin plastic bag, lay some more plastic around the hole. Then, force the door into its proper position and leave it pressed in that position for some time
- When convenient remove the door and dry it and the hole, exposed to the air. Replace the door later on so that it dries with a perfect fit
- The door handle is a block of carton tied and then strapped in place in the centre of the door. It serves two purposes because it is a handle and the elastic belt that encircles the stove passes over the handle which holds the door pressed into the hole. Therefore, the handle should be conveniently large.

Note: before you finally assemble the stove decide how you are going to fit the pieces of glass, that is will they fit into grooves or be held pressed against the sides of the stoves? Read on for details.

Fitting the oven glass
This is the most crucial part of stove-making. The process is explained at this point because some of it may be done at this stage, some during assembling and some after. Instructions are in general terms. You will have to interpret them to suit your stove which may have flat or curved glasses and be rectangular or trapezium-shaped according to the shape of the glass you have.

Specifications for fitting the pieces of glass follow:

- The smaller glass, if one is smaller, is the bottom piece
- Glass must be held quite firm as the fitting must be leakproof
- The ideal space between the glasses is 8 to 10mm all over, but this accuracy is not usually possible. If the glasses are two halves of the same windscreen they may almost touch at one corner and be nearly 20mm apart at the opposite corner, and
- The sides must finally be higher than the glass all round so that if a large object is placed on the stove, or if the stove is turned upside down (and it will be as it is made) the glass will not be touched.

Two alternative methods are used to fit the glass. Either very narrow grooves are cut and rubbed with a pasted tool and the glass is fitted into them, or the stove is assembled so that it tightly holds the glasses at certain points. In both these methods crushed tubes of pasted paper (paper putty) are pressed in along the angles where the glass joins the stove side, below and above the glass. The stove must be made leakproof on both sides of both glasses.

Two other devices are sometimes used to supplement these methods. First, at two or more points edges of the glass may be rested on or let in to the top of the stove wall which is then built up to enclose and overlap the glass. This applies particularly to the top glass. Second, where there is a corner of the stove which it is difficult to cover with one or both the glasses, the walls near the corner are built up from below, even from the bottom if desired, to close the gap and support the glass. The building up does not need to be very strong. It can be done with crumpled paper layered over or with layers of corrugated card.

When you have made all the preparations and are satisfied with your mock assembly, paste all the joining parts and assemble the stove. The order in which you do the operations is for you to decide, but on the whole, the sooner you can get one glass (at least tempora-

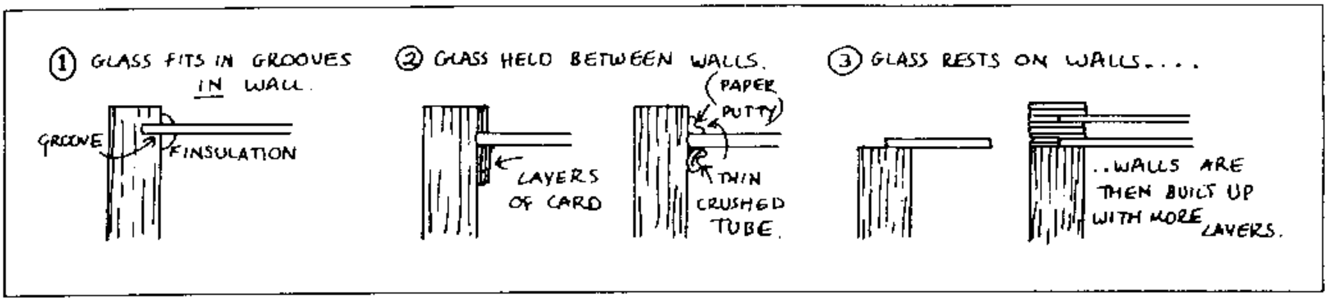


Figure 10.3 *Three ways of fitting the glass*

rily) in place, the better. With the glass in, the stove is stable and can be pressed, turned on its side, and so on, with no fear.

Construct the oven as follows:

- Hold the walls tight together by strong elastic belts, or by whole nylon stocking
- Plug all corners and any gaps with slightly pasted soft paper
- Strengthen all joins, outside and in, with angle pieces wrapped around or pressed tight in all joins
- Make and fit the door (if not done already)
- Colour all the inside of the stove black, by applying a layer of black card or strips of black paper or soot paint. Make the inside of the door black
- Fit the glasses. If possible, leave a small stick, say 5mm diameter, between the glasses at the top corners which, when removed, will leave air holes between the glasses. Also ensure that the top surface of the bottom glass and the bottom of the top glass are perfectly clean before they are assembled. Once in place the surfaces between them cannot be cleaned again
- Tidy the stove. Strengthen all over the outside with at least two layers of strong paper
- Drying may take two or three days. It should be done in the shade. The door must be left open. For a day or two there will he steam condensing between the glasses. The little stick referred to above is withdrawn to leave an air hole or small holes must be pierced from outside at the top into the space between the glasses. The holes must be closed when the stove is quite finished and has dried in the sun for a few days.

Water heaters

Water heaters and cookers are made in the same way, but the water heater is a larger and designed to hold and expose to the sun a number of water containers. The door needs to be large and in some cases, for example if your vessel is a 20-litre drum, it has to be specially shaped.

In most water heaters a back high shelf is needed to lift the back row of containers as high as possible. This shelf could be made as part of the stove. However, there is one danger in water beaters, which is that more than in any other stove leaks and spills are likely. A built-

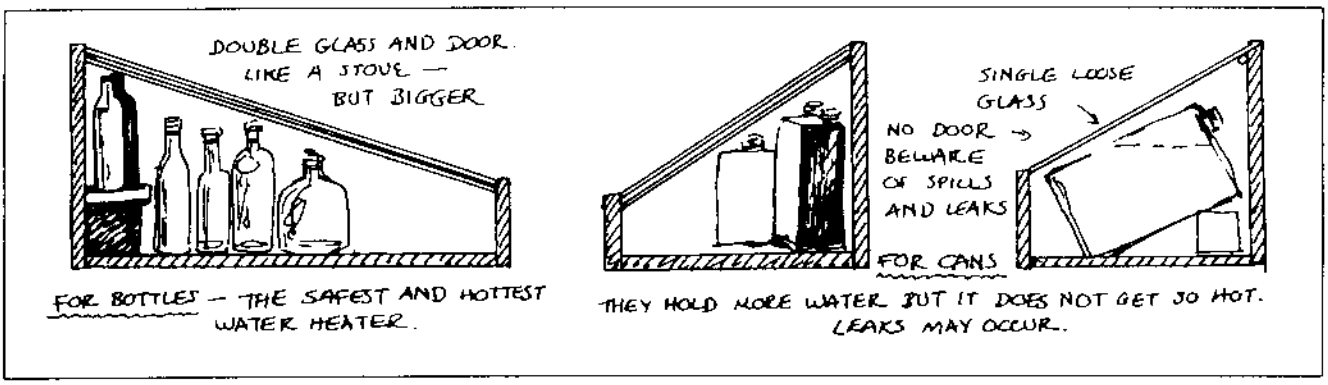


Figure 10.4 *Water heaters*

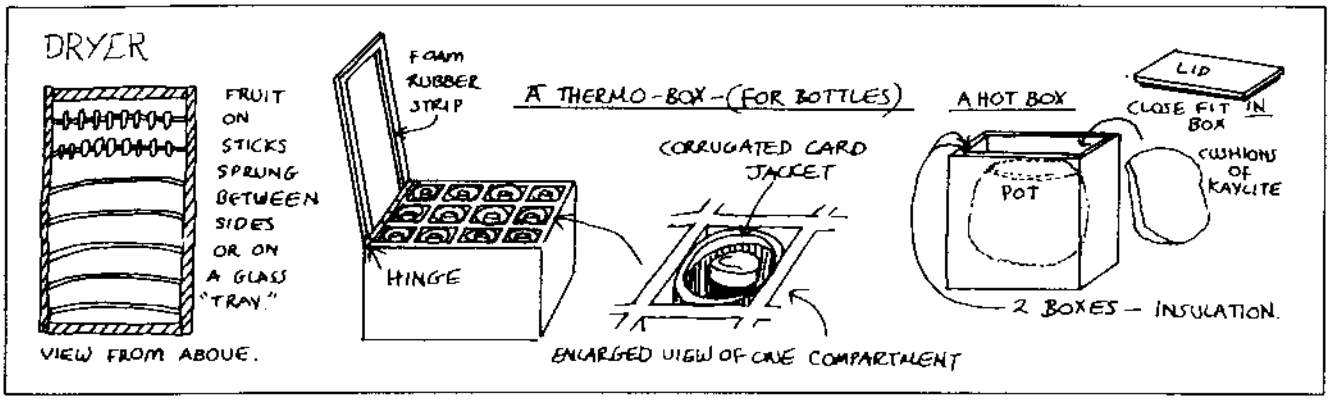


Figure 10.5 *Dryer (a) and Heat- or cold-conserving boxes (b)*

in shelf has to be very strong to prevent its surface becoming uneven.

A water heater should be as efficient as a cooker but because of its large size it heats up more slowly, and because of the amount of water it has to heat it does not normally heat it to boiling point.

Fruit dryers

A fruit/vegetable/meat/fish dryer must not get too hot and must have air moving through it. Therefore, an APT dryer differs from a cooker in the following respects (although it can be used as a cooker on hot sunny days):

- Its walls are only about 2cm thick
- It has only one glass, which is movable
- It has ventilation holes at the bottom that can be closed, and
- It does not need a door (but some people like their dryer to have a door so they can use their dryer as a second-class cooker if necessary).

Details of modifications for dryers are:

- The loose glass – plan this so it rests on and completely covers the top, so insects do not get in at night. Also plan the glass so it can slide open (sideways or at an angle) for ventilation and be completely removed to put things in and out. The simplest plan is to make ridges around the bottom and one side of the stove to prevent the glass from falling off, and to have a device for lifting and wedging open the top edge. Because the top of the box is not held firmly by two fixed glasses (as it is in stoves), be sure that your box is really strong at all its corners
- Ventilation holes – should be right at the bottom, preferably one or two on each side; the size of a cream carton so that you can use a cream carton as a bung, and
- Drying rod ridge – drying rods are often just bent and sprung between the two sides, but it is better to build one or two ridges on each side and parallel to the bottom, so rods can rest on them as well.

Thermo boxes, hot boxes and cold boxes

Thermo boxes keep water hot. Hot boxes keep food hot. Cold boxes keep food cold. They work on the same principles as the stoves in that they do not let heat out. However, in these boxes the heat is in the food in the containers and does not come directly from the sun.

A further difference is that whereas in stoves we try to keep the heat in the stove itself, in the boxes we try to keep the heat right there in the food inside the containers and prevent it from even getting into the boxes. Nevertheless, the boxes are heatproofed.

The aim of the boxes is to keep the contents as hot as possible for as long as possible. Indeed, water kept in a well-made thermo box, if it is put in almost boiling, is still warm the next morning. Unlike the stoves, the more hot bottles the thermo box has put into it the better it will work.

Thermo box for bottles

This box uses corrugated card to retain heat. To make it:

- Plan a conveniently sized box, for example to hold four rows of three bottles. Compartments are approximately one-third larger than a bottle. Make the box with corrugated card (carton) dividers joined by halving joints (see Figure 4.4)

- In each compartment fit a roll of corrugated card (card on one side only) that will form a jacket for each bottle to fit into. The jacket itself should fit closely into its compartment, and
- Make a lid from about four layers of laminated card to fit closely into the box top. Hinge it if desired (see Figure 4.24). Strips of foam rubber attached to its lower edges can help make a heatproof fit.

Thermo box for cans

Make this in the same way as the box for bottles. Adapt the compartments to accommodate cans.

Hot box (for food)

It is better if the box is made as heatproof as possible, although the main components are the cushions. The cushions must be large enough so that the bottom one can be made into a nest in which the pot sits, and the top one cover the pot's top and sides.

The best filling is Kaylite, broken into the smallest possible pieces to make crumbs or powdered into snow (the commercial product). Crumbs are probably best made by breaking odd pieces of Kaylite with the fingers. Other methods seem to spread crumbs everywhere. If Kaylite cannot be found, straw or wood shavings or crumpled paper, or even newspaper or cement bag wrapped thickly round the pot without being made into a cushion, will work quite well. A blanket could also be used.

Plan for an insulated box by making two boxes. One must be large enough to hold the pot and the cushions. The other should be about 4cm bigger all around than the smaller one, and a little bit taller. The smaller box fits inside the bigger box, resting on and pasted to its bottom, but with a space around it. Fill the space with insulating material (as for the cushion above).

Heat tends to escape mostly from the top the box. Make a lid that fits well into or over the box (see Chapter Four: Lids). A carton card lid, for example four layers thick, would be suitable if the food inside is also insulated.

To use a hot box efficiently, the containers should be removed from the stove when they are boiling and put quickly and without being opened into the box and the box closed immediately.

An alternative and less efficient way of using Kaylite cushions is to stuff them into the stove where the food is, and to try to wrap them round the container. It improves heat conservation if the cushions and boxes are warmed by the sun before the containers are put into them (or for cold boxes, if they are cooled).

Cold box

There is no difference, theoretically, between a hot box and a cold box. Both are made to maintain temperatures. However, there is a practical problem. Cold items are likely to cause moisture, even liquid inside the box. Such items should be made quite safe by being wrapped in strong plastic bags.

Accessories for APT solarware

Turning bases

The stove must not rest on damp ground. It must be raised. A 40-gallon drum is an excellent base. However, stoves, especially if they are full of water bottles, must not stand on sharp drum edges or small bases that only support in the middle. They should be set on flat boards that rest on the base. Two stoves can share a board, provided the doors are on opposite sides. It will probably then be found that the board, and not just the stove is the item that turns on the base.

Hotplates

These are used for cookers and water heaters. They can be flattened rectangles of tin from large cans, painted black and laid as the floor of the stove or on the shelves.

Stove blocks

Rectangular closed boxes, for example made of carton card, stuffed with paper, strengthened and layered over with black paper, to hold hot plates or containers as high as possible in the stove.

Reflectors

Large reflectors, made from tin foil on strong cardboard boards, outside the stoves proved to be a lot of trouble in windy or wet weather, and when the stove had to be turned that the author no longer uses them. However, recent experiments have shown that an octagonal reflector, its boards set outwards at 60°, placed on the stove and directed at the sun, collects much heat, very rapidly. Small reflectors, cut from the shiny tin of 5-litre oil drums, can be bent to shape to form a reflector that stands against the back, behind cooking bottles and jars, and seems to increase the heat a little.

Cooking containers

Cooking pots black on the outside heat up very quickly and are excellent for stewing. Transparent glass containers, jars for stewing and wine bottles for water are extensively used and have three advantages. They heat up very quickly, take up relatively little floor space, and you can see what is happening to their contents as they cook.

Cans and drums hold more water but are difficult to handle. They may damage the stoves by spills and leaks and by their weight.

Whenever possible, containers should be filled almost to the top. For small amounts use small containers. Reasons are that on the one hand, since heat goes upwards, the top part of the container gets hottest, but if it is empty much of that heat will get lost. On the other hand, liquids expand as they are heated and containers filled to the brim will spill over long before they boil.

Equipment for dryers: rods (sticks) to hold fruit; glass bottom for the dryer; and dried fruit containers

The rods must be springy so they are held between the dryer's sides. Bamboo is ideal. A piece of glass, such as a car window, to rest on the bottom or on blocks and to hold fruit that cannot be hung is useful. Screwtop jars or plastic bags can keep dried fruit airtight.

Using APT solarware

Care for solarware

Solar ovens and water heaters

Neglect of solar ovens soon reduces their efficiency. Care includes:

- Protecting items from rain and damp. Have a waterproof plastic handy and an elastic belt to slip over it. Cover solarware with this hood before it rains or night falls, or better, use a permanent cover of clear plastic
- Keeping glasses clean
- Cleaning up any spills as soon as they happen, and
- Repairing, for example if papers lift or leaks show, as soon as possible.

Use a solar oven to maximum effect by:

- Opening it early
- Turning it frequently
- Keeping shelves and hotplates clean
- Putting food as high as possible in the stove
- Using a hot plate on the floor of the stove as well as on blocks (shelf)
- Using suitable containers (see accessories earlier in this chapter) with lids
- Not overloading the item. Too much food means slower cooking, and
- As soon as the sun leaves the stove remove from it any food or water you want to keep hot and put it in a thermo or hot box.

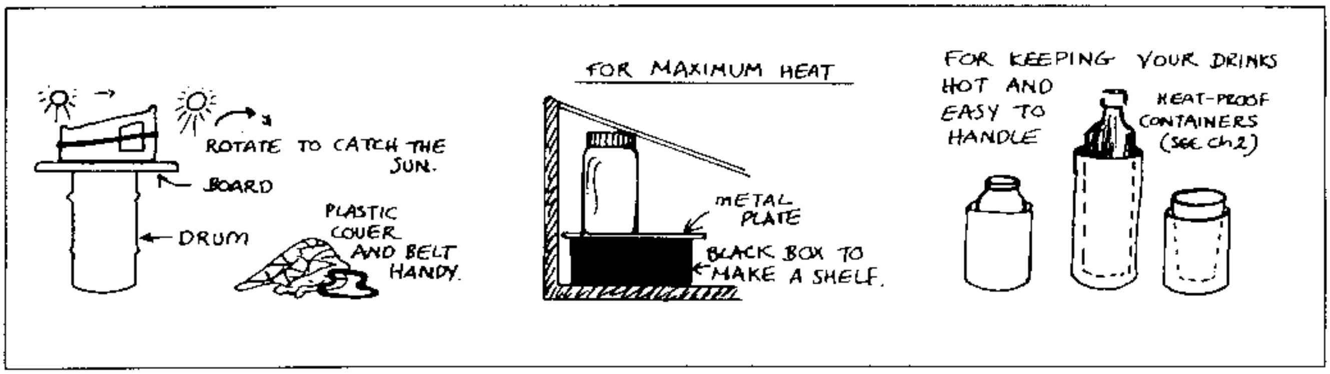


Figure 10.6 *The cooker in use*

Dryers

To ensure maximum use from dryers:

- Always close at night to keep insects out
- Check ventilation frequently, and
- Do not leave the lid on for too long, otherwise your fruit will get baked instead of being dried.

Cooking and recipes

There is not one answer to the question everyone asks, how long does it take for things to boil? On a good day a small jar or bottle of coffee, milk or water, if put out at sunrise, should boil by 10.30am. The same drinks put in on the hotplate at 10.30am should boil within an hour, because the stove takes time to warm up and so does the sun. On a fairly cloudy day things may not boil at all, but if they have been in the stove all day they may well have cooked.

Temperatures inside the stove often rise well above boiling point. The containers, and if glass containers, their contents also, receive their heat from the sun striking directly on them and from the hot metal plate on which they are standing. In the very early hours of sunlight the sun strikes bottles more directly than when it rises higher. For these reasons it is important to put bottles and jars in the cooker as early as possible. If a bottle has not quite boiled by noon it is not likely to do so until about 2.00pm when the sun will again strike the sides of the bottle directly.

As much of the heat is developed in the actual containers and contents, it must be imprisoned there by loose lids and not allowed to escape into the stove and out from there. Therefore, baking should be done in closed containers. The disadvantage is that if the container is completely closed moisture does not escape and the food is not crisp.

That information should help you to use your stove efficiently to perform the following, and many other cooking tasks:

- Boiling, for example, water for tea, coffee. Making coffee from grains (cheaper than instant coffee). Heating milk
- Doing any slow cooking, for example, stews, soups, vegetables, fruits, rice
- Warming up any food, such as rolls and the like
- Slow baking, for example apples, potatoes (under jars), and biscuits (which will be very hard), and
- Making *sadza*, although you will have to discover which is the easiest and best way of doing it.

APT recipes for preserving food

Fruit and tomatoes (bottling or canning):
The APT no-cost method of bottling is different, and far simpler than the usual method. Therefore, it is explained here in some detail. Be sure your jars have good seals. Card washers are no use. They should be replaced by home-made washers cut from the hard plastic of an ice-cream container or some similar material. Hard plastic lids are excellent.

The best way to add sugar is to keep ready-mixed syrup of sugar and water and to boil the food in this. Other methods waste time and heat because you have to open the stoves, take the bottles out and put the sugar in, stir it and spoil the fruit, then put it back in again.

First, pack the washed fruit fairly tightly in bottles. Pour in the syrup leaving a space of 2cm at the top. Put the lids on loosely and place in a hot part of the stove. Exactly when you screw the lid down after the fruit boils depends on the fruit and how well you want it cooked. When the fruit boils, either screw the lid down immediately or remove it to prevent boiling over and continue cooking it.

When screwing the lid down protect your hand with a cloth, take the bottle out and when it has stopped boiling screw it down fairly tight and leave the cloth over it as a precaution. In fact, explosions have never been known to happen. What does happen, harmlessly, is that the liquid starts boiling again after it has been screwed down, due to the increase of pressure inside.

Do not screw down any more as the fruit cools. When the bottle is cold, if you wish to check it press or tap the centre of the lid. It should feel and sound tight. Look inside up at the top to see that washers have not been sucked in, or lay the bottles on their sides. If all precautions have been taken failure is very unlikely.

Jam and jelly-making
You must have a flexible approach. Depending on the weather, two days or even six may be needed to make jam, jelly or syrup. The full method for jam-making is not explained, just the APT modifications of it.

One APT method is to start with the fruit in the jam jars in which it will finally be preserved. Another way is to start off in a large pot and only put the fruit into the jars some time after you have put the sugar in and dissolved it.

Cooking the fruit from the start in the small jars means quicker boiling and, without opening the stove, you can monitor the boiling. But it does mean that, as the fruit level goes down in all the jars, the contents from some jars have to be poured into the others to fill them up.

To make jam, jelly and syrup put the washed fruit in containers with no, or very little, water and boil it for some time – it may be more than a day. When it is thoroughly soft and boiling pour in the sugar and stir as needed to dissolve it. Continue boiling for some time – possibly more than a day – until the contents are the consistency of jam.

Fruit syrup (cordial)
Most fruits make delicious drinks (cordial). Mulberries, guavas, mangos and grapes sometimes ripen in large quantities at once but must have a lot of juice. They are particularly suitable for cordial-making.

The syrup must be corked or screwed down in containers. Screw-on-top wine bottles with extra plastic washers added are suitable, as are wine bottles with corks that have no holes in them. But wine bottles hold a lot of cordial (which has to be diluted). Smaller containers are more suitable for families. Sauce bottles, which often have good seals, and jam jars are convenient sizes.

You must decide on the amount of sugar to use. It depends on the fruit, and the sweetness desired, but a fairly large amount (possibly one-third of the volume of the liquid) may be needed.

To make fruit cordial put the fruit in jars. Crush it down. Add more fruit. Crush it and continue until the liquid is near the top of the jar. For guavas add a little water. Boil thoroughly for one or two days. Strain and squeeze it by handfuls through a cloth (see jam and jelly-making). Boil again. Add and dissolve the sugar. Screw down cautiously when all the sugar is dissolved and the liquid is boiling. Cordial frozen in ice trays makes delicious lollies.

Drying fruit
Drying vegetables or meat is done in much the same way as drying fruit. Almost any fruit can be dried. When dried it can be kept almost indefinitely, preferably in a screw-top jar or wrapped in plastic.

Dried fruit can be sucked or chewed like sweets and is more nourishing than bought sweets. Or it can be soaked in water overnight, which will soften it and bring it almost back to its original size, then stewed with sugar like fresh fruit.

The main advice about making dried fruit is to learn to dry by drying and testing your results.

The dryer is made so that any fruit that can be pierced and hung on sticks is dried in that way. Smaller fruit, or fruit that is too soft, can be dried, or at least started off, on the glass tray. The process may take two or three days or more than a week. It is best if you can start the fruit off at least on a sunny day so that its surface dries quickly. After that, the dryer should be put out for as long as possible every day. Even on cloudy days drying continues.

Decide:

- Should the fruit be sliced or not? (Only slice if it is necessary), and
- How dry should the fruit be before it can be kept safely? Generally speaking, do not dry fruit until it gets hard, although mulberries dried until they are brittle make amusing sweets for children.

Continually watch the stove when you are drying, especially to check ventilation.

Chewy sweet-making – fruit leather
This is a promising field waiting to be developed. Fruit such as paw-paw or mulberries, or a mixture of both is mashed, flavoured if desired with orange or lemon and sugar to taste. The mixture is then spread on the (very slightly

Solar cookers (eleven years old) in action (Ch. 10) bottling fruit and heating milk and coffee. Note curved (cracked windscreen) glasses and two-tier shelf to reach hottest part of stove. Hinge for reflector on stove left. Reflector not used.

A day's fruit bottling (canning) – any jar with a good lid-seal can be used – resting on thermo-box next to the oldest (1983) solar stove with fixed (car window) glasses.

greased) glass tray about 8 to 10mm thick and dried like fruit. The surface dries, while underneath the mixture is still moist. The glass can then be inverted with the mixture still stuck to it, and drying completed in that way. When dry, but not hard, the sweet can he cut into squares, or into long strips and rolled. It keeps well in screw-top jars (see accessories).

CAUTION: Solar cookers, like electric and gas cookers as well as open fires can be dangerous. People need educating in the use of solar cookers so no harm comes through them. People who make solar cookers and particularly those who buy them, besides being shown how to care for them and use them, must be made aware of three dangers to be guarded against, which are:

- Poisoning – from eating food which has been made warm for a long time without being cooked, or which has been cooked but left to cool slowly with the lid on in the stove. This danger applies particularly to meat, and weak children have been known to die as a result of eating warmed but uncooked meat. Meat the cooker fails to cook should be well-cooked on the fire the same day or he thrown away
- Explosions – this danger has already been mentioned. Explosions of containers should be possihle, but have not been reported. What can happen is that a jar is inadvertently screwed down and heated then unscrewed, or the cork of a boiling bottle is against the top glass of the stove and is moved. In such cases (which should never happen) the contents spurt out dangerously, and
- Fire – in theory this is a danger. The sun shining through clear glass bottles may burn little holes in the back of the stove. The bottoms and sides of some of our ten-year old stoves seem to be quite charred, but no actual fire has been heard of.

It is essential that education about the dangers, as well as the use of solarware should be included in any programme on the subject. The author has written this chapter as an expert in APT. He is not an expert on solar energy and nutrition. There is ohviously a need for positive research by practical experts in these fields.

18. Laminating

(a) This term is used for layering card pieces on top of each other to make a board (see 8e, The stretch/shrink factor).

(b) The thickness and composition of boards depends on:

- The intended purpose, and
- The material available to you.

(c) Different boards have various qualities:

- Boards of thin card may have as many as 12 layers. They are easy to make and very thin, strong and stable. These are the best boards for tables and chairs
- Carton boards of two or more layers are easy to make but slow to dry right through. They are not as hard as thin card boards. Sitting on them can make depressions. Humid weather makes them slightly soft, especially if they are not varnished. Carton boards are very useful as the bases of utility-type furniture and in all solarware. They are also heat and cold-resistant
- Sandwich boards of one or more carton cards in between thin cards (at least two on each side as one tends to come unstuck), have harder surfaces than carton boards. They are easy to make, but need care when drying. These are also called hard-top carton boards. Sandwich boards are recommended for the seats of utility furniture, and
- Paper boards, if well-made, are extremely hard and strong (see (g) below).

- Smear paste all over one surface of the first card. Place the second card on it, paste its surface. Continue in that way
- Work quickly to race the stretch (see 8e, The stretch/shrink factor)

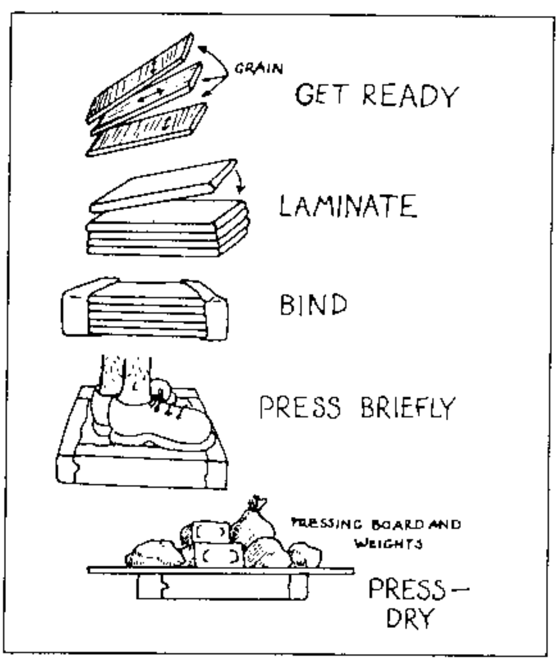


Figure 1.9 *Laminating – work quickly, race-the-stretch*

(d) To make boards from thin card, first get all your cards ready. Layers need not consist of whole cards. Pieces of card fitted together can also be used. Arrange cards so when you layer, the grain of the cards alternates. Then:

- Bind the edges roughly, especially at corners, wrap in a sheet of newspaper
- Tread all over, and
- Press on a flat surface under a heavily weighted board (see 21a, Pressing and drying).

(e) To make boards from thick (corrugated) card use the same procedure as for thin cards. However, when pressing with feet tread cautiously to avoid footprints. Tube direction in corrugated card is treated as grain, but thick corrugated boards do not warp as much as thin card boards. Therefore, you can laminate thick carton boards with the grain of nearly all cards in the same direction. This will result in a board which is stronger in a certain direction to bear extra strain. For example vertical boards for chair sides have grain running vertically as pressure is downwards (see Chapter Four: Utility approach two). Seat boards are made with grain running across supporting rails.

(f) Some people practising APT use bars for rails, especially where thin card for tubes is hard to obtain. First, laminate a thick board of carton card, wide enough to make all the bars you need, with grain lengthwise. Cut fairly wide bars from the card. Bind the bars strongly with double layering. Control when drying as they tend to warp. Most models and instructions are for tube rails. Bars require no design modifications and fitting instructions are basically the same.

(g) Boards made from paper are hard and strong, but tricky to construct (see 15, Layering). To make paper boards:

- Layer and press flat a number of five-layer sheets with the grain in one direction as for bowl-making. Count each five-layer sheet as equivalent to one card
- Laminate in the usual way but iron well with the hands to get all surplus paste out, and
- Press and dry. This is the tricky part (see 21, Pressing and drying).

B

Utility approach three

In this utility style carton boards are used to make box structures. The box-making method described here is simple. However, the procedure can be used to make boxes of any size from thin card or carton boards. Usually templates are made, and boards are made slightly larger than the templates. The boards are then cut to the correct size, with sharp straight edges for assembling.

Boxes usually require five or six boards of the same thickness. It saves time if you can laminate boards as large as possible and cut components from them when they are dry.

Example: simple box pattern

The bottom is the inside size of the box. The ends are the same width as the bottom. The two sides are the length of the bottom, plus the thickness of the two end pieces.

The bottom of the box is enclosed by the two end pieces at its ends and by the side pieces which also enclose the ends (see Figure 4.23a). To assemble the box (see Figure 4.23b):

- Prepare two elastic bands (inner tubing) to encircle the box, and wooden nails if you intend to use them. Wooden nails (sharpened pegs) are not recommended for small boxes, but can be useful for large or awkward structures
- Rub paste into the joining edges and make the inner surfaces of the boards sticky with paste
- Press the parts together with one band around the very bottom and one near the top to help you. Strengthen all the corners with angle pieces with flaps – first inside then outside – strap, then layer over everything with strong paper, and
- Dry with a system of weights, bands, boards, and so on checking they hold the box in its correct shape.

Lids

Lids can be classified as fitting into a box, on to a box, or over it (Figure 4.24). Lids in each category can be made in several ways. Four ways of fitting lids have been described in Chapter Two.

Making a lid of thin card to fit over a box was described in Chapter Two: Approach one. Making a lid of thick card to fit over a box can be done in the same way if the card is bent sharply and accurately (see Chapter One:13). Alternatively, this can be constructed from component boards.

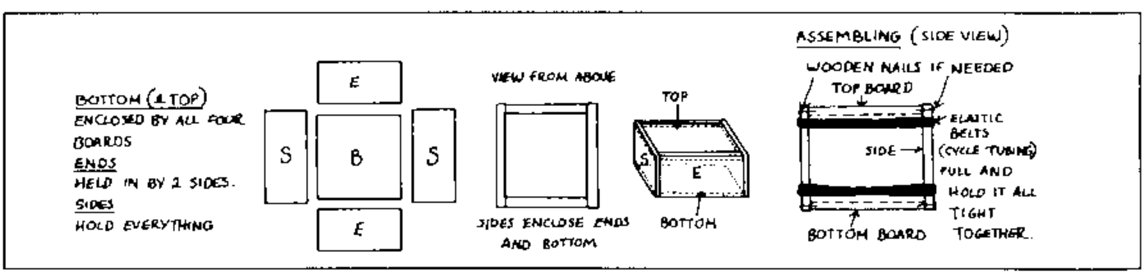


Figure 4.23 a and b *A box – standard APT pattern*

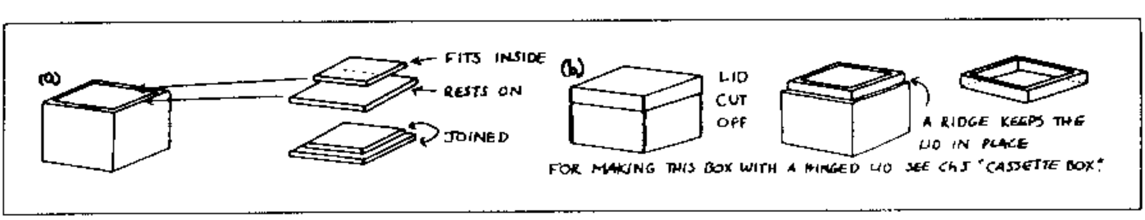


Figure 4.24 *A lid that fits into a box (a) and a lid that fits on to a box (b)*

D.I.Y. PLAN 6

HAYBOX COOKERY

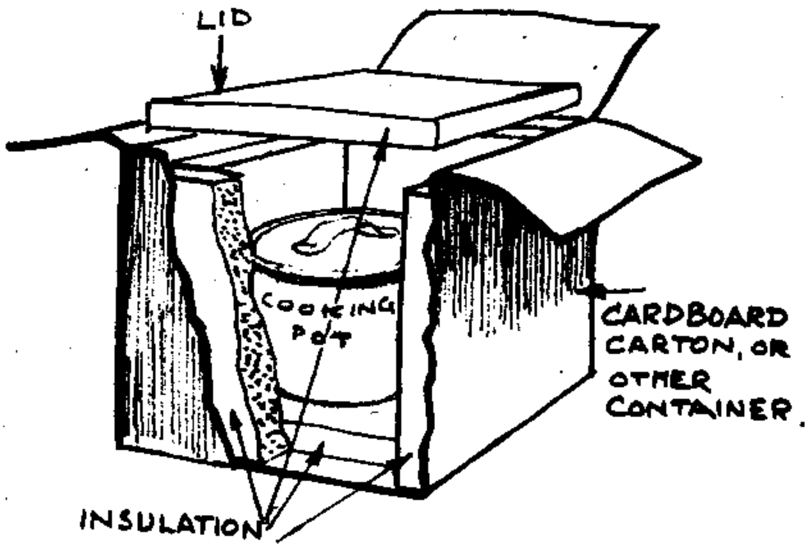
A Haybox is an insulated box used for slow cooking.

Its greatest advantage is that no energy is required to cook a dish once it has been brought to the boil; hence it saves both fuel and money.

There are commercially produced hayboxes on the market but they are expensive. In less than half an hour you could make one yourself using materials which cost little or nothing and which are easy to obtain.

Traditionally hay was used as the insulating material, as it was then easily available and cheap, but it has the disadvantage that it needs to be renewed fairly frequently and is messy. It is now also expensive and difficult for town-dwellers to obtain, so different insulating materials have become more common. Polystyrene and crumpled newspaper are two suitable ones.

The other requirement is for a saucepan with two small handles and a well-fitting lid. Ideally the haybox should be made to fit a particular saucepan - the less space there is round the pan, the less heat will be lost - but this is not essential.



The Advantages of Haybox Cookery:

The types of food which cook well in a haybox include soups, stews, sauces, stewed fruits, milk puddings, brown rice, stock etc.. The box may also be used to keep pans or dishes of food warm, to make yoghourt and to keep food cold for short periods.

The advantages of using a haybox, besides saving fuel and money, are that it costs little or nothing to make, it cooks food well, and it can't overcook or burn food.

How to use a Haybox:

Bring pan to the boil, put on the lid. Open the box and put the pan inside. Quickly cover with the lid of the box to prevent heat from escaping. Cooking will continue at a little below simmering point. If the pan is removed from the box at any point during cooking for any reason, such as to stir the contents, bring it to the boil again before replacing it. It is also advisable to boil meat dishes for a couple of minutes just before serving them. Cooking times are likely to be about half as long again as simmering on the stove, but it is best to experiment for yourself. Approximate times might be:

Soups: 1 - 2 hours; stews: 3 - 5 hours; lentils: vary, 1 - 3 hours; milk puddings: 1 hour.

Some Recipes suitable for a Haybox:

1. Potato and Onion Soup (any soup may be cooked in the Haybox)

2 medium onions, sliced
1oz butter or margarine
½ pint water or stock
1lb peeled potatoes, sliced
1 bayleaf
1 pint milk

Melt butter in pan, add vegetables, cover and stew slowly for about 5 mins. until softening. Add bayleaf, milk and water, bring to the boil. Simmer for 2 or 3 minutes, cover and put quickly into the Haybox. Leave for about 45 minutes.
When cooked, remove bayleaf, put through sieve, Mouli or liquidiser. Season with salt, pepper and a grate of nutmeg (optional).

2. Casserole of Lamb

1½-2lb middle neck of lamb (in pieces)
2 medium onions, sliced
Small turnip or piece of swede, chopped
¼lb mushrooms, washed and quartered
½lb tomatoes, skinned and quartered
2 tablespoons dripping or oil
2 carrots, sliced
Bouquet garnis
1 tablespoon flour
1 pint water or stock

Melt fat in stewpan. Add pieces of meat and brown well on both sides. Remove from pan, add vegetables, except tomatoes, and brown also. Stir in flour and continue to cook for a few minutes. Return meat to pan, add tomatoes and bouquet garnis. Add stock or water to just cover the meat. Bring to the boil and allow to cook for 3 or 4 minutes, then put quickly into the Haybox. Leave for about 2 hours. Reboil before serving and sprinkle with chopped parsley.

This information sheet has been prepared for the Centre by Diana Brass ©. Other information sheets are available from the Centre; for further information write, enclosing s.a.e., to:

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Reprinted March, 1977

Printed on 100% recycled paper

34: Solar cooking & recipes from many different sources.

Dear Friend, - Congratulations !

People all over the world, are suffering from lack of firewood and inexpensive fuel. Many of them will benefit from the solar cooking method. They will not have to gather as much firewood, and buy as much charcoal or kerosine. Trees, forests and soil can be saved. We wish you much success, and hope that many others will follow your example.

What is a solar-cooker ?

A solar-cooker changes sunlight into heat and cooks food. It does not use any fuel, like wood, charcoal, gas, kerosine, etc. It noes not even require a match.
Your solar-cooker traps sunlight and becomes a "hothouse" with the 2 panes of ordinary window-glass. The reflecting cover-lid helps catch more sunlight. It is important that the glass-lid fits tightly and that the heat in the cooker cannot escape.
Solar cooking not only saves fuel, but also time and money. A day's cooking can be done in a solar-cooker, and it can keep food warm for hours.
The cooker helps you prepare healthy food without the problem of smoke in your house, which may be dangerous to your health.
The sun is a source of energy - free of charge, and ready almost all year round - Why not use it !

Some Important Tips for the Use of the Solar-cooker/oven -SO

When you use the SO for the first time, do not cook any food in it, as long as the inside black paint discharges badly smelling fumes.

The SO only works with direct sunlight. Clouds, mist, or dust reduce radiation and lengthen the cooking-time accordingly.
On the other hand the temperature of the atmosphere, has only limited influence.

Place the SO at a sheltered place, where no shadows may cover the SO during cooking time.
To catch the greatest possible radiation energy you must align the SO correctly. At a low sun position, the reflector increases the light that is taken in. The best position of the SO can be controlled as follows:
The shadow of the reflector prop falls straight onto the part of the glass-frame that lies beneath. The reflection of the sun from the reflector is in the middle of the trough. You may observe this better if you move the reflector slightly up and down.
Fix the reflector in the best position with the prop, and tighten the cord.

It is not necessary to keep re-adjusting the position, it is advisable to position the SO slightly in advance of the sun, before starting the cooking operation. You may therefore leave the SO to cook, without being in constant attendance.

So that one may lose as little heat as possible, do not open the SO during the cooking process. If this is unavoidable, open as briefly as possible. It is advisable to add all seasonings at the beginning of the cooking process, except salt, which should be added after cooking. It is not necessary to stir, because nothing will burn, or boil over.

The cooking or baking time, will be about 2 - 4 hours, depending on the dish, the quantity of the food, and the intensity of the sun radiation. As the food, hardly ever boils down, it may be left inside for longer than necessary. Normally temperatures from 120 - 150 degrees C. are attained in the SO. Therefore it is not possible to fry or to crisp-bake. It is preferable to cook food soaked in water, such as cereals, beans, and vegetables.
The usual amount of water must be reduced by about 1/3, because little will evaporate. However the SO, is also good for stewing of meat, and the baking of bread or cakes.
Other possibilities, among others — roasting of nuts, boiling of water, and sterilizing of medical instruments.

To keep cooked food warm for a longer period, f.eg. until after sun-set, simply shut the reflector-lid. With an additional heat energy storage element, placed inside the SO, such as a stone, or a piece of metal, heat may be retained for a longer time.

For good thermal efficiency; - pots, crockery, and baking molds should be dark on the outside, - the best colour is a dull black. To attain short cooking times, use thin-walled aluminum pots. Use several smaller pots, rather than one large pot. For better heat-exchange, do not place pots directly on the floor, but on a grate, or simply on two wooden bars of about 2 cms. height. This will allow the hot air to circulate under the pot, and heat it from below.

Except from cleaning the glass window, the SO need hardly any maintenance. It should given a protective covering of paint or linseed-oil. It is necessary that it should protected from rain, and damp. Taking care of the SO, is worthwhile, as it will provide many years of useful operation.

" Practice makes perfect " is a useful motto for cooking with the SO. One should practice cooking various dishes in order to obtain success. With more practice, - the more success, - then the more understanding that cooking and baking in the SO can be fun.

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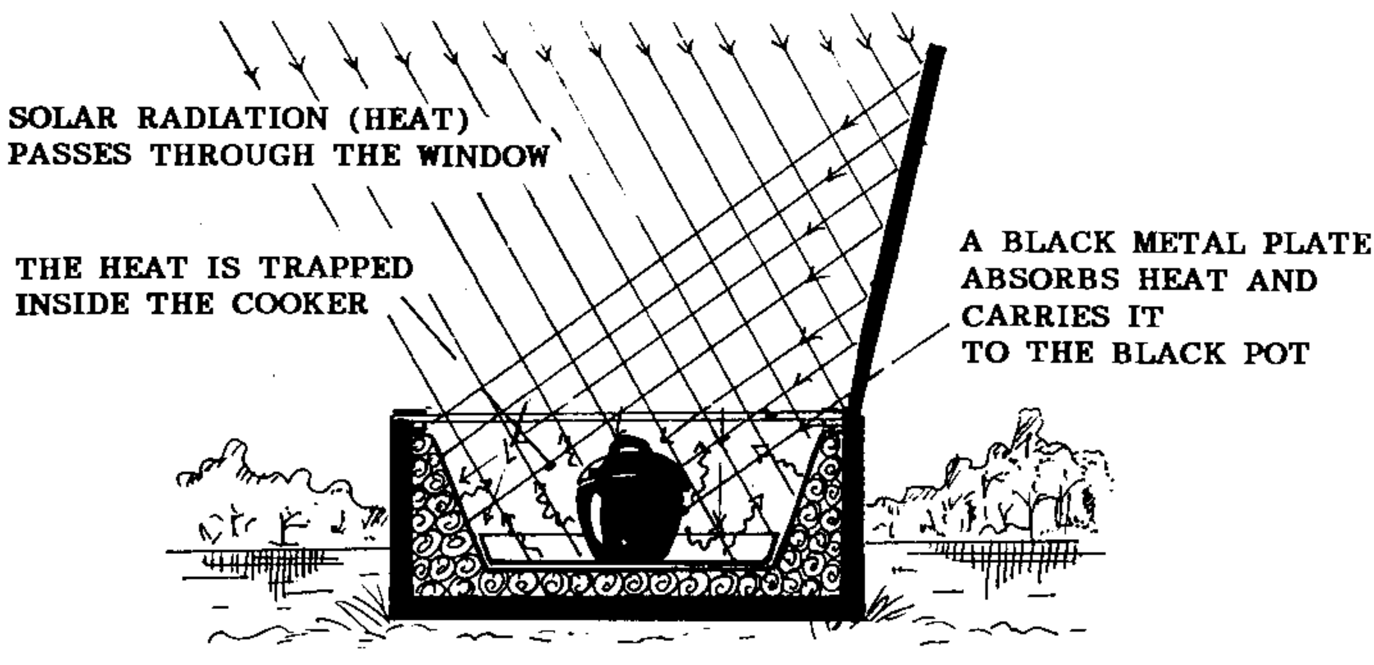
How does a solar box cooker work?

The box cooker, which is the simplest and the cheapest solar cooker type, is still able to heat food to 150° C (300 °F). It consists of an insulated box with a glass or a plastic window. The window acts as a solar energy trap by exploiting the greenhouse effect.

Solar radiation passes through the window, and is absorbed by the walls, the bottom of the cooker and the cooking utensils (pots, pans, etc.). The darker the pots and the inside of the cooker are, the better they are heated. The window is not transparent to heat radiation, which means that the heat radiation coming from the walls and the pots will be trapped inside the cooker, thus heating the air.

To maximise the heating effect, the cooker's walls, and the cooking pots should be painted black. The bottom should be covered with a black metal plate to carry heat to the pots. A double window is better than a single window because it reduces heat conduction. To increase the incoming solar radiation, reflective plates can be used; and in less-than-optional solar condition, their use is essential. They should be positioned so as to reflect radiation from a wider area into the box. In addition, the box should be mad as airtight as possible, so as to minimise the flow of hot air to the outside.



How to use the solar box cooker

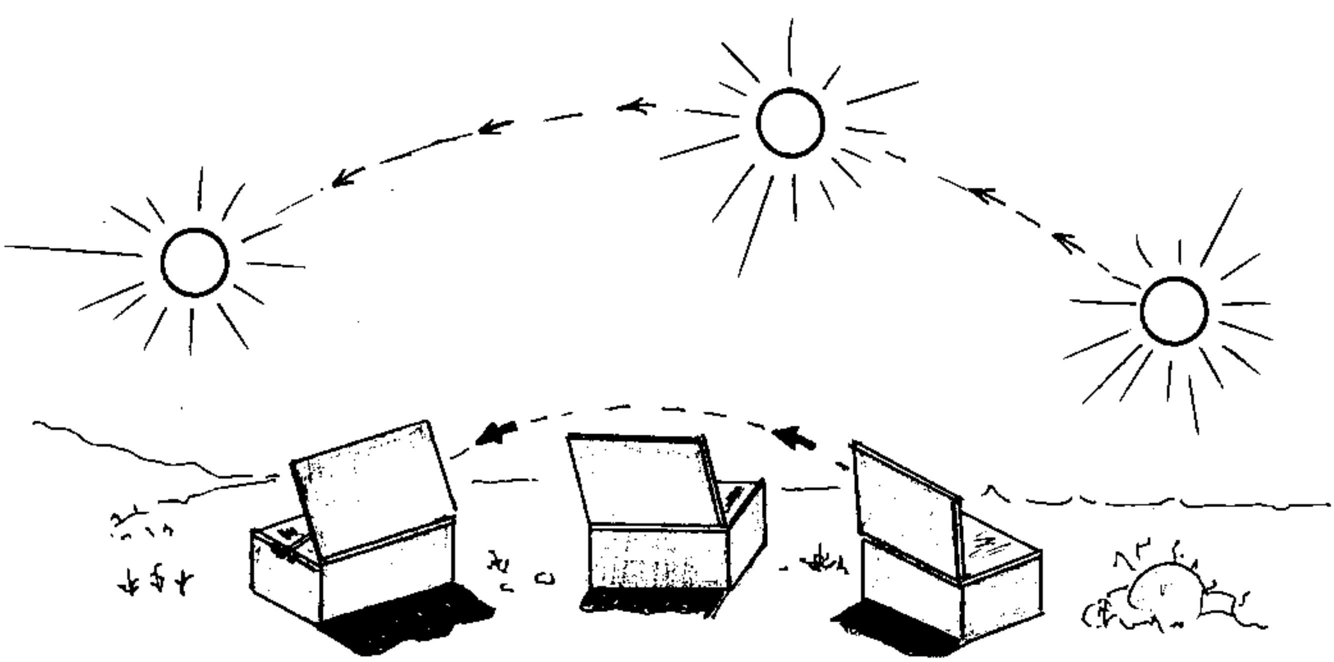
General instructions

Place your solar box cooker outdoors in a sunny place, which is not windy. Choose, for example, a fenced garden, a roof-top or a balcony, because then it will be safe from animals. The nearer the cooking-place is to your house, the easier it is to prepare food and to keep an eye on the cooker. A strong wind may deposit rubbish and sand on the cooker's glass, which will slow down the heating process. Further, the outside temperature affects the temperature inside the cooker. Warm weather is always better than cold.

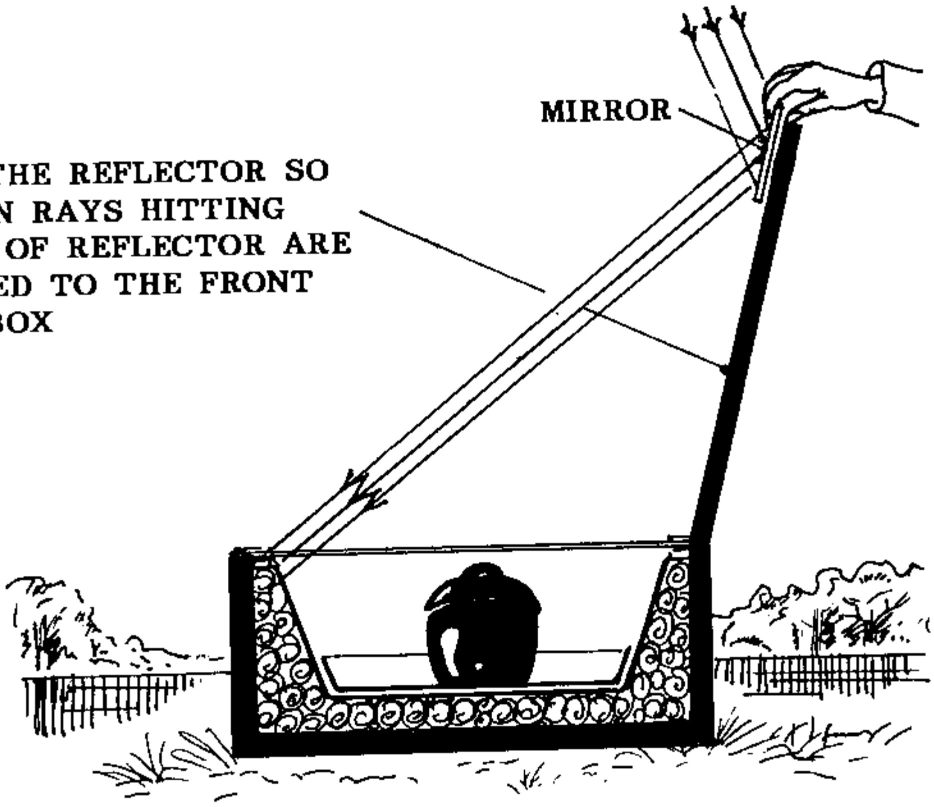
When you use your solar box cooker for the first time, pay attention to the cooking times of different meals. With practice you can learn to estimate the time necessary for cooking, and the food will be tasty without your continuous supervision . When you lift up the glass, watch out for the burning hot steam that may rise from the box. Because pots get hot in the solar box cooker, you should use pot-holders when lifting them out.

Directing solar box cookers

It is best to use solar box cookers when the sun is shining from a cloudless sky and when the outside temperature is over 20°C (70° F). The cooker should be placed facing directly towards the sun, so that no shadows fall inside the box. In this way the



TURN THE SOLAR BOX COOKER
TOWARDS THE SUN



cooker will get the maximum amount of sunshine, and cooks fastest. Adjust the cooker's lid to reflect all the sunshine you can inside the box.

The cooker's position has to be changed so as to follow the sun's movement. If you are in a hurry and there is a lot of sunshine, you can pre-set the cooker in the morning to the position where the sun shines at midday. Then it needs no futher adjustments. If you are not in a hurry, you should change the cooker's position 1-2 times an hour.

The cooker's reflecting lid should be adjusted downwards or upwards according to how high (the vertical angle) the sun is shining. Remember not to use too much force in closing the lid, otherwise you might break the glass.

Maintenance and care of the solar box cooker

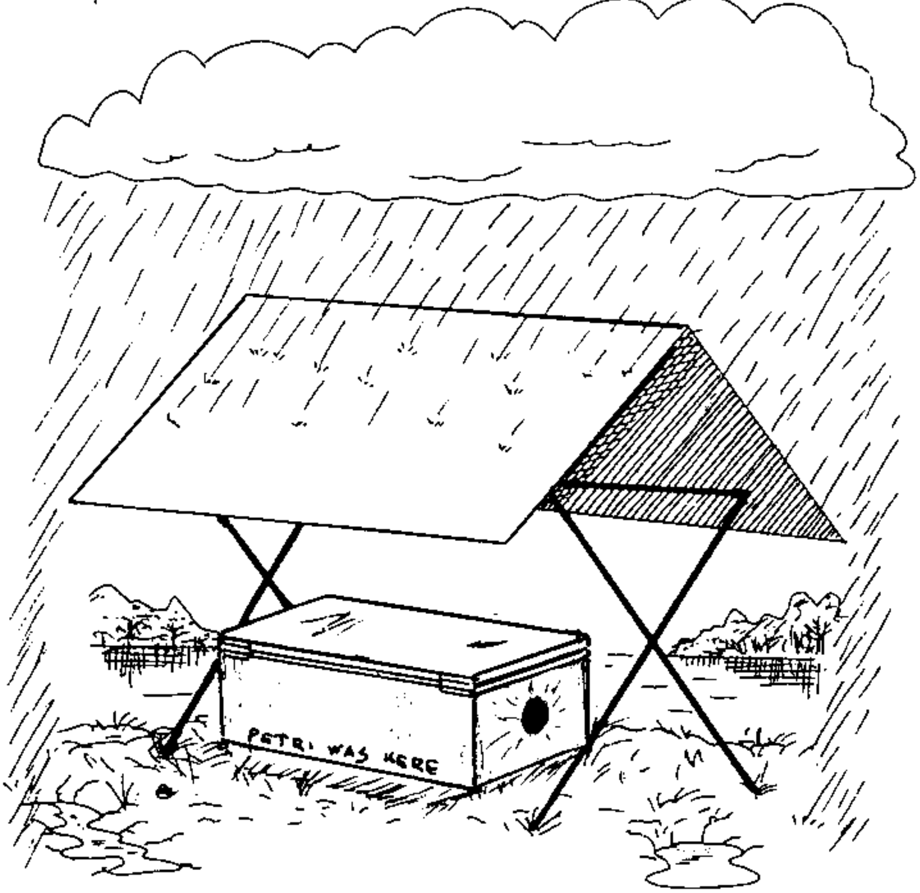
Because the solar box cooker is light, you can carry it inside overnight to protect it from rain and animals. Take good care of surface materials and the glass, because they are easily damaged or broken. If the glass is dirty, wash it to help the sun's rays pass freely through it. Keep the box clean inside, too, so that cooking will be safe and the cooker will remain nice. Reflecting surfaces lose their effectiveness if they become broken or are covered by dust or dirt. Wipe dust and dirt off the seals and repair broken seals immediately. Taking good care of the cooker increases its lifetime and increases its effectiveness.

POTS GET HOT!

USE POTHOLDERS!

DO NOT LEAVE
THE BOX COOKER
IN THE RAIN!

KEEP THE COOKER
IN A DRY PLACE
WHEN YOU ARE
NOT COOKING



11 Using the Solar Box Cooker

On a clear and sunny day, the temperature in cooker will reach 100-120°C. This is hot enough to cook or bake almost anything, if you are patient. On a hazy or partly cloudy day, the cooker temperature will reach a lesser degree, but you can still cook rice, potatoes or vegetables and even meat or fish, but don't try to bake bread or cakes. On completely cloudy days, the cooker won't work !

Be certain that all your cookware is tightly covered. (The flat, round *rotli dabba* works well.) If moisture escapes, it will condense on the lid and block the incoming energy.

Any conventional recipe suitable for an oven will work in a solar cooker, but you will have to adjust the time to account for the lower temperature. A good rule is to double the regular cooking time.

BE CAREFUL when you open the cooker. IT'S HOT INSIDE. Use potholders or oven gloves to handle the hot cookware.

Lift the glass or plexiglass lid from the top. Put the cake rack inside the solar cooker. Put in a thermometer so that you can read it when the lid is closed. Record the temperature. Close the lid and focus the cooker. Preheat for 30 minutes.

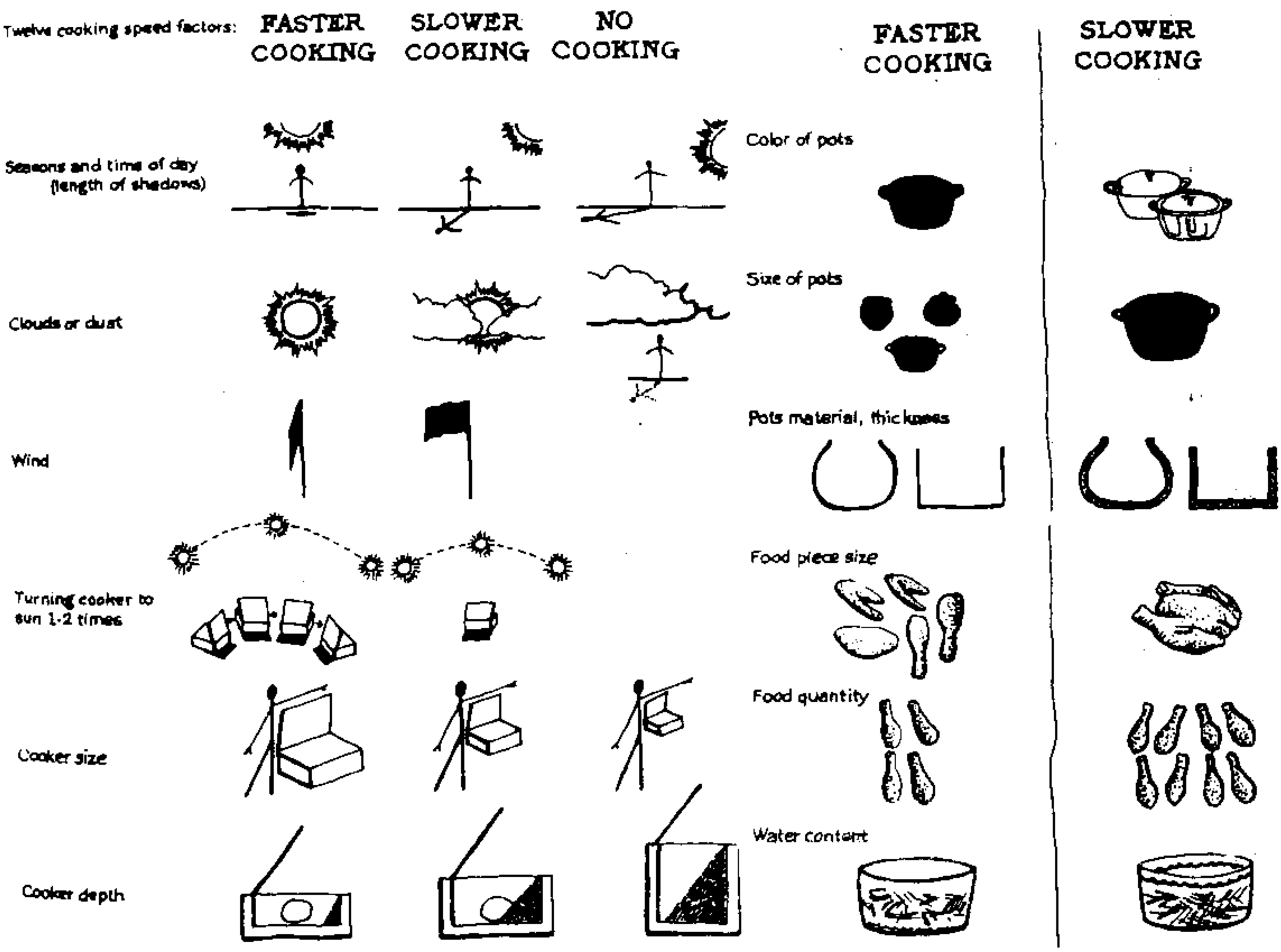
Record the temperature. Open the lid. Put the blackened vessels containing your food on the cooker rack. Close the lid.

Record the temperature inside the cooker every 15 minutes. (Don't open the lid of the cooker, just look inside through the glass lid.)

Measure your cooking time. When the estimated cooking time is up, record the temperature, carefully open the lid, remove the hot cookware, and sample the food. If the food is not yet done, cook it a bit longer. Be patient !

Conclusion

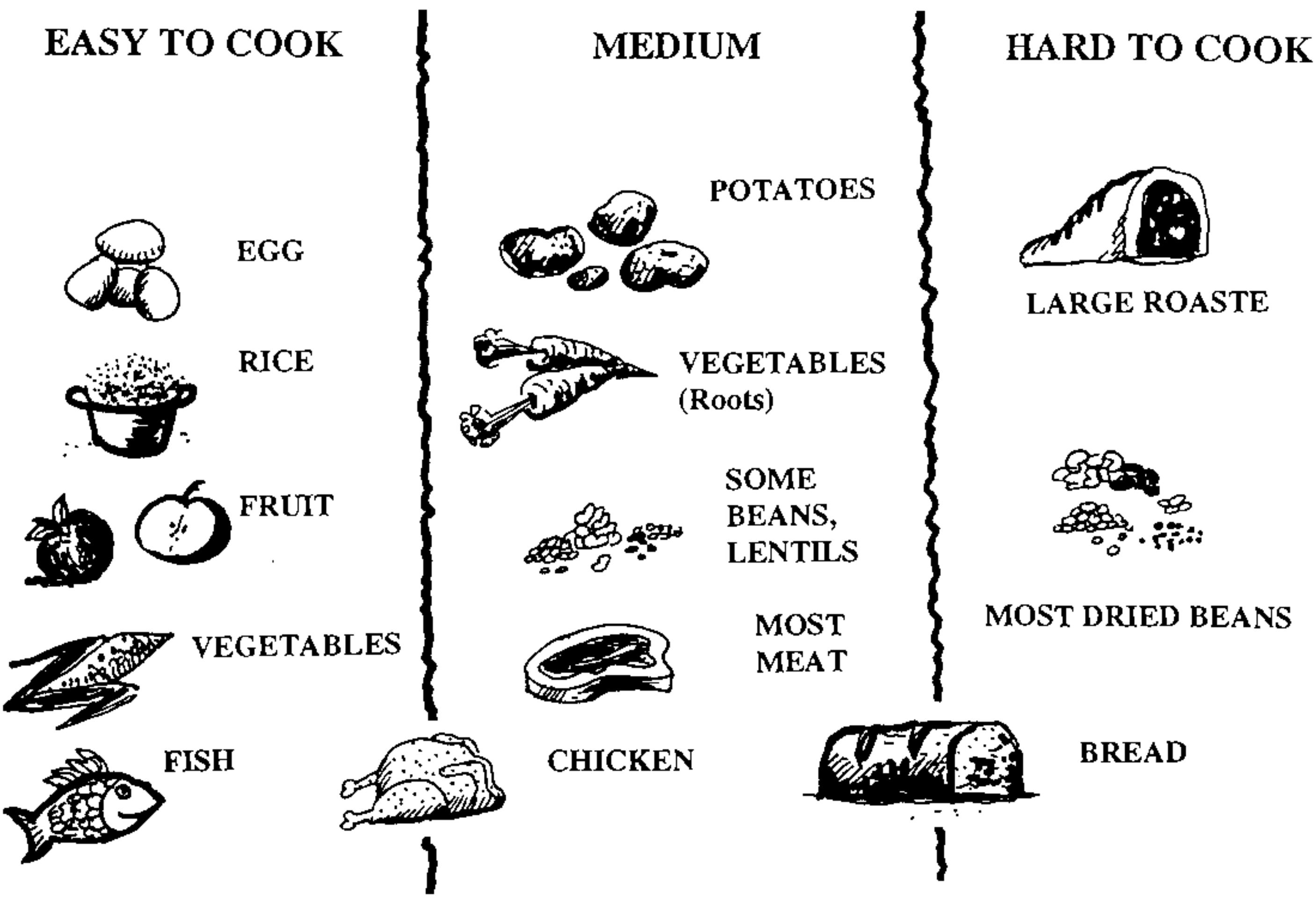
Describe the temperature changes and the foods you cooked. Include a labeled drawing of the solar box cooker. How could you improve the design of your cooker ?



Cooking times for solar box cookers

The cooking time with a solar box cooker will be longer, but **you will need less time** to prepare your meal because cooking does not require your presence. With some practice you can easily estimate cooking times for different raw materials. Times vary according to the quantity of food, the number of pieces, the outside temperature and naturally the intensity of the radiation. The kind of pot you use will also have an effect on the cooking time. However, it's difficult to overcook food in a solar box cooker, so you can safely leave it unattended for much longer than the minimum cooking times.

Cooking times can be roughly divided into three categories. Easy-to-cook foods take from half an hour to two hours; these include fish, chicken, eggs, vegetables, fruits, rice and pasta. Medium-cooking foods take from three to four hours; these include potatoes, roots, most meats (especially small pieces), seeds, lentils, bread and pastries. Slow-cooking foods take from five to eight hours; these include big amounts of food; large roasts; soup and stew; casserole; and most dried beans. Heating water also takes a long time, especially if you want to heat large amounts.



Practical tips

You should use water as usual when cooking swelling foods such as beans, rice and porridge. Do not use any water for meat, fish, eggs, vegetables and roots, or to heat foods up. Food simply does not burn in the solar box cooker; although it might get dry after several hours.

Stirring and mixing the food during cooking decreases the cooker's temperature and therefore slows down cooking. It is advisable to put the food in pots so that you do not need to stir it. However, if you must stir, do it quickly, only a few times and not before the food is already hot. Make sure to close the lids of the pots and the cooker's glass carefully after opening the cooker while cooking. If possible, use tightly-closing pots, because otherwise steam from the food covers the inside the glass, and this slows down cooking.

The temperature inside the cooker rises quickly to 100° C (210° F), which is high enough for cooking most foods. If you are baking bread, the temperature must be higher (140° C, 280° F); similarly, if you want to get a brown baking surface on the food. The temperature stays high (over 65° C, 150° F) from two to four hours (if you put a blanket on top of the lid, 1-2 hours without the blanket) after closing the cooker's lid, depending on the outside temperature. It is not advisable to store or eat dishes below 65 °C, because after this point the reproduction of microbes is high and the risk of food poisoning increases. Food is safe inside the cooker from rubbish, insects and animals, but do not store it there overnight because of the microbe risk.

It is easy to sterilise water in the solar box cooker, if you have clean pots with tight lids. After water has boiled for ten minutes, it is sterilised for drinking. Boiled water stays usable in a clean, closed pot or in an unopened, tightly-closed cooker.

Suitable pots for solar box cookers

The pots you use should be steady and have tightly-closing lids. The best colour for pots is dull-black, which absorbs sunshine well and converts it to heat. You can easily paint the outside of the pot yourself with a low-cost black heat-resistant (spray) paint. Do not paint the inside of the pot! The bottom of the pot should be flat.

Materials for pots must resist, conduct and retain heat well. Cast iron, pottery, aluminium (especially tefloned) and enamelled steel are suitable materials. The thicker the material is, the longer it takes to heat. However, thick material also stays warmer longer than thin material.

Keep your pots clean both outside and inside. If you have painted pots, and the surface has worn away, it is easy to repaint them. Small handles and knobs make the handling of the pots easy, but long handles take a lot of space inside the cooker.

Recipes for the solar box cooker

Porridge

1 part millet-flour (Mahango) 3 part water

Mix well 1 part flour and 3 parts water in a pot. With practice, you will learn the exact relationship, so that you will not need to stir.

or

Put water into the solar box cooker. Wait until it boils. Add flour and mix well. Boil the porridge for one or two hours while stirring.

Porridge for the children (for 5 children)

1 cup millet-flour (Mahango) 2 cups water 1 egg 2 tablespoon milkpowder 1 tablespoon sugar 1 tablespoon vegetable oil

Make loose porridge. Add one egg and mix well. Add the other ingredients and mix well. Serve porridge when it is still hot.

Cabbage Casserole (for 10 persons)

1 kg cabbage 5 dl water 3 dl rice 0,5 teaspoon salt 300 g ground beef 1-2 chopped onion 1-1,5 teaspoon salt 0,5 teaspoon white pepper powder (2-3 tablespoon syrup)

In the bottom of the roaster pan, place 1/3 of chopped cabbage and a little salt. Mix together ground meat, rice, chopped onion and spices. Spread this mixture over the cabbage. Then cover the mixture with 1/3 of chopped cabbage and salt. Spread the rest of the mixture over the cabbage and top with remaining cabbage. Pour over water in casserole. Cover and bake for 3 hours in solar box cooker

Meat-vegetable casserole (for 5-6 persons)

500 g meat
2 onion
2 tomatoes
1 dl cooking oil
salt
black pepper
season as you like

Put meatcubes, chopped onions, chopped tomatoes and all other ingredients in casserole. Cover the casserole and bake in solar box cooker 1 to 2 hours.

Fish-vegetable casserole (for 5-6 persons)

4 large tomatoes
2 carrots
4-5 potatoes
salt
white pepper
lemon juice (half lemon)
1 onion
500 g fish (fresh or frozen)
1-2 dl peas

Peel potatoes, carrots and onion. Cut potatoes into halves, carrots into small cubes and chop onion. Mix all ingredients slightly in casserole and cook in the solar box for about 2 hours.

Macaroni-meat casserole (for 6-8 persons)

3 dl macaroni
250 g ground meat
1 onion
1 teaspoon salt
white pepper
5 dl milk
2 eggs
salt

First boil macaroni in water (1 litre) in the solar box for about half an hour. Pour off water and put ground meat, chopped onion, spices, mixed milk and eggs into the pot and bake casserole for about 3 hours in the solar box. The casserole will be ready when it has acquired a firm texture.

Cooked beans (for 6-8 persons)

about 3 dl soaked beans 3/4 l water 1 teaspoon salt 1 bayleaf 1 bouillon cube

Soak beans overnight. Pour the water off and rinse beans with clean water. Put all ingredients into a pot and cook beans until their size has doubled.

White beans in tomato sauce (for 6-8 persons)

2 onions 1-3 tablespoon butter or margarine 4 large tomatoes 1 tablespoon tomato purée 1/ teaspoon salt 1 teaspoon basil 5 dl cooked white beans parsley (lemon juice)

Boil chopped onions in margarine. Add mashed tomatoes, purée and salt, and simmer in the solar box for about half an hour. Add herbs and cooked beans. Let the mixture boil and serve with grilled meat or sausages.

Finnish meat stew (Karelian stew) (for 6-8 persons)

500 g meatcubes (half beef, half pork) 1-1 1/2 teaspoon salt 4-5 allspice (pepper) water (2 onion)

Put all ingredients in a pot. Pour water in until two-thirds of the meatcubes are covered. Let the stew boil slowly in the solar box for about 4 to 5 hours. When this meal is ready, the meat will have become very smooth and tasty.

ADVANTAGES OF THE SOLAR COOKER

- the food cannot burn or overcook. It does not need stirring, turning or supervision. It saves time which can be used for other tasks

- it does not produce smoke and does not make the air dirty. So there is no chance that smoke will damage your eyes or lungs

- it saves money

- it is always ready for use and it's construction is very simple, solid and stable

- it is safe to handle

- there is no possibility for accidents like catching fire, bursting of gas cylinders, electrical shocks etc.

- since it is a slow cooking method, it preserves the healthy value of the food

- several foods can be cooked at the same time

- it can be used for boiling and steaming. You can also bake bread, cakes, puddings etc.

- it keeps cooked food warm for several hours

- sufurias and other cooking pans can easily be cleaned, the food does not stick to the pan

- etc etc etc

WHAT A SOLAR COOKER CANNOT DO:

- it does not work at night

- in the early morning, late afternoon or on partly cloudy days it does not cook well.

N O S O L A R C O O K I N G W I T H O U T S U N !!!!

- there is no fast cooking: food takes longer to cook than on a usual jiko (time is depending on quantity to be cooked - about 2 to maximum 4 hours)

- it cannot be used for frying

IMPORTANT POINTS TO BE OBSERVEO IN USING THE SOLAR COOKER

Preparations:

- place cooker in full sunlight
- make sure the glass is clean during the cooking process. The cooker will be less effective and cooking process takes longer with dirty glass
- place two small wooden sticks (not thicker than your finger) on the bottom of the solar-box. Put the sufuria on these sticks. The hot air can then circulate underneath the pot and the food will get heat from all sides. It will cook more evenly and faster

Actual cooking:

- prepare the food to be cooked or baked as you would for your normal stove, however make sure to use about a third less water and less salt
- all dark-coloured pots, sufurias, pans, cake tins and heat-resistant Pyrex cooking dishes are good for cooking and baking. Host important is that pots are covered and lids are painted with matt-black paint. The matt-black color absorbs the heat of the sun and increases the temperature in the cooker
- close glass lid of cooker tightly
- do not open the cooker once you have put the pot inside, otherwise the hot air escapes and it takes again time to reheat the cooker
- since hot air is lighter than cold air, the temperature is higher in the upper part of the cooker. The food gets cooked from above. The space between the lid of the sufurias and the glass cover must be at least two centimeters (one inch). If there is not this space, the high heat within the cooker can break the glass. To avoid breakage use another sufuria not quite as high.
- food gets cooked faster if you use large, flat sufurias. It takes less time to cook food in a large sufuria filled up to one third, than the same quantity of food in a small sufuria filled to the top!
- a thermometer is used to measure the temperature in the cooker. Food will cook (or boil, but without bubbles!) when the meter reaches appr. 100 degrees Centigrade. In Kenya the thermometer can rise up to 150 degrees, which is very high and helpful as it speeds up the cooking process. Your cooker has been tested and use of the thermometer is not necessary. Of course a thermometer makes cooking more interesting for you, but it is quite expensive.

SOMETHING ABOUT COOKING HOURS AND COOKING TIME:

- solar cooking usually takes about double the time required on a regular jiko. It depends on the strength of the sun (clouds, dust, time of the day etc.), and also on the quantity of food to be cooked. The outside temperature is not important. If the sun is shining you can use a solar cooker even in very cold weather

- put the cooker out in the sun while you are preparing the food. It will be hot when you put the sufurias in and the food will cook faster. When you put a sufuria into a cold cooker, it will take longer to cook. This does not really matter, if the meal is intended for dinner

- the reflector on the inside of the top lid increases the heat in the cooker and your food will be ready in shorter time. Around noon it takes about twenty minutes to heat the cooker to 120 degrees Centigrade, with the reflector you may reach 150 degrees in the same time

- The cooker should not be opened when baking bread or cakes prepared with yeast or baking powder. Keep it closed during the entire baking process. The drop of temperature will make the dough sink in and bread or cakes will no longer raise to the desired quality

HOW DO WE CLEAN AND CARE FOR THE SOLAR COOKER?

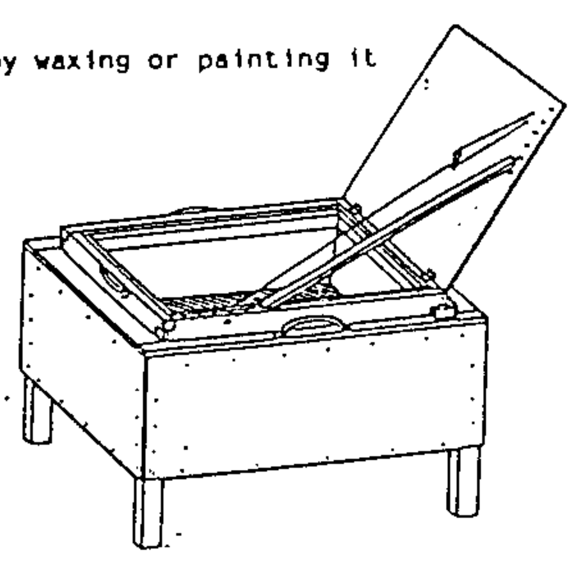
- the two glass plates in the lid cover and the shiny reflector on the inside of the top cover lid must always be perfectly clean before cooking.
  Dust, dirt and wind-blown sand absorb sunlight and reduce the cooking temperature

- when necessary clean out the cooking stove bottom and the sides with plain hot water. Be sure to always clean up whenever someting is spilled in the cooker

- When not in use protect the cooker against dust, rain and dampness. Cover it with a plastic hood and keep it in a protected place

- rain will harm your cooker, water can penetrate between the two glass plates and it will take time to unscrew the wooden fixtures to remove it

- if necessary protect the outside wood by waxing or painting it



RECIPES

Ugali

You will get an excellent ugali if you mix one part of Unga (maize flour) and one part of cold water. Stir well to avoid lumps and place the mixture in a covered pot in the solar cooker. After approximately 2-1/2 to 3 hours (depending on the quantity) the ugali is ready. It does not need any stirring or beating, and the sufuria can be cleaned very easily after cooking.

Rice

Rice turns out very nicely if you mix 3 parts of rice and 4 parts of water Be careful with the salt, it needs about a third less than usual. Place the covered sufuria in the cooker. Rice should be ready in about 1-1/2 to 2 hours, depending on the quantity you cook.

Potatoes

Boiled: Get potatoes of about the same size, wash them well, pour about one centimeter of water into the sufuria, add the wet potatoes and place the pot with lid in the cooker. Cooking time: approximately 2-1/2 hours

Baked: Select one to two good sized potatoes per person, wash them well, rub their skin with Kimbo or cooking oil and put them in a covered sufuria. Do not add any water! After approximately 2-1/2 hours remove the lid from the sufuria and bake the potatoes for another 15 to 30 minutes. They will then have the typical "baked" look!

Sweet Potatoes

Wash the potatoes, pour about 1 centimeter of water into the sufuria, add the wet potatoes. Put the covered sufuria in the cooker. Cooking time is approximately 2 to 2-1/2 hours, depending on the quantity and size of the potatoes.

Cooking Bananas

Fry meat (minced or cut in small cubes), onions and tomatoes in Kimbo or cooking oil on a normal jiko. Peel bananas and cut them in small pieces. Add bananas to meat, stir well and add 1 cup of water, little salt, spices (beef or chicken cubes), half a teaspoon full of sugar and again stir well. Make sure that the bananas get all wet and put the covered sufuria in the cooker. Depending on the quantity the dish will be ready after about 2 to 2-1/2 hours.

Many people like to cook bananas together with potatoes. Add the peeled potatoes (cut in cubes) with the bananas to the meat, onions and tomatoes.

K i t h e r i

Soak the beans in cold water during the night .
Fry onions and tomatoes in Kimbo or cooking oil on a normal jiko. Add one part of soaked beans and one part of maize, about one cup of water, salt and other spices to your taste. Stir well, be sure that all the maize gets wet when stirring, then put the covered sufuria in the cooker. In about 3 hours you will taste an excellent kitheri! The longer you cook it, the better!

B e a n s - mumbeans, red beans, any kind of dried beans

Soak the beans in cold water during the night.
Fry meat (cut in small cubes), and plenty of onions in Kimbo or cooking oil using a normal jiko. Add some sliced tomatoes and one or two chopped green peppers (without the white seeds), they give a nice flavour. Stir well and then add the soaked beans, about one cup of water, a little salt, spices (1/2 or 1 chili cube), stir again and place the covered sufuria in the cooker.
After 3 to 3-1/2 hours a very good meal will be waiting for you! The longer you let it cook, the better!
This dish can also be prepared without meat.

S u k u m a

Wash desired quantity of sukuma wiki, remove stems and bad parts, cut in fine stripes.
Fry onions and tomatoes in Kimbo or cooking oil on a normal jiko, add the washed and still wet sukuma, half a cup of water, little salt, spices, and stir well. Make sure that all the sukuma is wet! Put the covered sufuria in the cooker. Cooking time 1-1/2 to 2 hrs.
The sukuma will even taste better if you add some meat, minced or cut in small cubes. Fry it in the beginning with the onions and tomatoes and allow some more time for cooking.

S p i n a c h

Prepare like sukuma, but also use the white stems. They have a very special flavour and many vitamins and important minerals.

Mixed vegetables

Wash and cut vegetables like cabbage, carrots, tomatoes, green beans, cauliflower, broccoli, zucchini, mushrooms, egg plants, green peppers, potatoes and others according to your taste.

Cut onions and fry in Kimbo or cooking oil on a normal jiko, add all the prepared vegetables, 1 cup of water, little salt, spices (beef or chicken cubes) and stir well. Be careful that all vegetables are wet when you cover the sufuria. Place it in the cooker - the food will be ready after about 2-1/2 to 3 hours, depending on the quantity you cook.

The meal is especially good if you add some meat. It can be minced or cut into small cubes. Fry in the beginning together with the onions.

Cabbage, carrots, tomatoes, green beans, cauliflower, broccoli, zucchini, egg plants, mushrooms etc. can also be cooked individually.

Wash and cut the desired vegetables. Cut onions and fry in Kimbo or cooking oil on a normal jiko, then add vegetables. Add a cup of water, a little salt, some spices and stir well. Be sure that the vegetables are all wet when you cover the sufuria

Some additional hints:

Cabbage tastes very good if you cook it together with onions, tomatoes and carrots

Carrots get a special flavour if you add half a teaspoon of sugar

Zucchini, a lot of tomatoes, green pepper and, if you wish, eggplants, all cooked together, give a very tasty dish called "Ratatouille" in southern France.

Fry quite a lot of cut onions and a little piece of finely cut garlic in Kimbo or cooking oil on a normal jiko, add the cut and sliced vegetables, 1 cup of water, a little salt, pepper and spices (chicken or beef cubes), stir well and make sure that all vegetables are wet. Place sufuria in cooker and cook for 2 to 2-1/2 hours, depending on the quantity. This dish goes well with Ugali or Rice.

Mushrooms should be washed very quickly so that they do not soak up too much water, then cut them into thin slices.

Fry cut onions in Kimbo or cooking oil on a normal jiko, add the cut mushrooms, sprinkle about 1 teaspoon of wheat flour over the mushrooms, stir well, add 1/2 cup of water, little salt, spices (1 chicken cube) and about half a cup of milk. Stir again and place sufuria in solar cooker for 3/4 to 1 hour. When the meal is ready you may add about 1 teaspoon of butter or Blueband. This will increase the creamy taste. This dish is very good with rice or ugali. Why don't you try it once!

M e a t - beef, lamb, pork, goat, rabbit etc.

All meat tastes very good when prepared in the solar cooker.
Cut all meat into small cubes, large pieces require longer cooking time.

Fry meat, cut onions and little finely cut garlic in Kimbo or cooking oil on a normal jiko, add, if you like, a handfull of cut cabbage, 3 medium carrots, sliced, about 4 to 5 sliced tomatoes, 1 small green pepper (without seeds) and stir well. Add salt, pepper, spices (beef or chili cubes) and 1 cup of water, then stir well again and make sure that everything is wet before you put the covered sufuria in the cooker. Depending the quantity, the food will be ready in 2-1/2 to 3-1/2 hours - the longer the better!

Chicken

Cut the chicken into nice portions, rub them with little salt, pepper and spices, fry the pieces shortly on both sides in Kimbo or cooking oil on a normal jiko. Remove the fried pieces on a plate, then fry cut onions, sliced tomatoes and, if you wish, some sliced mushrooms in the same fat. Put the meat back into the sufuria with the onions and tomatoes. Add 1 small cup of water, little salt, pepper and other spices (1 chicken cube). Put the covered pan in the cooker. The dish will be ready in about 2 to 2-1/2 hours.

Fish

Wash the pieces of fish in fresh water. Dry them in a clean towel or household paper. Rub the fish with little salt and pepper on both sides.

Cut onions and some tomatoes in slices and sprinkle them with little salt, pepper and spices.

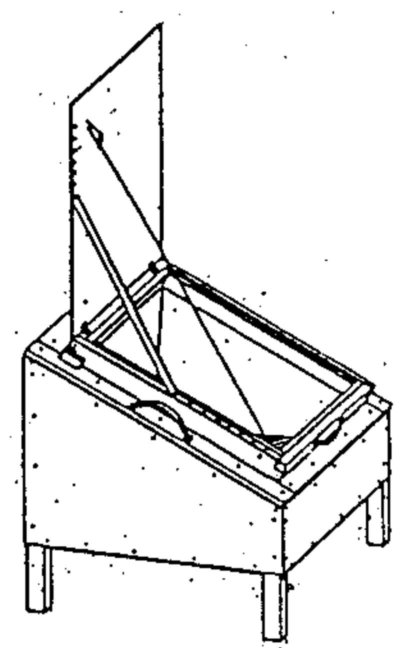
Fry the fish on a normal jiko in Kimbo or cooking oil for a short time on one side only. Put the cut onions and tomatoes in the sufuria around the fish. Put the covered sufuria in the solar cooker and cook for about 45 minutes to 1 hour. Serve this dish together with cooked rice or potatoes. It is delicious!

Chai

Chai is best if you mix 3 parts of cold water and 2 parts of milk. Add sugar and tea leaves and place covered sufuria in the cooker. Over lunch time it takes about 45 minutes to bring 1 liter of liquid to the boiling point, 1-1/2 liters should be ready in approximately 1-1/4 hours.

Boiled eggs

Eggs do not need to be in water to get boiled. Wash them and place them still wet into a covered pot or sufuria in full sunshine in the preheated cooker. They should be ready in about 20 to 30 minutes. We noticed that the egg yolk gets cooked first, the egg white stays soft slightly longer



B A K I N G in the solar cooker is a great thrill! Try it! A cake pan is very practical, but you can also use any of your sufurias, as long as you cover it with a black painted lid

Baking requires much heat - in an electric oven 200 to 250 degrees centigrade.

Therefore choose a nice sunny day and try to put your cake or bread not later than 10 a.m. in the preheated cooker. Baking can then take place during the hot part of the day. Leave your bakings in the cooker until about 2 to 3 p.m. in the afternoon!

C a u t i o n !!! Once your baking pan is in the solar cooker do not open the lid of the cooker again until close to the end of the estimated baking time. The drop of temperature by opening the lid will make the cake or bread fall and it will not rise again to its intended height!

Bread

Ingredients: 1/2 half kg of wheat flour, 30 grams of yeast, 1/4 liter of lukewarm water or milk to which you add 1/2 teaspoon of salt.

Prepare yeast according to instructions on package (usually dried yeast powder which must be mixed with 4 times its weight of lukewarm water). Let this mixture rise for 10 minutes.
Pour the flour into a bowl or even better on the clean surface of your kitchen table. Dig a little hole in the middle of the flour heap and put the liquid yeast in this hole. Mix some more of the flour with the yeast and let the yeast rise again for a few minutes. Now start mixing carefully all the flour with the yeast and slowly add the water/milk/salt mixture until you have a nice, smooth dough. If the dough is too wet, add more flour.
Now put the dough back into a bowl, cover the bowl with a clean wet towel and place it in a warm place for about 1/2 to 1 hour. The dough will rise again .
After kneading the dough again give it a nice shape and put it into a cake can or sufuria, which was previously rubbed with very little cooking oil or Kimbo and dried with just a dust of flour. Put it in the preheated cooker and bake it for about 3-1/2 to 4 hours.

Maizecake, sweet

Ingredients: 3 (normal) cups of Unga (maize flour), 3/4 cup of sugar, 4 teaspoons (not heaped) of baking powder, 2 pinches of salt, 2 eggs, 1/2 cup of melted Blueband (or cooking oil or butter) about 1 cup of milk or water, 1/2 cup of raisins (the small, fine kind - soak them in water for 10 minutes). grated peel of 1 lemon.

Mix the unga, sugar, baking powder and salt in a bowl and add the raisins and grated lemon peel. In another bowl beat 2 eggs, add melted Blueband (or melted butter or cooking oil) and mix well. Add this mixture to the flour mixture and knead well by slowly adding the milk (or water), until you have a slightly wet dough. You may need additional liquid, but do not add too much at a time. The dough should not be too wet.

Fill the dough into a cake pan or sufuria, which was previousy rubbed inside with very little cooking oil or Kimbo. Put it in the preheated cooker and bake it for about 3-1/2 to 4 hours.

Alu Chaat

Cooking Time : 2 hours

Ingredients : Potatoes - 2/3
Green Chilli (chopped) - 1
Ginger (grated) - 1/4 teaspoon
Coriander Leaves (chopped) - 1 teaspoon
Black Pepper Powder - 1/4 teaspoon
Amchur Powder - 1/4 teaspoon
Chaat Masala - 1/4 teaspoon
Juice of Lemon - 1 teaspoon
Salt to taste

Method : Wash the potatoes. Cut them into halves and place them in the container with some water in the solar cooker. Once boiled, remove skins and mash the potatoes. To the mashed potatoes add salt, the finely chopped chilli and grated ginger. Roll the mixture into small balls. Mix the powdered masalas in the lemon juice and sprinkle over the potato balls. Garnish with coriander leaves and serve.

Chhunda

Cooking Time : 2 - 3 hours

Ingredients : Rajapuri Green Mangoes - 2 (medium size)
Sugar - 3 cups
Turmeric Powder - 1/2 teaspoon
Chilli Powder - 1 teaspoon
Cumin Seed Powder - 1/2 teaspoon
Asafoetida - 1 pinch
Salt to taste

Method : Wash, peel and grate the mangoes. Add salt and sugar to the grated mangoes. Mix well and leave aside for a few hours. Put the mixture in an open steel container and place it inside the Solar Cooker for 3 hours. When done, set aside to cool. (Take a little mixture between your thumb and forefinger, and part your fingers. If you get a thread-like consistency, you will know it is done.) Then add the chilli, turmeric and cumin seed powders and asafoetida. Mix well and store in an air-tight bottle.

Bread Pudding

Cooking Time : 2 - 2-1/2 hours

Ingredients : Milk - 1 cup
Egg - 1
Bread - 2 slices
Sugar - 4 tablespoons
Chocolate Powder - 1 teaspoon
Vanilla Essence - 2 drops

Method : Soak the bread in milk for about 20 minutes. Add chocolate powder, sugar and vanilla essence to the egg and beat well. Mix the egg with the soaked bread. Put the mixture in a container, close the lid and place it in the Solar Cooker for an hour.

Roasted Peanuts

Cooking Time : 4 hours

Ingredients : Peanuts - 1/2 cup
Salt - 1 tablespoon
Water - 1 cup

Method : Soak the peanuts in salted water for about an hour. Drain the water and spread the peanuts on a clean cloth. Leave them to dry on the cloth for half an hour. Then put the peanuts into an open container and place in the solar cooker.

* For a healthy tasty snack you can also experiment with roasted soyabeans. Follow the same method, only soak the soyabeans for 3-4 hours. Cooking time will be about 6 hours.

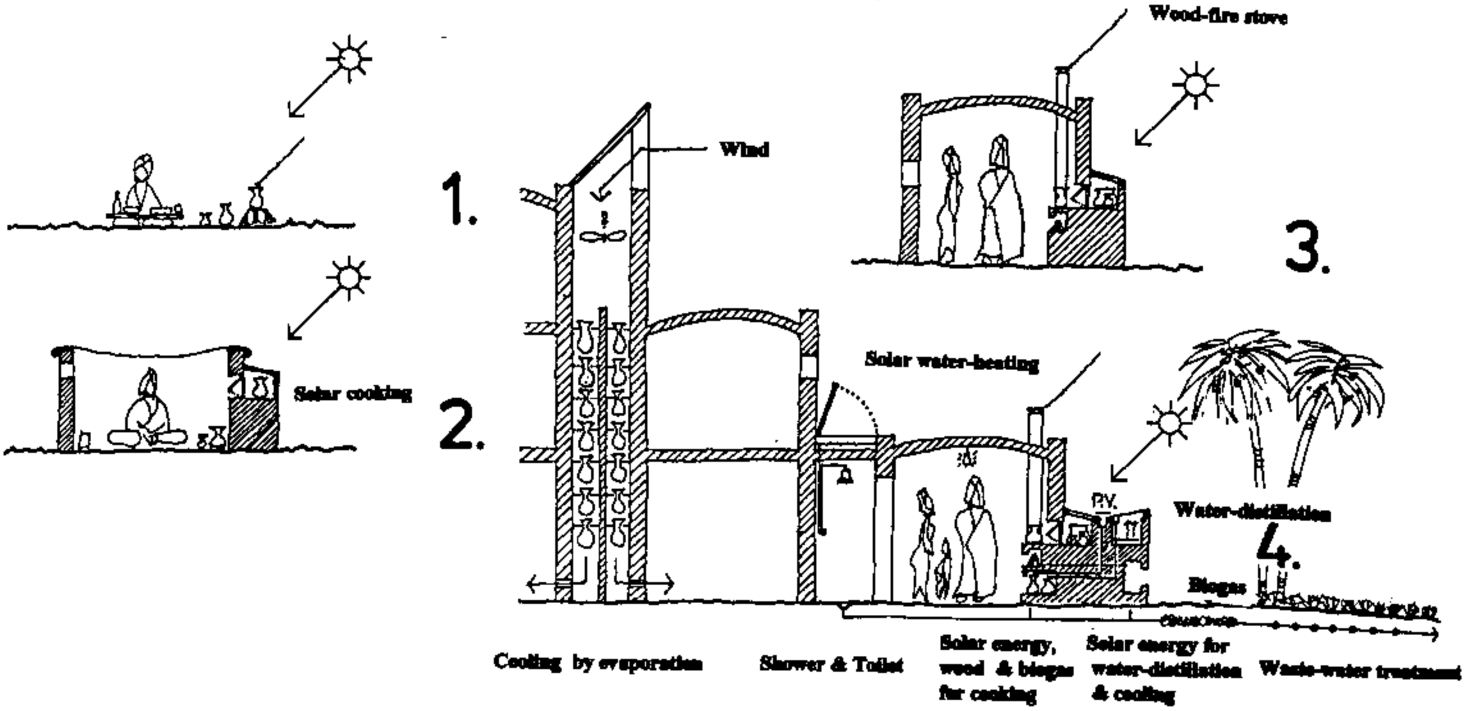
Khichadi

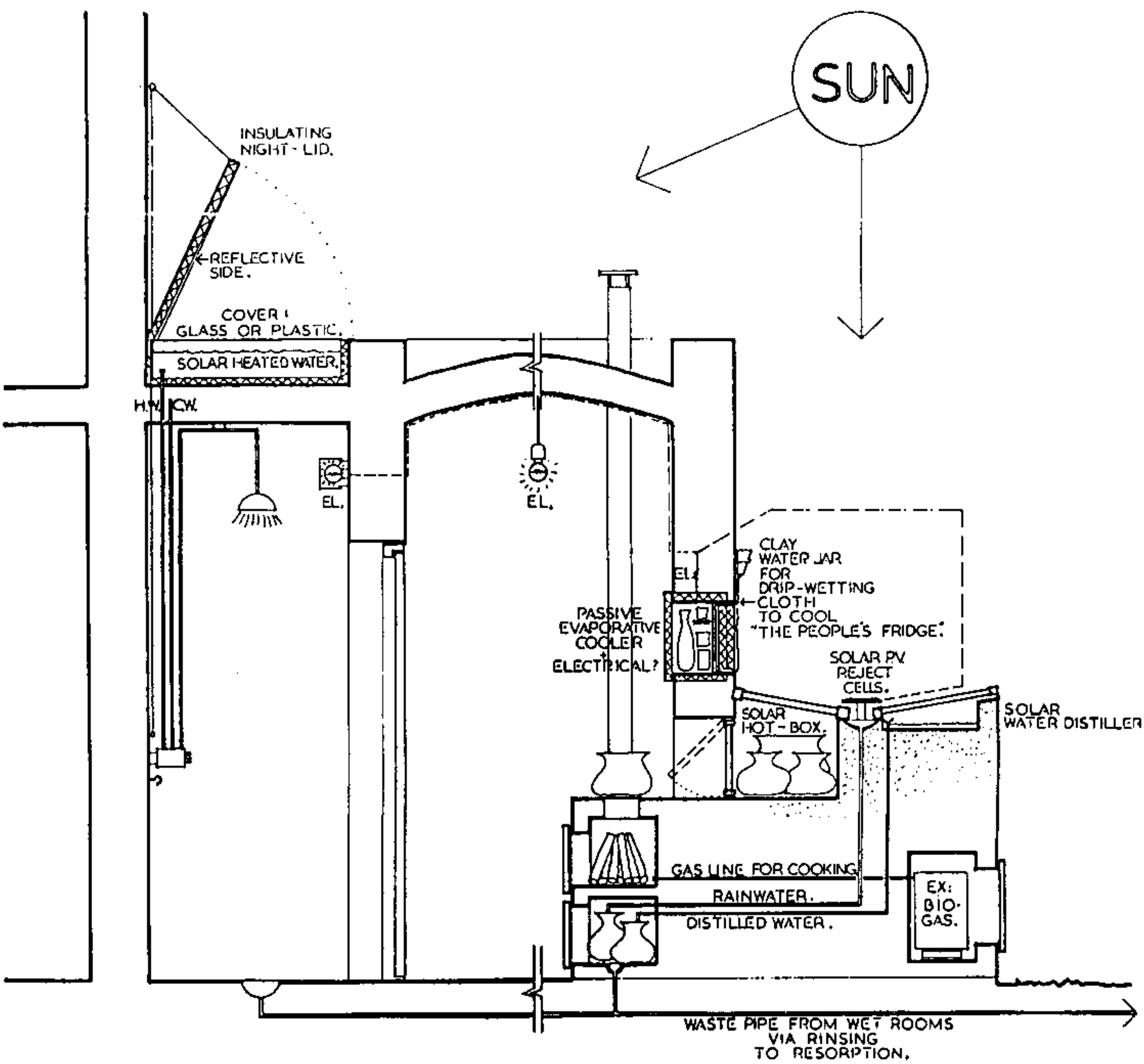
Cooking Time : 2 - 2 1/2 hours

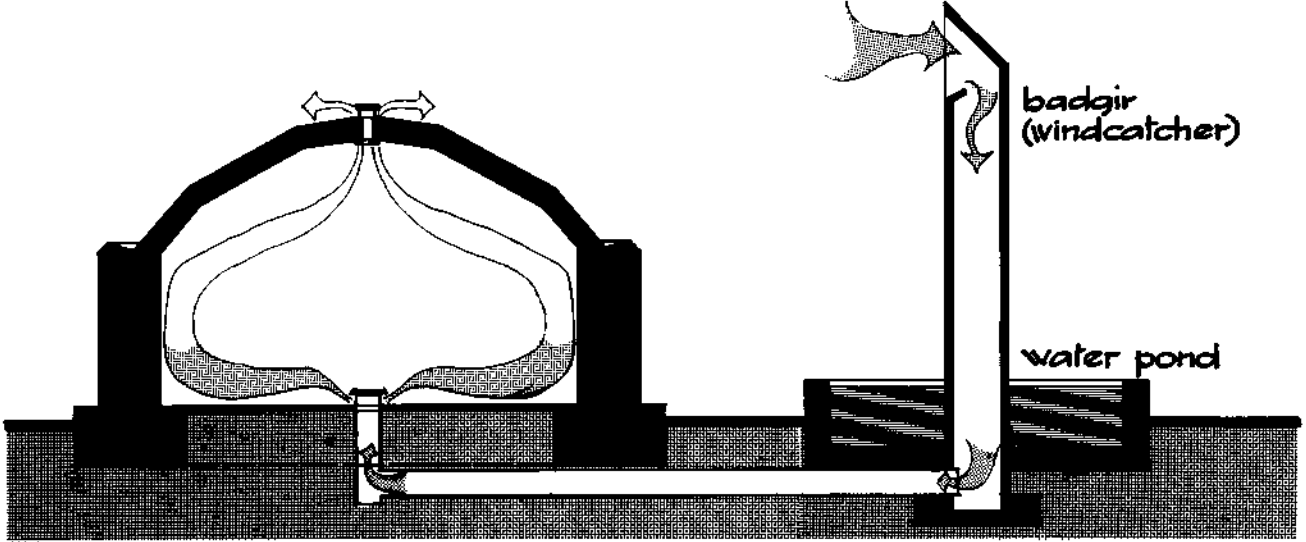
Ingredients : Rice and dal (tuver or moong) mix - 1/2 cup
Water - 1 1/2 cups
Oil - 1/2 tablespoon
Turneric Powder - 1/4 teaspoon
Mustard Seeds - 1/4 teaspoon
Green Chilli - 1 (chopped)
Asafoetida (Hing) - a pinch
Solt to taste

Method : Clean and wash the rice-dal mix thoroughly and keep aside in the cooker container. Heeat the oil on the gas stove in a separate vessel. When the oil is hot, add the mustard seeds and the chilli. When mustard seeds begin to splutter, add the asafoetida and immediately pour over the rice-dal mix. Add salt, turmeric powder and water. Shut the container and place it in your solar cooker. If you are using tuver dal, let theKhichadi cook for another half an hour.

35: Sunshine Revolution. Røstvig. Norway/USA 1992.







natural air-conditioning system (evaporative cooling)

Above: The cool tower keeps Charles Van Meter's house cool all summer long.

How to Stay Cool in the Hot Desert

Charles Van Meter

When the thermometer starts to hit 90°F nearly every day, even though "it is a dry heat" as we say here in the desert, we start thinking seriously about ways to stay cool. More than 14 years ago when we were planning to build a renewable energy powered home, cooling our home was the big question.

We had no doubt our new home, to be constructed on a 20 acre hilltop near Vail, Arizona, would be powered with wind and solar. We chose the site with wind power in mind. The domestic hot water system would be a passive solar system. We would use solar for space heating the structure, but how do we cool the home using renewable energy?

No Information on Low Energy Cooling

Air conditioning is not practical for a renewable energy (RE) powered home because the compressor and blowers consume a lot of energy. Evaporative coolers work well and use considerably less energy, but the blower still requires lots of energy. Plenty of books and information discuss all types of solar heating, but little to none describe passive or low energy use cooling.

I first thought about building most of the house underground. After choosing a site on the property to construct the house, I realized that excavating and removing the rock at the site would be difficult. Secondly, an underground house would deny us the outstanding views at the house site. We decided to build at a different site on the property. The house would be a two story structure. The downstairs would be mostly (80%) earth-sheltered, and the upstairs completely above ground with many windows.

Underground Cooling Tubes

The downstairs would not require much cooling because it is thermally connected to the earth, but the upper portion of the house would require considerably more cooling. I had researched underground cooling tubes and thought this could be part of the answer. I would feed air through a tube about 150 feet long and two feet in diameter. The air would pass through an evaporative cooler pad as the air entered the house. This cooler would be located underground. To move the air I would use an upwind air scoop at the cooling tube's intake. A solar chimney at the top of the house would help move the air through the house. No blowers would be required to move the air. So I started digging the ditch for the cooling tubes. I soon found the rocks that I had abandoned at the other higher site had deep roots. In addition I still had to come up with a material for the tubes: it had to be rust proof, a good heat conductor, the proper size, workable, and affordable.

Finding A Better Way

The ditch and the search for the tube material became an ongoing project. Then one day, about three years into the search, I stopped by the Environmental Research Lab where a friend, Bill Cunningham, worked as an engineer. He told me about a low energy use passive cooling system — cool towers. A cool tower requires no blowers or fans to move the cool air. The only power required is for a small DC pump to circulate water over the pads. A cool tower seemed the perfect answer for cooling an RE powered dwelling. From that day on, some major design changes took place in the already half completed structure. The solar chimney planned for the west end of the house changed to a cool tower. We filled in the mini Grand Canyon (the ditch) and avoided many hours of digging.

Normal Evaporative Cooling

Folks that live in places other than the desert may not be familiar with an evaporative cooling system. Blowers are used to move air through wet pads. As the air flows through the wet pad, water evaporates and cools the air. You cannot recirculate this air because the humidity increases and evaporation stops. At that point your evaporative cooler becomes a humidifier only. With evaporative coolers you must leave an exit for the air to escape from your house. Many newcomers to the desert don't realize you must open a window to make an evaporative cooler work properly.

How Cool Towers Work

Cool towers operate on the same principle as a standard evaporative cooler. The magic starts with the way the air is moved. Special pads made of CEL-dek sit at the top of a tower with a pump recirculating water over these pads. Air passes through the special pads with little resistance and is cooled by evaporation of the water. This cool moist air is heavier than the hot dry outside air and drops down the tower and into the structure to be cooled.

In order for the cool air to flow in, hot air must be exhausted from the structure. Open windows exhaust

Above: The upwind scoop on the cool tower guides hot dry air past the wet pads. Water evaporates, and the moist cool air drops down inside the house. Downwind scoops on the roof exhaust warm air.

this air with conventional evaporative coolers. If the wind blows hard against the side of the house with the open windows, the cool tower air flow will be reversed: no cooling. A large solar chimney can be used to exhaust air from the structure, which eliminates constantly watching the wind and opening the appropriate windows on the lee side. Downwind scoops are another alternative.

The Normal Cool Tower

Most cool towers have the pads around the very top of the tower. They use baffles inside the pads to keep the wind from blowing through the pads and out the other side.

My Cool Tower

I never do anything the way most people do a similar task. Maybe my situations are always different. I wanted to reduce the cost of the system as much as possible. The pads are expensive, so the fewer pads used that still accomplished the job, the better. I also used some cooling tube ideas in the design of the cool tower. Since the wind blows at a good steady pace here most of the time, I wanted to use wind power directly to help move the cool air through the house.

To create the additional flow down the cool tower I installed one large upwind scoop above the pads in the cool tower. This is an air scoop with a tail to keep the

Top: Wind both powers Charles' home and cools it off. The upwind scoop is made of a 72 inch wide by 39 inch high welded steel frame covered with canvas.

Bottom: A 12 Volt pump sends water cascading over the two CEL-dek pads. Collected rainwater leaves little mineral deposits on the pads when it evaporates.

scoop oriented into the wind, thus creating a positive pressure. Instead of one large outlet for the hot air, like a solar chimney, I installed smaller openings in the roof with downwind scoops to help remove heat. With these scoops the wind can blow from any direction and the cool tower continues to work properly.

On my design the pads are just below the scoop. This reduces the size and area of the pad, thus reducing cost. I have 18 square feet of four inch thick pads in my tower. Placing pads at the top of the tower would have required 72 square feet of pads. Pads down below the scoop are protected from direct sun, so they last longer. The tower itself is six feet square and 27 feet tall. The air scoop occupies the top three feet. Two pads three feet square by four inches thick are located just below the air scoop. Just below the pads is a tank containing 20 gallons of water with a float valve keeping this tank topped up. Located outside the tank is a small 12 Volt Teel bilge pump. This is a submergible pump, but I found the hard way not to submerge this pump. The first pump only lasted two months. The replacement pump mounted outside the tank lasted six seasons.

Some General Design Rules

I am not an engineer. I build things by what many refer to as "back yard engineering". I suspect some of you have completed projects engineered in a like fashion. Most of the time things work out pretty well. I did get some suggestions from my friend Bill Cunningham, an engineer and co-inventer of the cool tower.

A good way to visualize the air flow is to compare air flow to water. Water is, of course, a much denser fluid than air, but the principle is the same. Tower height, or the distance from the bottom of the pads to the air outlet, will determine the velocity or pressure of the air. The greater this distance, the more air pressure created, similar to a water column. We are using a column of cool moist air (compared to the hot dry outside air) to create this pressure.

To determine tower width, or cross section, use the water analogy here, too. The larger the size of a pipe, the greater the volume passes through the pipe at a given pressure.

Enhancements will increase the air flow; upwind and downwind scoops are my choice. Other methods include rigid and movable cloth baffles. Barometric operated louvers also work to direct the air through the pads and create increased pressures.

Pad material choice for me is CEL-dek. At first I installed the expanded paper pads that are much less expensive. Even the old standby for coolers, aspen pads, will work. Water must flow down the pads and air must pass through the chosen medium. The CEL-dek pad works best because it has low resistance to air passing through it.

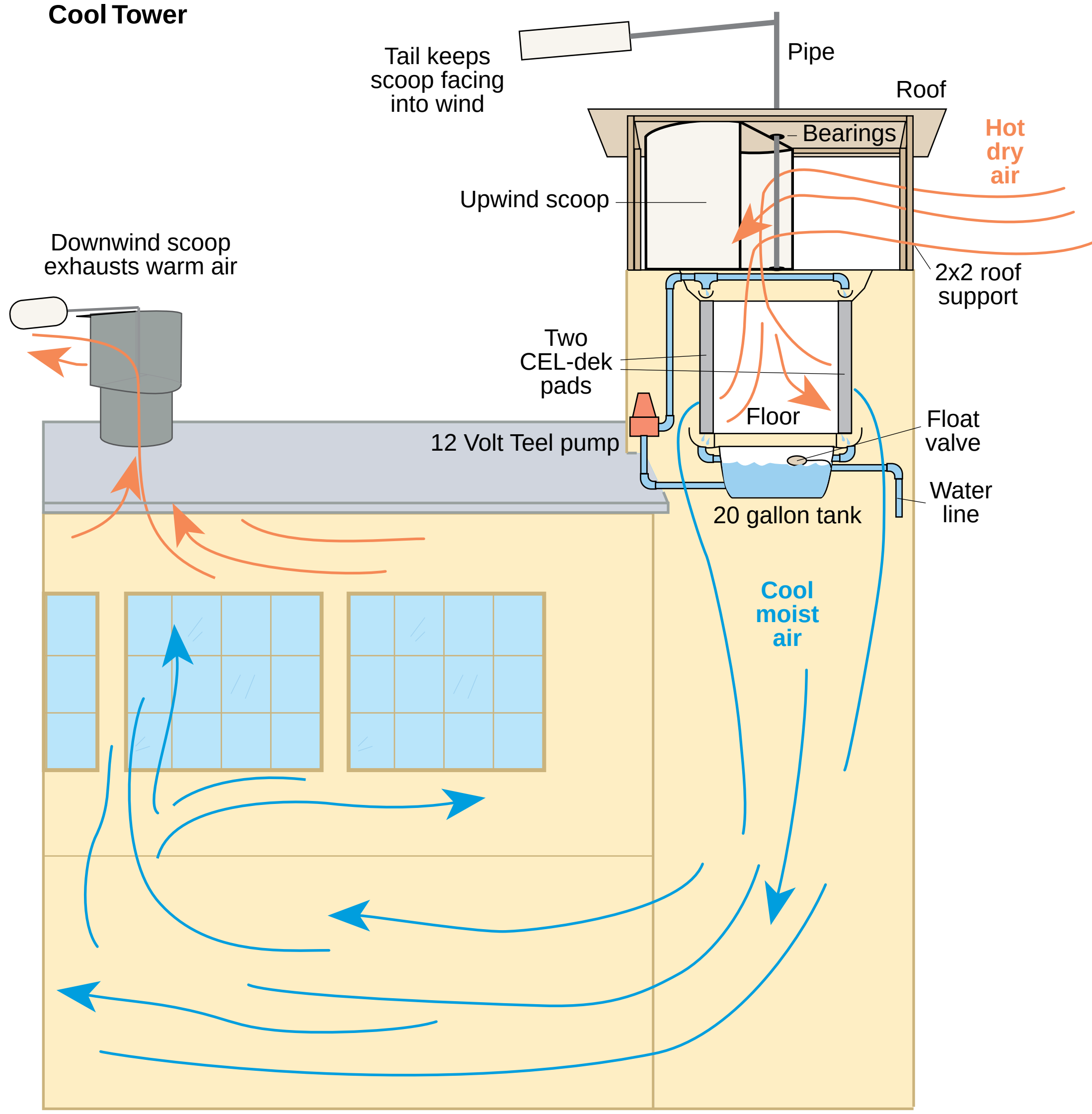
Duct work must be as large as possible. Having the air move through hallways and doors of the structure is best. An open floor plan works well. Cooling a large open area is much easier than cooling many rooms. If you use duct work with the cooling tower, the ducts must have a larger cross sectional area than ducts in a forced air system.

Vents must have a larger opening than those used with a forced air system such as conventional air conditioning or evaporative coolers. We are moving the air naturally with small pressure differences. Use large openings that don't restrict air movement.

What Kind of Water?
Evaporating water is what creates the cooling and makes evaporative coolers and cool towers work. Rainwater is the perfect source for the water used in cool towers because it does not have dissolved salts or minerals. Well water can contain dissolved minerals. As the water evaporates from the pads, whatever minerals it contains are left behind. This buildup will eventually clog the pads and block air flow.

We chose to get water for all our needs from the water harvesting systems we installed. Yes, we live in a desert, with an average annual rainfall of only 12 inches and we have plenty of water for all uses. The CEL-dek pads in our cool tower have had only rainwater on them since 1986. They have little mineral buildup on the surfaces.

Cool Tower



Normally you can expect to replace cooler pads every year, or at best every other year. I have seen cooler pads fed with ground water that have more buildup after less than one season than my eight year old pads fed with rainwater.

How Much Water
Approximately 1000 BTUs of cooling is created per one pound of water evaporated. On a hot summer day with low humidity you can expect to use 50–100 gallons of water. The most we have used in one day is about 60 gallons to cool the entire house. When we only cool parts of the house (“zone cooling”), we reduce this by 50–75%.

Other Benefits to a Cool Tower
Would you believe the cool tower helps heat our home in the winter? Our greenhouse has excess solar gain, so we open a small door in the cool tower leading to the greenhouse. The upwind scoop on the cool tower forces cool outside air into the greenhouse and excess heat is pushed downstairs. Cool air escapes through a vent located low in the downstairs room and is replaced by more warm fresh air from the greenhouse. We call this our fresh air heating system.

When we go away for an extended period of time in the summer, we open all the vents from the cool tower but leave the water pump off. With a slight breeze, fresh air flows through the house. This keeps the house from building excess heat.

Bill Cunningham built a cool tower on his office and shop/garage with south and east facing windows in the cool tower. They provide light and heat for both areas in the winter. In the summer they provide soft indirect light.

Conclusion
We started construction on the cool tower in the spring of 1985 and used it that summer. The system has undergone several changes. The first upwind scoop was metal, and not a good choice unless you use aluminum. Our scoop now has a framework of steel covered with heavy canvas. The cool tower has been in operation nine years. On a hot dry day (100°F with 10% humidity) the air coming from the tower is 65–70°F. We are very pleased with the performance. I am saving the finishing touches for a 110°F day — that's when working inside the cool tower is quite enjoyable!

Access
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Custom Cool Tower & Solar Design, Bill Cunningham, 5085 S Melpomene Way, Tucson, AZ 85747 • 602-885-7925

Suppliers of CEL-dek: Munters Corporation, Mrs. Pat Thomas, Box 6428, Fort Myers, FL 33911 • 1-800-446-6868

12 Volt Teel bilge pump: Stock # 1P811, W.W. Grainger Inc., local phone book

36: Thermische Solarenergie. Müller. Franzis-Verlag. Feldkircken Germany 1997 3-7723-4622-7.

Raumkühlung mit thermischer Solarenergie

Daß man mit Sonnenwärme kühlen kann, erscheint zunächst nicht logisch. Dennoch, gibt es Möglichkeiten, gerade die Sonnenwärme zur Kühlung zu nutzen.

Die Kühlung von Gebäuden mit Solarenergie ist sogar ein äußerst günstiges Anwendungsgebiet, da logischerweise gerade dann Raumkühlung benötigt wird, wenn die Sonneneinstrahlung und die Außentemperatur besonders hoch sind.

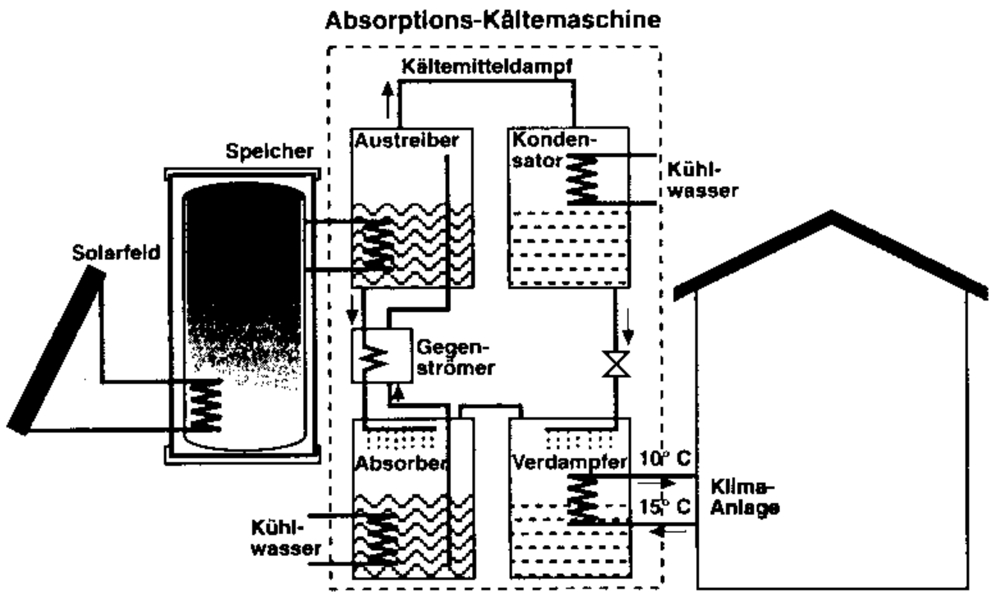
In äquatornahen Regionen mit besonders großem Klimatisierungsbedarf ist auch überdurchschnittlich viel Sonneneinstrahlung gegeben. Gerade in diesen Ländern ist die Raumkühlung mit Solarenergie deshalb von besonderer Bedeutung.

Aber auch in Mitteleuropa kann die Raumkühlung in den Sommermonaten effektiv umgesetzt werden. Besonders interessant und wirtschaftlich ist die Nutzung einer Solaranlage, die im Sommer nicht nur zur Kühlung eingesetzt wird, sondern auch in der Zeit mit Wärmebedarf zur Raumerwärmung genutzt wird.

Der Übergang von der Raumkühlung zur Raumerwärmung kann fließend erfolgen. Mit nachlassendem Kühlungsbedarf nimmt allmählich der Wärmebedarf zu, bis Solarenergie ausschließlich der Raumerwärmung dient und umgekehrt.

Nachfolgend werden zwei Verfahren vorgestellt:

1. Kühlung mit Absorptions-Kältemaschine



Die Technik von Absorptions-Kältemaschinen und Absorptions-Wärmepumpen ist seit längerem bekannt und auch in der Praxis für verschiedene Anwendungen eingesetzt.

Neu ist die Kombination mit Sonnenkollektoren.

Hierzu werden sehr leistungsfähige Sonnenkollektoren benötigt, denn die Betriebstemperatur liegt bei ca. 100 °C und darüber.

Eine Kühlung nach diesem Verfahren ist durch die relativ teure Absorptions-Kältemaschine in Kombination mit Hochleistungs-Sonnenkollektoren kostenaufwendig.

Funktionsbeschreibung

Solaranlage

Das Solarfeld beheizt einen Wasserspeicher mit einer konstanten Temperatur von ca. 100 °C. Dieser Wasserspeicher führt seine Wärmeenergie - dann wenn sie benötigt wird - dem Austreiber (Generator) der Kältemaschine zu.

Kältemittel

Das günstigste Kältemittel für eine Solare-Absorptions-Kälteanlage ist $LiBr\text{-}H_2O$ (Wasser als Kältemittel und Lithiumbromid als Lösungsmittel).

Die hier im Austreiber benötigte Temperatur von ca. 92 °C liegt für hocheffiziente Solarkollektoren in einem akzeptablen Bereich.

Austreiber

Dem im Austreiber befindlichen Arbeitsstoffpaar LiBr-H2O, das noch reich an Wasser ist, wird hier unter Zuführung dieser Wärmeenergie, mit einer Temperatur von ca. 92 °C, Wasserdampf ausgetrieben.

Kondensator

Der Wasserdampf strömt zum Kondensator. Hier wird der Dampf verflüssigt und die Kondensationswärme abgeführt.

Drosselventil (D)

Über ein Drosselventil (D) wird das Kondensat auf den Verdampferdruck entspannt.

Verdampfer

Das Wasserkondensat gelangt zum Verdampfer. Hier wird das Kältemittel unter Aufnahme der Wärme des zu kühlenden Mediums verdampft.

Absorber

Der Niederdruckdampf strömt dann in den Absorber, wo die wasserarme Lösung aus dem Austreiber eingesprüht wird und das Wasser aus der Dampfphase (Verdampfer) absorbiert. Dabei entsteht Absorptionswärme die durch Kühlwasser abgeführt wird.

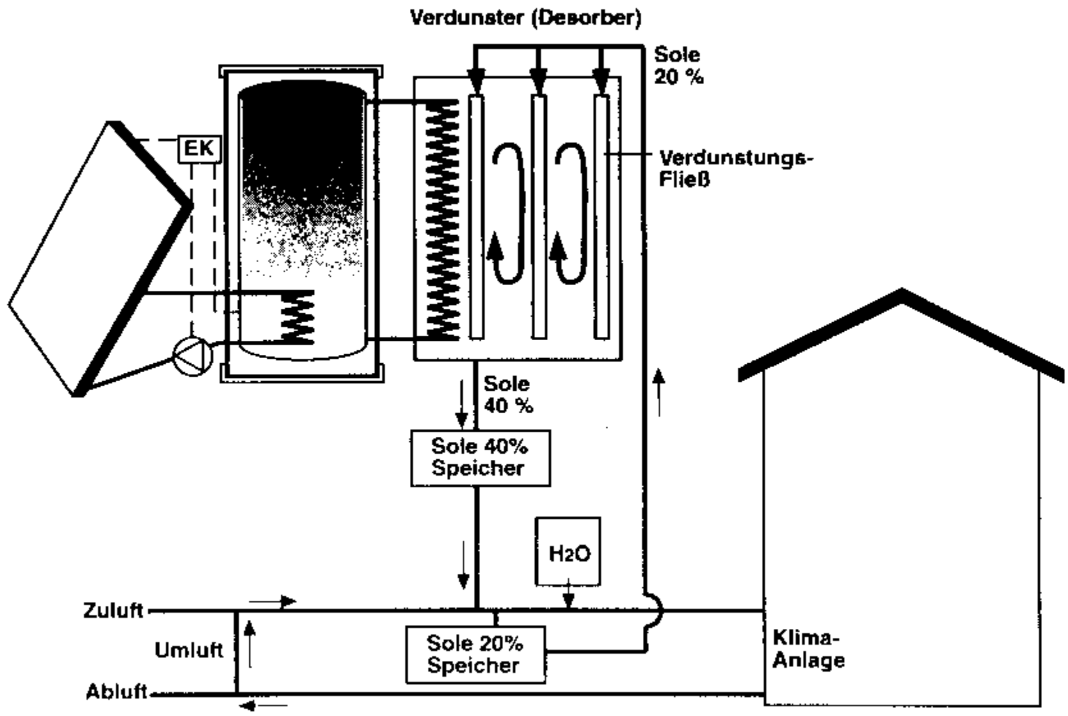
Gegenströmer

Sodann wird die mit Wasser angereicherte »reiche« Lösung zum Austreiber befördert und auf dem Weg dorthin, mittels eines Gegenstromwärmetauschers, durch die vom Austreiber in den Absorber strömende »arme« Lösung vorerwärmt.

Die Absorptions-Kältemaschine arbeitet mit einem Wirkungsgrad von ca. 50% und benötigt - im Gegensatz zur Kompressor-Kältemaschine - nur einen geringen Teil elektrische Energie.

2. Solare Kühlung durch Verdunstungsprinzip

Dieses Verfahren ist wesentlich preiswerter und es werden weniger effiziente Kollektoren benötigt als bei dem Verfahren mittels Absorp-tions-Kältemaschine. Das Kältemittel Wasser wird nicht verdampft, sondern arbeitet nach dem Verdunstungsprinzip.



Solaranlage

Wie zuvor wird mittels Sonnenkollektoren ein Wasserspeicher beheizt jedoch mit niedrigeren Temperaturen von ca. 80 °C.

Verdunster (Desorber)

Von diesem wird dem Verdunster die Wärme zugeführt, um Wasser aus CaCl2-Sole zu verdunsten. Daraus entsteht eine 40%-Sole die einem Solespeicher zugeführt wird.

Trocknung der Luft

Aus dem Solarspeicher wird die konzentrierte Sole im Zuluftkanal der klimaanlage auf Kühlwasserrohre gesprüht. Dabei entstehende Kondensationswärme wird abgeführt.

Die stark hygroskopische Sole entzieht der Luft Feuchtigkeit. Die dadurch entstehende verdünnte Sole wird über einen weiteren Solebehälter dem Verdunster wieder zugeführt.

Kühlung

Nun wird in die getrocknete Luft Wasser eingesprüht das dort verdunstet. Aufgrund der dadurch entstehenden Verdunstungswärme kühlt sich die Luft ab.

Auch hier kann die Anlage für die Raumerwärmung genutzt werden, zumindest die Kapazität der Sonnenkollektoren und die des Wärmespeichers.

Natürlich ist die Anwendung der Solarenergie-Nutzung nicht auf die Haustechnik beschränkt.

Bei vielen weiteren Anwendungsgebieten läßt sich mit der Solartechnik Energie sparen.

Diese Anwendungsgebiete werden jedoch in diesem Buch nicht beschrieben. So ist z. B. die Meerwasserentsalzung für mitteleuropäische Breiten wenig interessant.

Die Erzeugung von Prozeßwärme wiederum, für die ein hoher Bedarf vorhanden wäre, ist mit Solartechnik unwirtschaftlich. Prozeßwärme erfordert Betriebstemperaturen von über 100 °C, die sowohl von guten Flachkollektoren als auch Vakuum-Kollektoren erreicht werden. Der Wirkungsgrad reduziert sich jedoch bei so hohen Temperaturen sehr stark und macht eine Solaranlage für diesen Anwendungszweck deshalb uninteressant.

Earlier in this century, refrigerators were available that worked exactly like Faraday's experiment, except that water absorbed the ammonia rather than silver chloride.[8] Once a day, you would light a kerosene burner under the absorber/generator, producing high pressure ammonia which then liquefied in a condenser. For the rest of the day this ammonia would slowly evaporate, keeping the refrigerator cold. These intermittent cycle refrigerators worked, but they were not very convenient.

Later, the continuous absorption system was developed, providing continuous cooling with a continuous heat input. This was pioneered by Servel in the 1930's. The Servel system utilizes ammonia, water, and hydrogen in a relatively complex arrangement. This type of refrigerator is still available today, and may be fired by natural gas, LPG, electricity, or other heat source.

To convert an absorption refrigerator to solar energy, one must devise a way of getting solar heat to the generator, where the ammonia is liberated. In some refrigerators, the generator must be quite hot for efficient operation (as high as 500°F). This can be done in two ways: using a solar concentrator to heat oil or steam to high temperatures, and piping the hot fluid through the generator; or heating the generator directly with the solar concentrator. On the other hand some systems will work with a generator temperature as low as 190°F, so that water heated by ordinary flat plate collectors can be used.

Besides the Servel units, experimenters might try converting the small absorption refrigerators available for campers and mobile homes, which work on LP. Bernz-o-Matic makes a portable model weighing only 42 pounds; other manufacturers make larger units for mobile homes.

The most important measure for an absorption system is the coefficient of performance, or COP. This is the ratio:

$$COP = \frac{\text{cooling output}}{\text{heat input}}$$

Thus, if you achieve 500 kilocalories of cooling with 1000 kilocalories of heat input, the COP is 0.5.

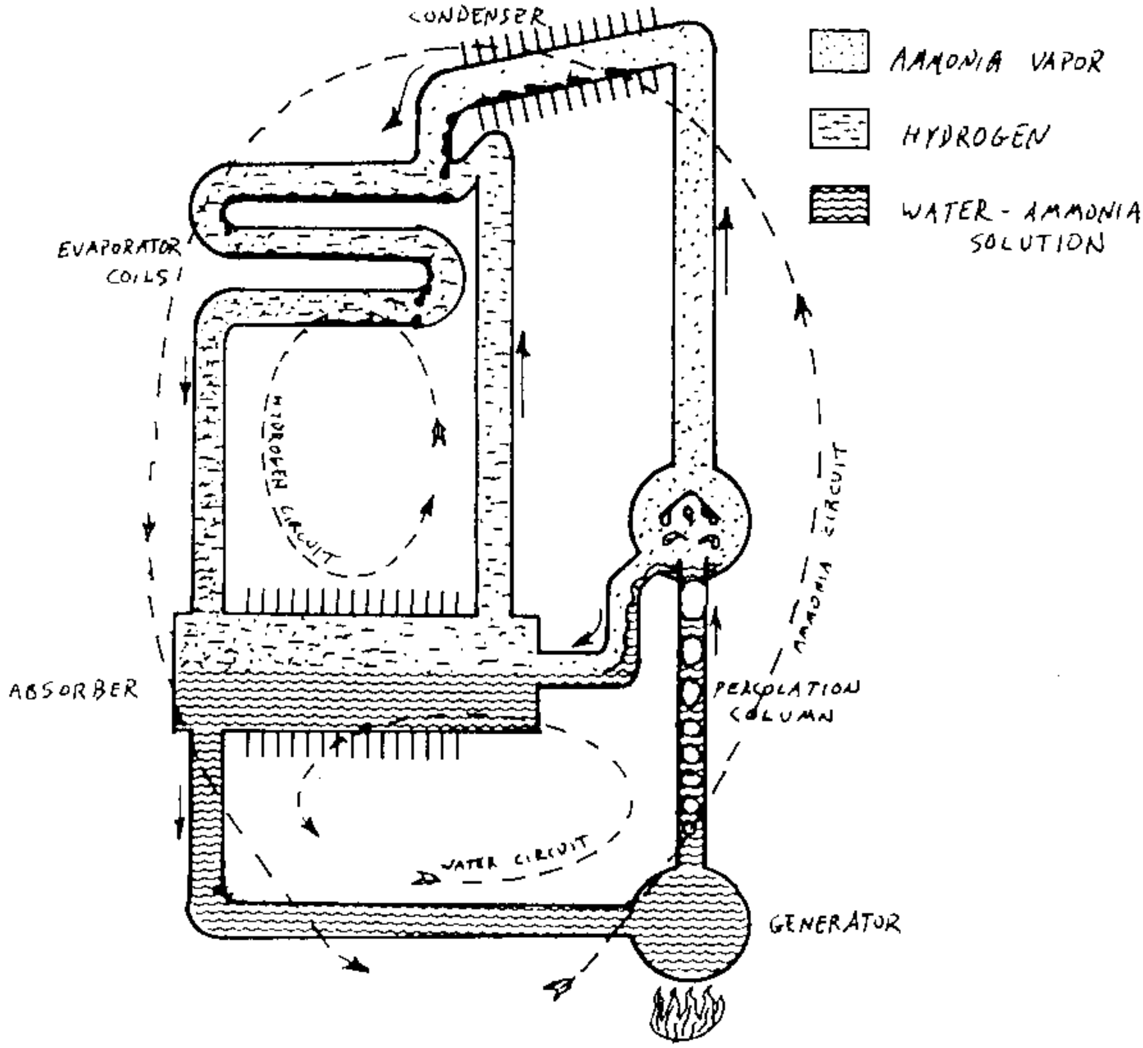


Fig. 5: The Servel cycle. Ammonia-water solution is heated in the generator. Bubbles of ammonia vapor are released. Percolation causes circulation of the solution. The ammonia vapor travels up to the condenser, where it drips into the evaporator coils. Hydrogen gas is also present in this area, in order to give the proper partial pressures for condensation and evaporation. Evaporation causes cooling of the coils, which are located in the icebox of the refrigerator. The ammonia vapor is then absorbed by the dilute solution in the absorber. Observe that there are three fluid circuits involved: an ammonia circuit, a water circuit, and a hydrogen circuit. Also note that the use of percolation means that no mechanical power need be supplied to move the fluids--heat is the only input to the system.

In solar work, the collector is not 100% efficient in converting the sun's energy to heat. Therefore, in a system where the solar collector was 50% efficient and the cooling system's COP was 0.5, the overall COP would be 0.25.

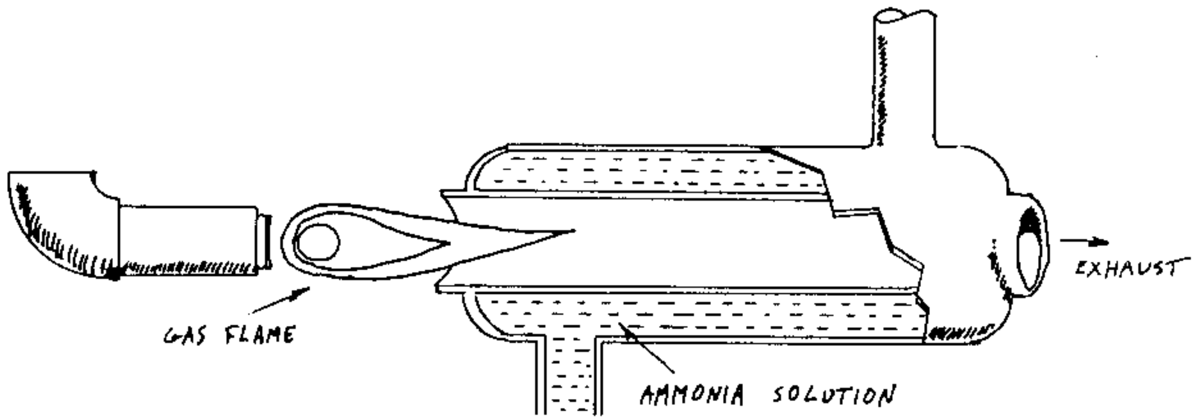


Fig. 6: One type of generator on a gas-fired absorption refrigerator.

Ammonia Systems

E. A. Farber has directed a good deal of research into ammonia absorption systems at the University of Florida Solar Energy Research Laboratory. In 1957 a large cylindrical parabolic reflector was used to heat cottonseed oil to 550°F, and this oil circulated to the generator of a standard Servel refrigerator.[9] More recently, Farber has been working on ammonia systems that can operate at lower temperatures, using flat plate collectors.[10] One such system is shown in Figure 7.

An experimental model was built using a 4 ft. by 4 ft. flat plate collector. Generator temperatures ran around 150°F, and generator pressures were about 200 psia. Under these conditions, the device produced 41 pounds of ice per day, giving an overall COP of 0.1. Presumably, higher temperatures would give improved performance, but in ammonia systems this requires very rugged construction due to the high pressures involved.

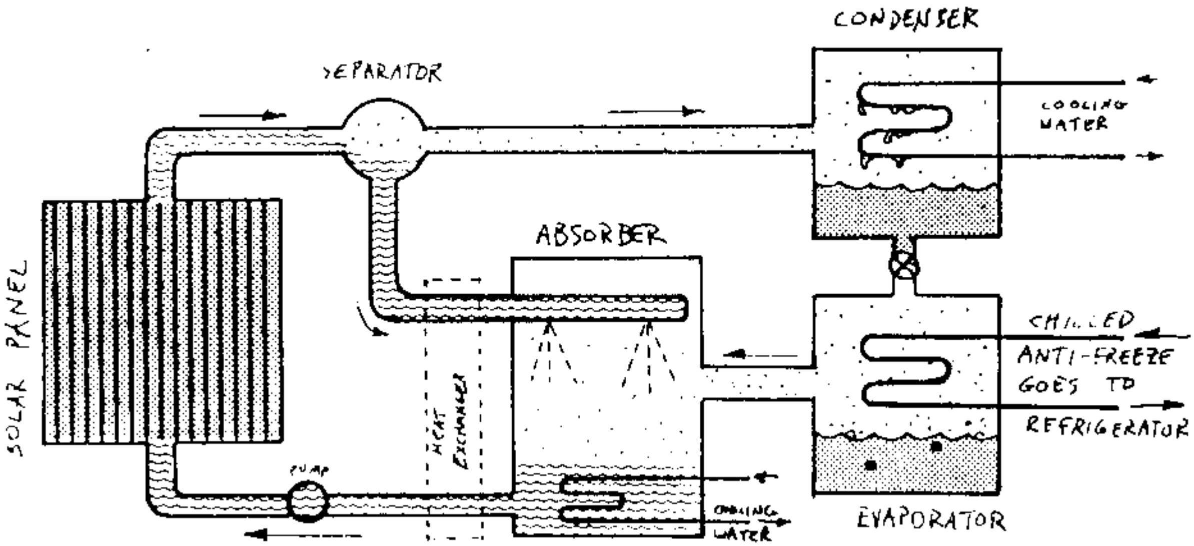


Fig. 7: Ammonia-water absorption system developed by Farber. The NH_3-H_2O solution is heated in a flat-plate collector. Ammonia vapor is liberated and then condensed, collecting as liquid in the condenser. Periodically, a valve is opened to allow liquid ammonia into the evaporator, where its evaporation chills coils of circulating anti-freeze (the chilled antifreeze is then used to cool the icebox, room, etc.). The resultant ammonia vapor is absorbed by the dilute NH_3-H_2O solution, in a spray chamber. Finally the solution returns to be solar heated again.

Isaac Solar Ice Maker

A *solar* ice maker? No we haven't been out in the sun too long, this is a real product with a number of working installations. Using only the heat of the sun, an Isaac will produce 10 to 1000 pounds of ice per day depending on model and available sunlight. The Isaac uses the Solar Ammonia Absorption Cycle that was discovered in the 1850s, and is still used on a smaller scale by all gas refrigerators. This refrigeration technology fell out of fashion in the 1930s with the arrival of cheap electricity and the discovery of the miracle refrigerant FREON. The Isaac uses no electricity, gas, or freon.

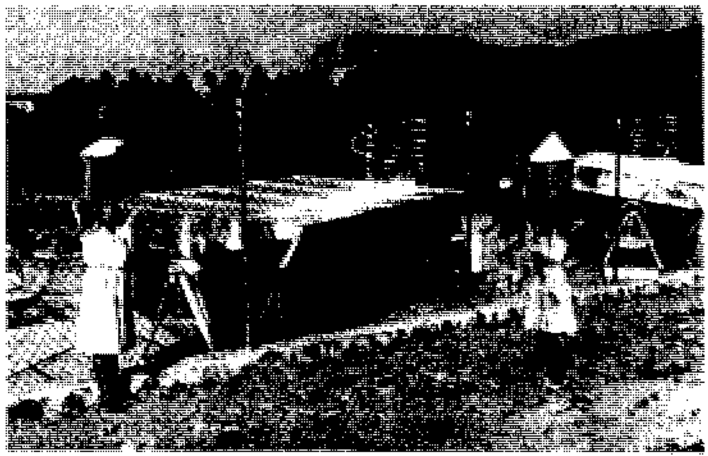
During the day the Isaac stores energy in the receiving tank as high-pressure, distilled, pure ammonia. At night the user checks the sight glass to judge how much ammonia was produced, adds an appropriate amount of water to the ice compartment, and switches the valves from Day to Night positions. The ammonia is allowed to evaporate back into the collector while providing refrigeration for the ice compartment. The refrigerant cycle is sealed. In the morning the valves are switched again and the process starts all over while the ice production from the night before is harvested.

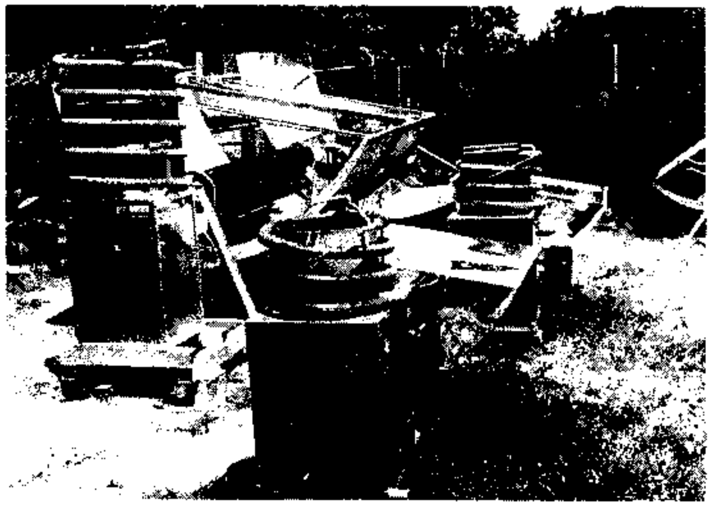
The Isaac is constructed of stainless steel for maintenance-free outdoor installation in oceanside sites (not to mention some pure industrial beauty). Many of the current installations are for fishing villages in remote sites. Maintenance consists of re-aiming the collector every four weeks to track the sun, and an occasional bucket of water to wash away any dust.

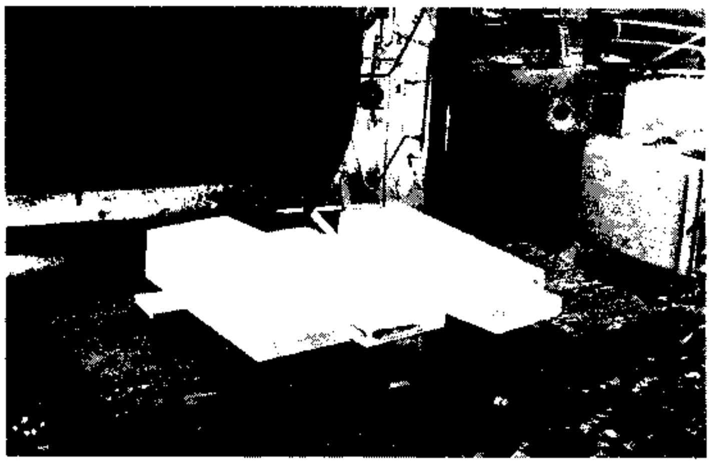
The Isaac is built-to-order in a variety of models. Delivery is 30 to 90 days. An experienced technician is required on site for installation and training; this is not included in the price. Discounts available for quantity orders. Call for more information.

•62-532	Isaac Standard Solar Ice Maker	$9,895
•05-218	Export Crating for Standard Isaac	$595
•62-533	Isaac Double Solar Ice Maker	$13,995
•05-219	Export Crating for Double Isaac	$995

Shipped freight collect from Maryland







38: Fishing Technology. National Academy Press. Washington DC. USA 1988 0-309-03788-3.

A biomass-fueled ice-making machine has been developed at the Asian Institute of Technology in Thailand. It requires little maintenance and has no moving parts. Almost any waste biomass can serve as the fuel (figure 5.5). This ice maker uses an intermittent ammonia-water absorption cycle. These refrigeration systems produce their cooling effect through the heat absorbed when liquid ammonia is converted to gaseous ammonia. As liquid ammonia vaporizes, heat is extracted from its surroundings. When this

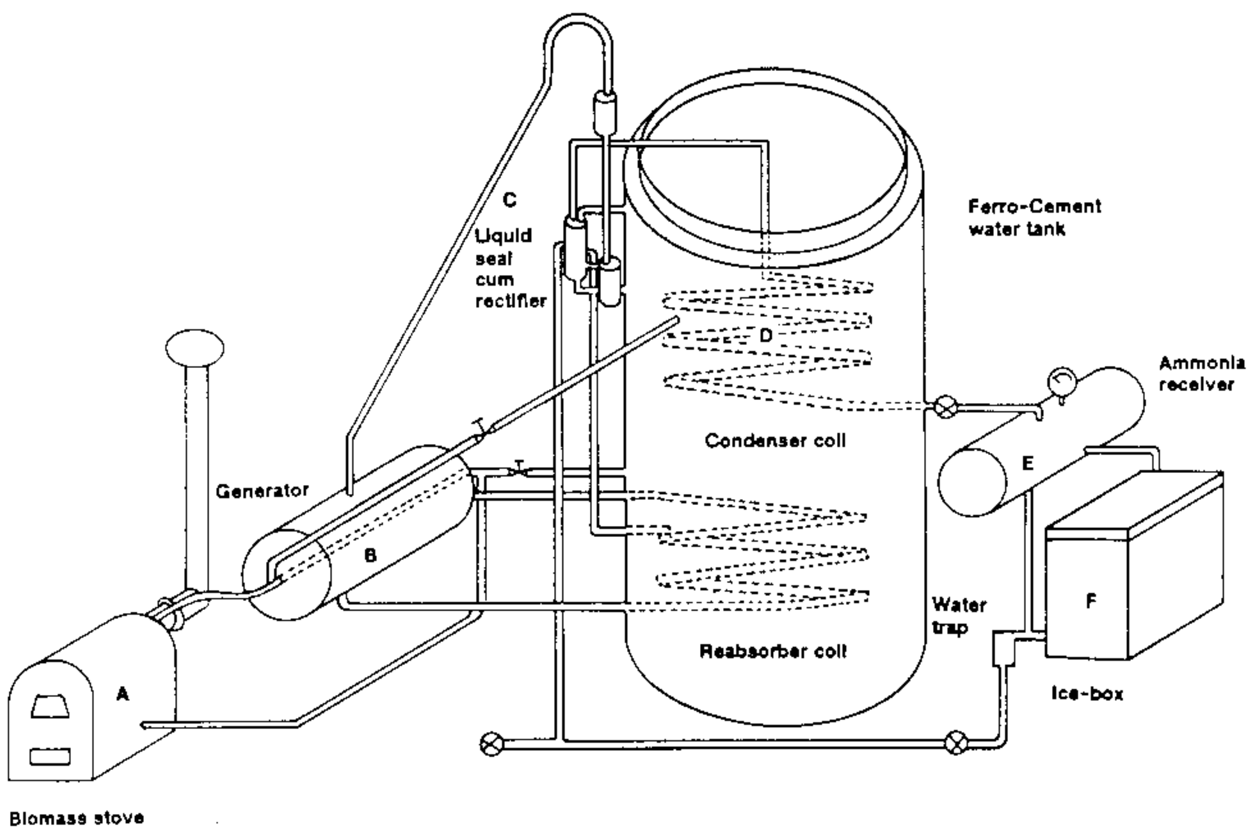


FIGURE 5.5 This refrigerator can make 225 kg of ice in about 12 hours using biomass as fuel. It has been successfully field tested in Khau Yai, a remote rural island off southern Thailand.

change occurs in a closed container so that heat is extracted from water, ice is formed.

As seen in figure 5.5, fuel is burned in the stove (A) to heat water, which is then circulated through the generator (B) that contains a mixture of ammonia and water. The ammonia is distilled out of the water mixture, passes through the liquid seal (C), and is cooled to liquid ammonia in the condenser coil (D). The liquid ammonia is held in the ammonia receiver (E). To make ice, the liquid ammonia is released into the ice box (F) where it reverts to gaseous ammonia and converts containers of water to ice. The gaseous ammonia is then redissolved in water in the generator (B) and the cycle can start over. The complete cycle takes about 12 hours and produces about 225 kg of ice. The ice maker was built in Thailand at a cost of about US$3,000.

A compact solar refrigeration system that uses the same technology as the biomass-fueled ice-making machine has also been developed (figure 5.6). In this case, the ammonia-water solution is heated in the pipes of a solar collector.

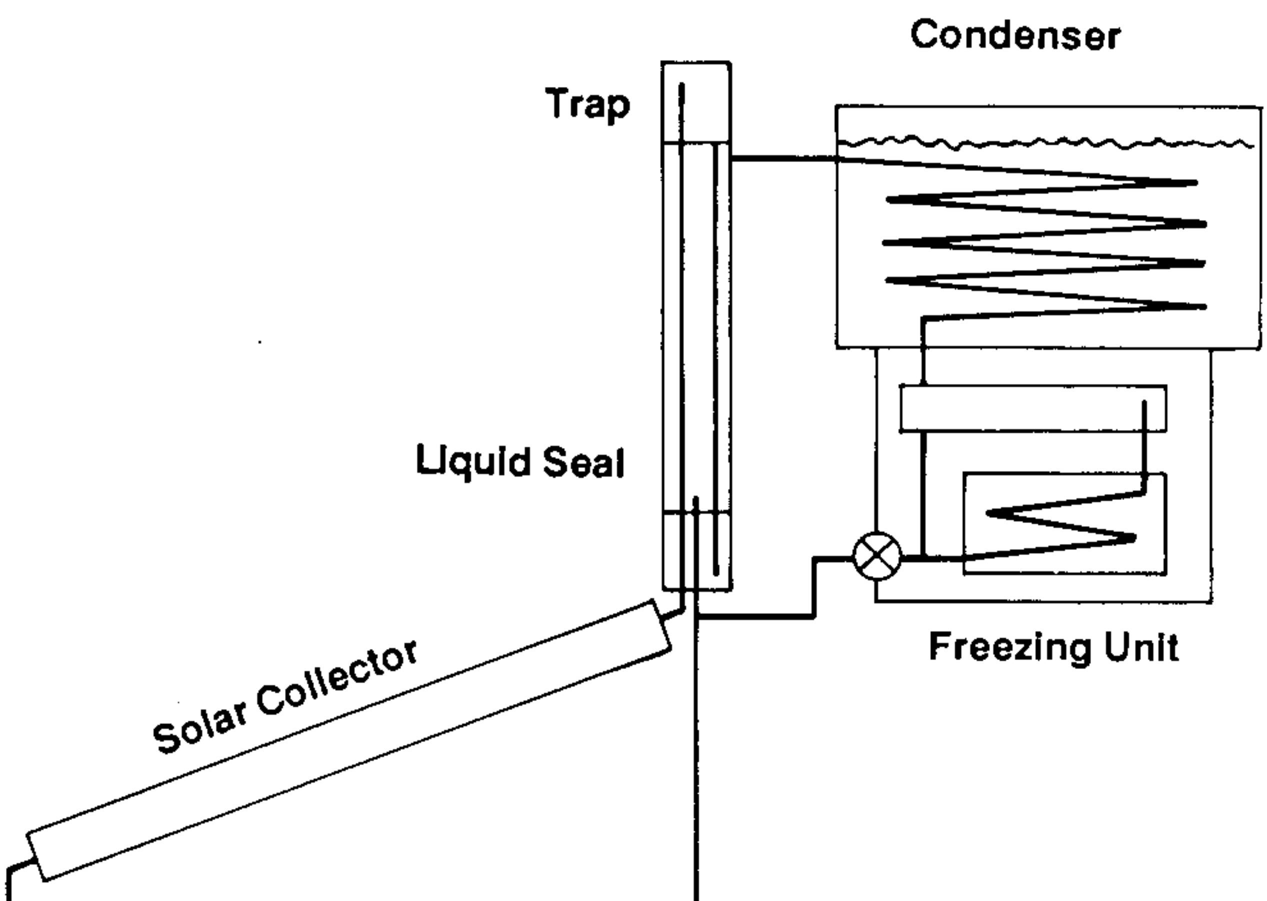


FIGURE 5.6 A solar-powered icemaker has also been tested in Thailand. During the day the sun's heat is used to produce liquid ammonia. At night the liquid ammonia is used to produce ice—about 40 kg in a 24-hour cycle.

A Solar Ammonia Absorption Icemaker

Jaroslav Vanek,
Mark "Moth" Green
Steven Vanek

Above: Steven Vanek with his machine which uses solar thermal energy to make ice.

Everywhere in our world, refrigeration is a major energy user. In poor areas, "off-grid" refrigeration is a critically important need. Both of these considerations point the way toward refrigeration using renewable energy, as part of a sustainable way of life. Solar-powered refrigeration is a real and exciting possibility.

Working with the S.T.E.V.E.N. Foundation (Solar Technology and Energy for Vital Economic Needs), we developed a simple ice making system using ammonia as a refrigerant. A prototype of this system is currently operating at SIFAT (Servants in Faith and Technology), a leadership and technology training center in Lineville, Alabama. An icemaker like this could be used to refrigerate vaccines, meat, dairy products, or vegetables. We hope this refrigeration system will be a cost-effective way to address the worldwide need for refrigeration. This icemaker uses free solar energy, few moving parts, and no batteries!

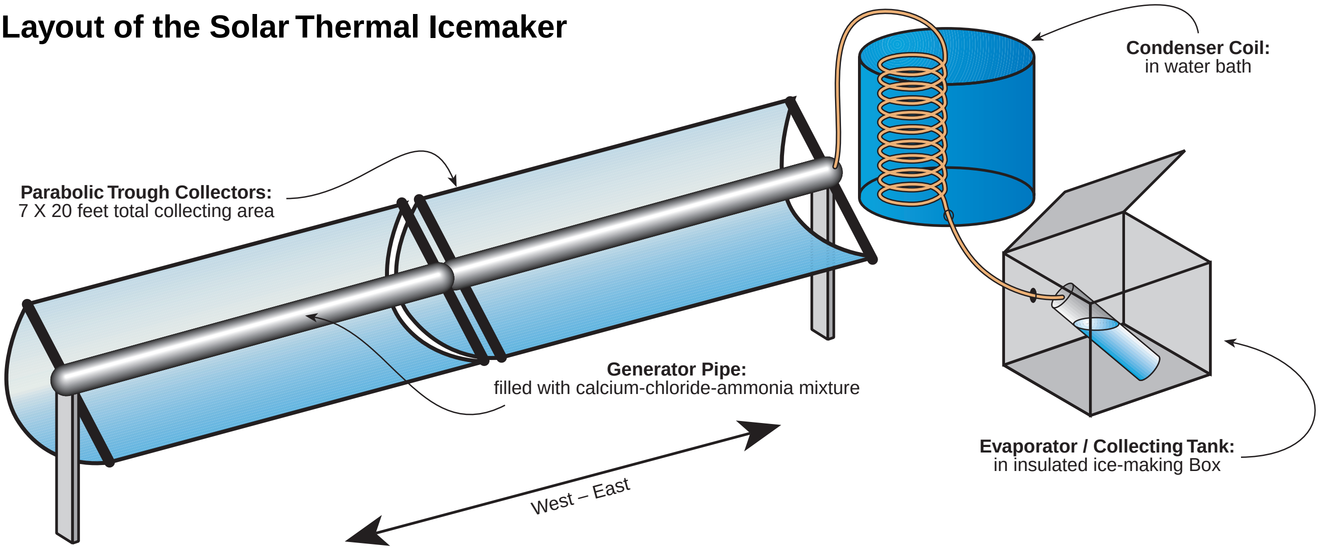
Types of Refrigeration

Refrigeration may seem complicated, but it can be reduced to a simple strategy: By some means, coax a refrigerant, a material that evaporates and boils at a low temperature, into a pure liquid state. Then, let's say you need some cold (thermodynamics would say you need to absorb some heat). Letting the refrigerant evaporate absorbs heat, just as your evaporating sweat absorbs body heat on a hot summer day. Since refrigerants boil at a low temperature, they continue to evaporate profusely — thus refrigerating — even when the milk or vaccines or whatever is already cool. That's all there is to it. The rest is details.

One of these details is how the liquid refrigerant is produced. Mechanically driven refrigerators, such as typical electric kitchen fridges, use a compressor to force the refrigerant freon into a liquid state.

Heat-driven refrigerators, like propane-fueled units and our icemaker, boil the refrigerant out of an absorbent material and condense the gaseous refrigerant to a liquid. This is called generation, and it's very similar to

Layout of the Solar Thermal Icemaker



the way grain alcohol is purified through distillation. After the generation process, the liquefied refrigerant evaporates as it is re-absorbed by an absorbent material. Absorbent materials are materials which have a strong chemical attraction for the refrigerant.

This process can be clarified using an analogy: it is like squeezing out a sponge (the absorbent material) soaked with the refrigerant. Instead of actually squeezing the sponge, heat is used. Then, when the sponge cools and becomes “thirsty” again, it reabsorbs the refrigerant in gas form. As it is absorbed, the refrigerant evaporates and absorbs heat: refrigeration!

In an ammonia absorption refrigerator, ammonia is the refrigerant. Continuously cycling ammonia refrigerators, such as commercial propane-fueled systems, generally use water as the absorbent, and provide continuous cooling action.

The S.T.E.V.E.N. Solar Icemaker

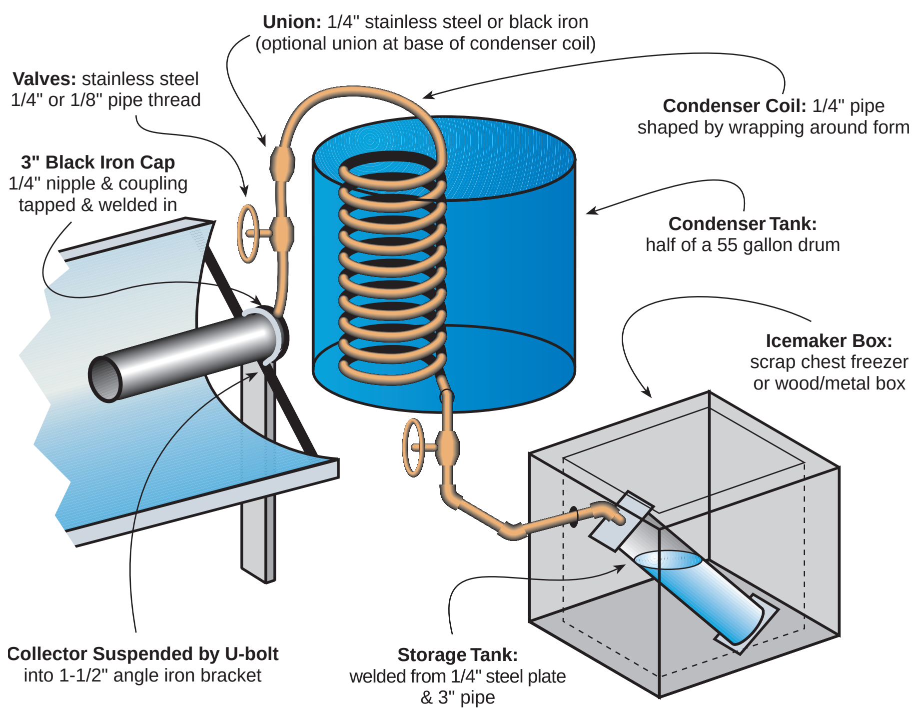
We call our current design an icemaker. It's not a true refrigerator because the refrigeration happens in intermittent cycles, which fit the cycle of available solar energy from day to night. Intermittent absorption systems can use a salt instead of water as the absorbent material. This has distinct advantages in that the salt doesn't evaporate with the water during heating, a problem encountered with water as the absorber.

Our intermittent absorption solar icemaker uses calcium chloride salt as the absorber and pure ammonia as the refrigerant. These materials are comparatively easy to obtain. Ammonia is available on order from gas suppliers and calcium chloride can be bought in the winter as an ice melter.

The plumbing of the icemaker can be divided into three parts: a generator for heating the salt-ammonia mixture, a condenser coil, and an evaporator, where distilled ammonia collects during generation. Ammonia flows back and forth between the generator and evaporator.

Plumbing Detail

All plumbing is ungalvanized steel (black iron) unless indicated



Above: Detail of the condenser bath, containing the condenser coil, and the icemaker box below.

The generator is a three-inch non-galvanized steel pipe positioned at the focus of a parabolic trough collector. The generator is oriented east-west, so that only seasonal and not daily tracking of the collector is required. During construction, calcium chloride is placed in the generator, which is then capped closed. Pure (anhydrous) ammonia obtained in a pressurized tank is allowed to evaporate through a valve into the generator and is absorbed by the salt molecules, forming a calcium chloride-ammonia solution ($CaCl_2$ - $8NH_3$).

The generator is connected to a condenser made from a coiled 21 foot length of non-galvanized, quarter-inch pipe (rated at 2000 psi). The coil is immersed in a water bath for cooling. The condenser pipe descends to the evaporator/collecting tank, situated in an insulated box where ice is produced.

Operation

The icemaker operates in a day/night cycle, generating distilled ammonia during the daytime and reabsorbing it at night. Ammonia boils out of the generator as a hot gas at about 200 psi pressure. The gas condenses in the condenser coil and drips down into the storage tank where, ideally, 3/4 of the absorbed ammonia collects by the end of the day (at 250 degrees Fahrenheit, six of the eight ammonia molecules bound to each salt molecule are available).

As the generator cools, the night cycle begins. The calcium chloride reabsorbs ammonia gas, pulling it back through the condenser coil as it evaporates out of the tank in the insulated box. The evaporation of the ammonia removes large quantities of heat from the collector tank and the water surrounding it. How much heat a given refrigerant will absorb depends on its “heat of vaporization,” — the amount of energy required to evaporate a certain amount of that refrigerant. Few materials come close to the heat of vaporization of water. We lucky humans get to use water as our evaporative refrigerant in sweat. Ammonia comes close with a heat of vaporization 3/5 that of water.

Above: About ten pounds of ice are created in one cycle of ammonia evaporation / condensation.

During the night cycle, all of the liquefied ammonia evaporates from the tank. Water in bags around the tank turns to ice. In the morning the ice is removed and replaced with new water for the next cycle. The ice harvesting and water replacement are the only tasks of the operator. The ice can either be sold as a commercial product, or used in a cooler or old-style ice-box refrigerator.

Under good sun, the collector gathers enough energy to complete a generating cycle in far less than a day, about three hours. This allows the icemaker to work well on hazy or partly cloudy days. Once generating has finished, the collector can be covered from the sun. The generator will cool enough to induce the night cycle and start the ice making process during the day.

Solar Ice Maker: Materials and Costs

Quan	Material	Cost
4	Sheets galvanized metal, 26 ga.	$100
1	3" Black Iron Pipe, 21' length	$75
120	Sq. Ft. Mirror Plastic @$0.50/sq. ft.	$60
2	1/4" Stainless Steel Valves	$50
	Evaporator/Tank (4" pipe)	$40
	Freezer Box (free if scavenged)	$40
1	Sheet 3/4" plywood	$20
6	2x4s, 10 ft long	$20
	Miscellaneous 1/4" plumbing	$20
2	3" caps	$15
1	1/4" Black Iron Pipe, 21' length	$15
4	78" long 1.5" angle iron supports	$15
	Other hardware	$15
15	Lbs. Ammonia @ $1/lb	$15
10	Lbs. Calcium Chloride @ $1/lb	$10
	Total	$510

Future Design
A refrigerator, which is able to absorb heat at any time from its contents, is more convenient than our current intermittent icemaker. To enable constant operation, a future design will include several generator pipes in staggered operation as well as a reservoir for distilled ammonia. Staggered operation will allow the refrigerator to always have one or more of the generators "thirsty" and ready to absorb ammonia, even during the day when generation is simultaneously happening. Generation will constantly replenish the supply of ammonia in the storage reservoir. We are currently in the first stages of making these modifications to the icemaker.

Caution: Safety First!
Working with pure ammonia can be dangerous if safety precautions are not taken. Pure ammonia is poisonous if inhaled in high enough concentrations, causing burning eyes, nose, and throat, blindness, and worse. Since water combines readily with ammonia, a supply of water (garden hose or other) should always be on hand in the event of a large leak. Our current unit is a prototype. We will not place it inside a dwelling until certain of its safety. Unlike some poisonous gases, ammonia has the advantage that the tiniest amount is readily detectable by its strong odor. It doesn't sneak up on you!

For the longevity of the system, materials in contact with ammonia in the icemaker must resist corrosion. Our unit is built with non-galvanized steel plumbing and stainless steel valves, since these two metals are not corroded by ammonia. In addition, during operation the pressure in the system can go over 200 psi. All the plumbing must be able to withstand these pressures without leaks or ruptures.

Would-be solar icemaker builders are cautioned to seek technical assistance when experimenting with ammonia absorption systems.

Conclusion
The S.T.E.V.E.N. icemaker has both advantages and disadvantages. On the down side, it's somewhat bulky and non-portable, and requires some special plumbing parts. It requires a poisonous gas, albeit one which is eco- and ozone- friendly in low concentrations, so precautions must be taken. In its favor, it has few moving parts to wear out and is simple to operate. It takes advantage of the natural day/night cycle of solar energy, and eliminates the need for batteries, storing "solar cold" in the form of ice.

Access
Authors: c/o S.T.E.V.E.N. Foundation, 414 Triphammer Rd. Ithaca, NY 14850

SIFAT, Route 1, Box D-14 Lineville, AL 36266

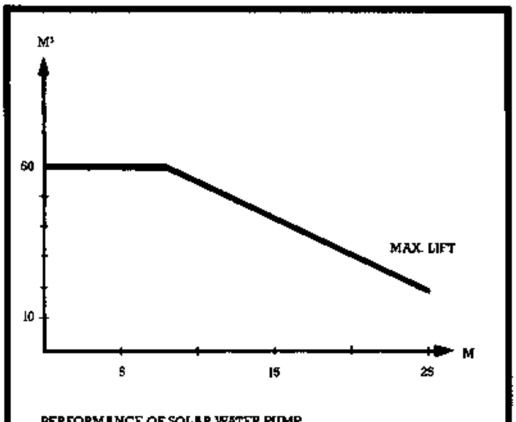
THE AQUILIA SOLAR WATER PUMP

The Aquilia Solar Water Pump is a unique, simple way of utilizing solar energy for pumping water.

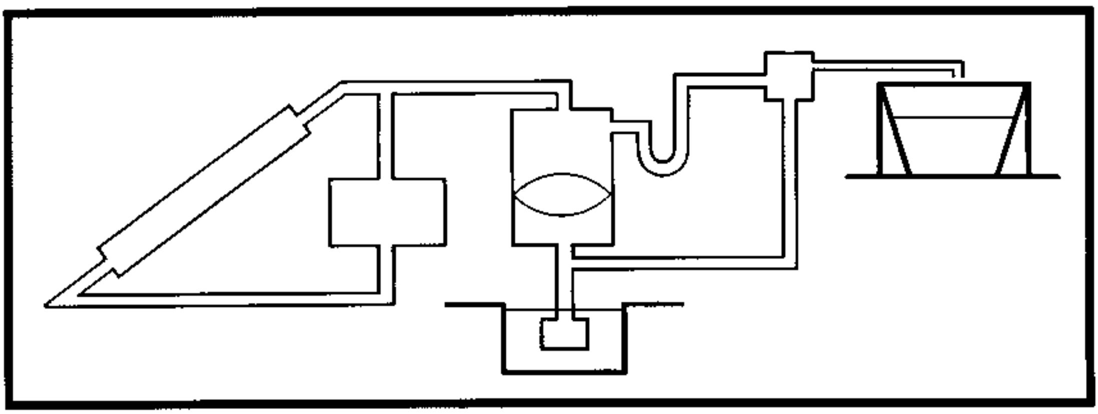
The system is self-contained and works independently of outside energy sources. All circuitry is enclosed within the system and requires no adjustment. The pump is highly reliable, requires little maintenance and has a long liftime.

The Solar Water Pump combines suction and pressure to raise the water, which gives a maximum static head of 25 metres.

The Aquilia Solar Water Pump with a solar collector area of 16 m² fulfills the World Bank specifications for Category B and C, which are as follows:
Category B - 60 m³/day at a static head of 7m
Category C - 20 m³/day at a static head of 20m with an irradiation of 5.5kWh/day



PERFORMANCE OF SOLAR WATER PUMP WITH 20 m² SOLAR PANEL



The system is filled with water only. During sunshine hours the water in the solar panels will be heated and steam will be generated. The steam forces the float in the pump house down. This pressure causes the foot valve in the well to close. The water from the pump house is forced upwards and runs through the condenser into the water tank.

When the steam level in the pump house reaches the bottom level of the steam tube, the steam escapes to the condenser because of the difference in pressure. The steam immediately condenses, and a partial vacuum is created in the pump house, which opens the foot valve and water is sucked up from the well refilling the pump house.

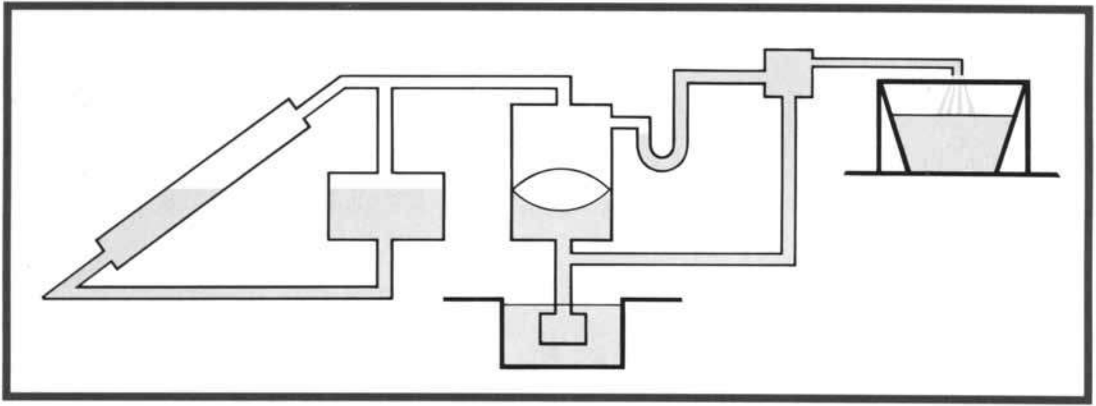
The equipment is manufactured to metric standards, any measurements other than metric are approximate and for comparison only. The company reserves the right to change the technical specification without prior notice.

TECHNICAL SPECIFICATIONS

Energy supply	The sun
Key components	8 solar collectors, water reservoir for solar collectors, pump house, steam control valve, stand

SØBY SUNICE A/S

Sortevej 30
Postbox 49
DK-8543 Hornslet
Tel. +45 86 99 44 33
Fax. +45 86 99 41 70
Telex 60 371 soeby dk



39: **Soft Tech. Baldwin,Brand [eds.]. Co-Evolution-Point/Penguin. USA 1978 0-14-00-48065.**

Inexpensive Evaporative Coolers for Short Term Storage of Fruits and Vegetables
Bill Hutchinson and Roger Chuang
1976; 107 pp. (Xeroxed especially for CQ readers)

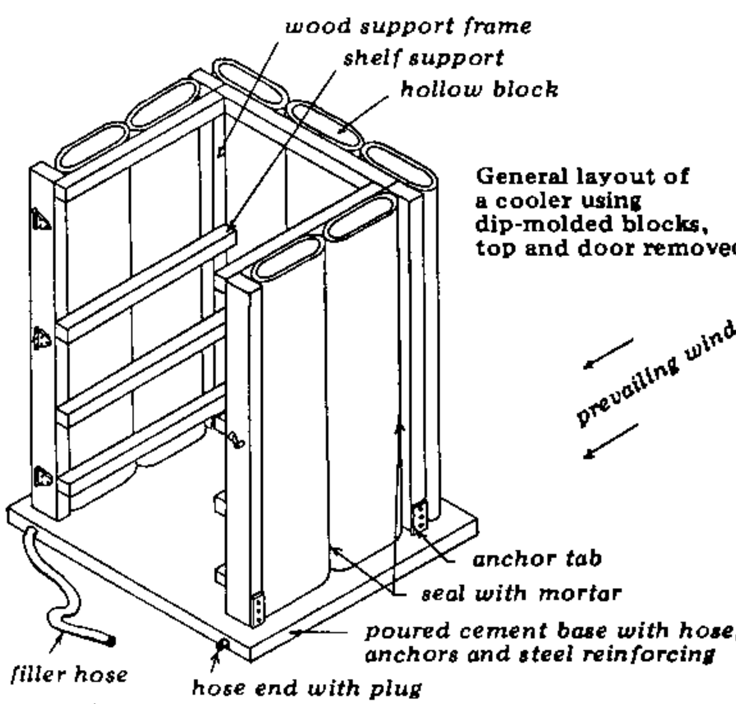
$8.50 postpaid
from:
Bill Hutchinson
1004 Ruby
Arlington, TX 76010

The Dip-Molding Process for Block Manufacture

The procedure for making a block is straightforward. A wooden frame is made to support the block. The frame is smeared with grease, kerosene or used motor oil to prevent the block from sticking to the frame. Next, strips of wet burlap or a similar coarse cloth material are dipped into a watery mixture of wet cement and molded around the frame to the desired shape and thickness. Seams and irregularities are sealed by smoothing over with cement.

The molded block is then allowed to harden for several days. The block should be covered with large pieces of wet cloth or burlap. This will prevent cracking of the outer surface caused by rapid drying of the cement. After the block has set up, the frame is then knocked apart and the block is ready for use. The frame can be re-used.

The most promising block material was found to be Type I (general purpose) Portland cement.



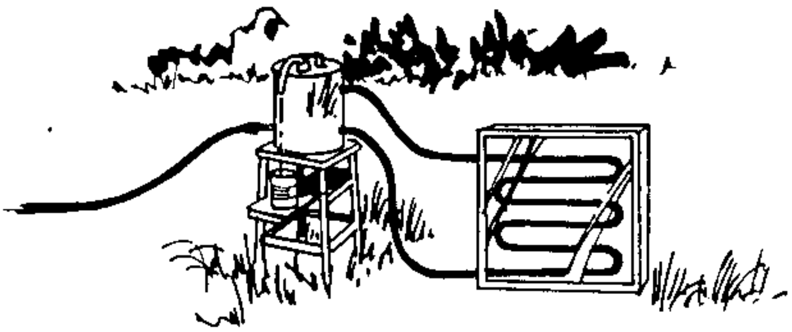
General layout of a cooler using dip-molded blocks, top and door removed

•

New Village Level Industries

The dip-molding process allows individuals to make their own blocks and coolers. More importantly, it enables unskilled people with little capital to start their own block and/or cooler manufacturing business.

In addition, the process can be used to make pipe. Pipe can be formed by wrapping burlap dipped in cement around a lubricated mandrel with a slight relief angle. If the relief angle and length of pipe are sufficient, the small end of one pipe can be fitted into the large end of another to act like a ball and socket joint.



HOW TO BUILD—AND USE!—A SOLAR WATER HEATER

MATERIALS

- 1-by-4-inch redwood board (eight linear feet)
- 1/2-inch plywood (one piece 24 by 24 inches)
- Single-weight window glass (one piece, cut to measure)
- 3/8-inch O.D. copper tubing (approximately 16 feet)
- Sheet copper (22 by 22 inches)
- 1/2-inch copper tubing (three inches)
- 1/2-inch valve (one)
- 3/4-inch female hose fitting (one)
- 5-gallon can (one)
- 3/8-inch I.D. plastic tubing (10 feet)
- 1/4-by-1½-inch wood screws (approximately 30)
- Flat black paint (one pint)

To risk a pun, the sun really shines when it comes to heating . . . either air or water. Conversion of solar rays into heat can be done with an efficiency as high as 50 percent, as compared with the 11 percent efficiency of the solar battery. There are thousands of solar water heaters now in operation, and we may expect widespread use of the sun as space heater and water heater in the future.

The water heater described in this chapter is not intended for domestic use, but primarily to demonstrate the principle of heat transfer and its use in this application. However, the five-gallon tank would make a good supply of the heated liquid for camping trips or for a cabin that has no provision for hot water. If desired, an enlarged version of the heater could be installed on a roof, connected to a water supply and used as a permanent source of hot water.

We'll begin our heater with the collector box itself. Make its sides from 1-by-4 material. Redwood, while desirable, is not absolutely necessary since there will be no dripping or condensing of water which might rot the wood.

At the lumberyard where you buy the 8-foot-long board (1 by 4 inches), have a 1/8-inch-wide groove cut in the plank to a

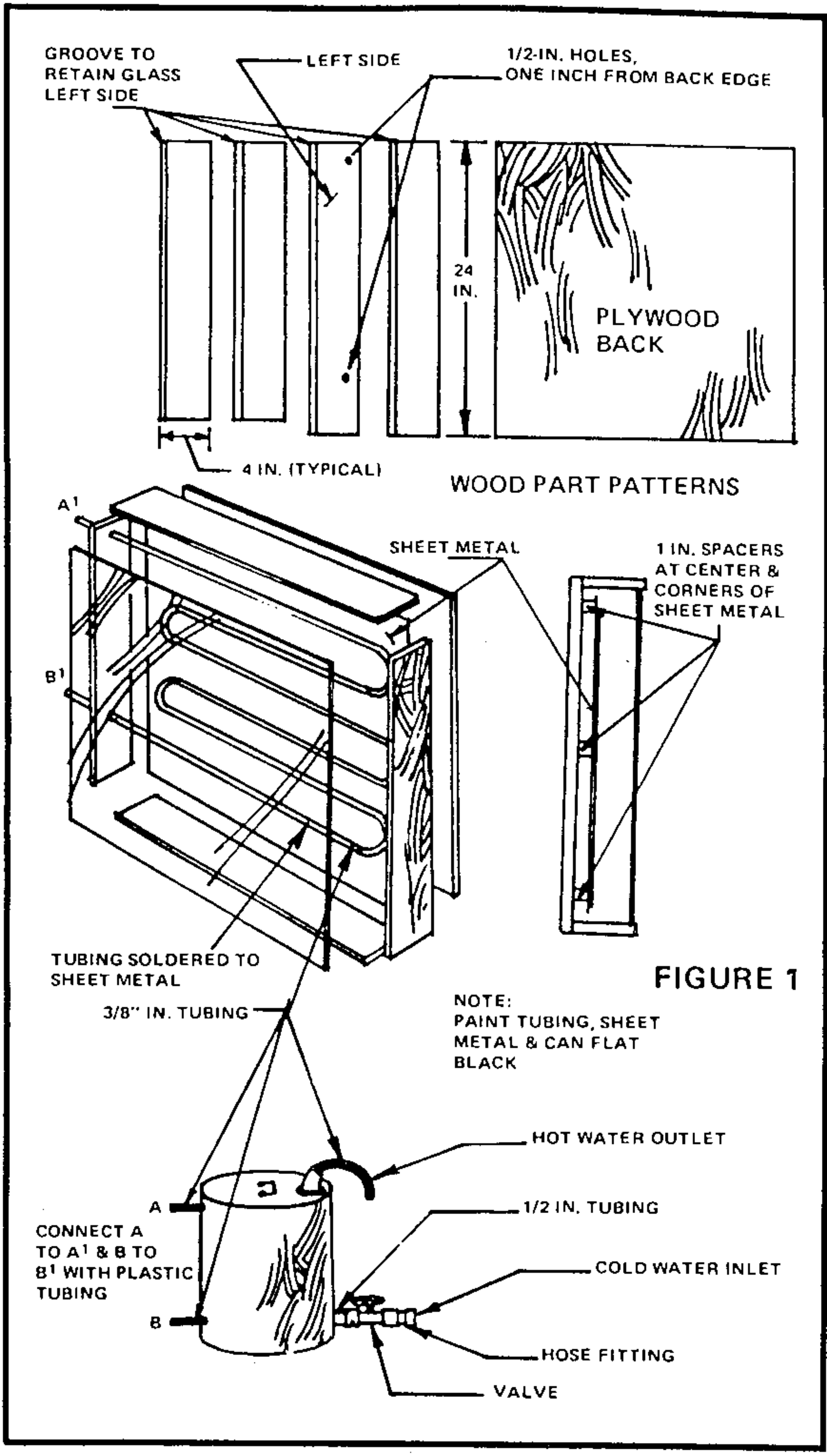


FIGURE 1: General plans for fabrication of solar water heater.

depth of 3/8 inch. Locate the cut 1/2 inch from one edge. This is the slot for the glass window.

The next step is to cut the board into four pieces, two 24 inches long and two approximately 22-1/2 inches long . . . being sure to keep the ends square both ways. The glass, of course, should fit snugly.

Next cut out a square of plywood 24 inches on a side and place the 1-by-4 pieces on it to make sure they fit. Assemble the sidepieces to the back with wood screws.

Take the box apart at this point and clean chips and shavings from the holes. Drill two 1/2-inch holes in one of the sidepieces as shown in Fig. 1 (one inch "up" from the back). These holes accommodate the copper tube coil which will carry water from the tank to the collector and back again. Now cement aluminum foil to the inside surface of the plywood base. This reflective material serves to bounce back radiated heat so that it will not be wasted.

Next, five small spacer blocks (1-inch cubes) are nailed into place as shown on the drawing. These blocks are the same thickness as the distance from the edge of the 1-by-4 piece to the 1/2-inch holes, and thus serve to hold the coil the proper distance from the plywood base. Small finishing nails will be fine for attaching the spacers, but it's best to drill a hole through each block first to prevent splitting the wood.

With the box itself completed, we can begin work on the copper coil and the collector plate. These are important parts of the heater, since they transfer the intercepted heat from the sun to the water inside the tubing of the coil. Copper is used because it's a very good conductor and will quickly carry heat to the water. Copper is quite expensive, however, and you may want to substitute galvanized iron for the plate to hold down cost somewhat.

If you use a copper sheet, have it cut to exact size. It's sold by weight, and there's no need to pay for scrap. Notice that the size specified allows 1/4-inch clearance all around the inside of the box. Before working with the copper sheet, trim a small piece from each corner at a 45-degree angle to prevent the possibility of being scratched or cut by the sharp edges.

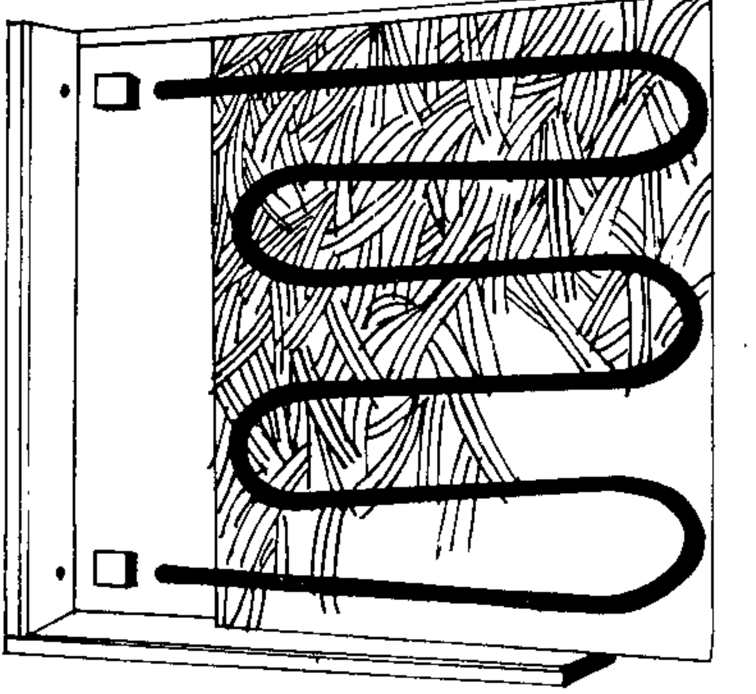
We will bend the heating coil from 3/8-inch copper tubing, the flexible kind that comes in a roll. The length called for in the list of materials allows for trimming. First of all, straighten out the tubing and make it as flat and true as you can. It's quite soft, and a little time spent should result in a smooth job. Now lay the tube across the flat sheet of copper, with a foot or so extending beyond the edge. Mark the start of the first bend in the tubing with a pencil and then carefully form it with your fingers into the U-shape shown. Work slowly and evenly so that you will not flatten the tube excessively.

After the first bend is made, replace the tubing on the sheet and make sure the bend is in the proper position and that sufficient tubing extends past the edge of the sheet. Mark the second bend and proceed as before. Continue to form the coil in this manner until the sheet is covered in a series of S-turns as shown.

Trim the long end of the tubing, check the shape of the coil once more and then lay it on a flat surface to see that it is level. Spend as much time as required to make the tubing lie perfectly flat, using your fingers and tapping it lightly with a rubber or wooden mallet for the finishing touches. The tubing must touch the sheet along its full length for the best heat transfer.

When you're completely satisfied with the job, the copper coil may be soldered to the sheet. Clean the tube and the sheet with emery cloth so that the solder will stick properly. Lay the

FIGURE 2



This drawing shows the partially assembled solar water heater.

sheet on a wooden surface (the inverted collector box itself will do nicely) and place the coil in position. Remember that the ends of the tubing must fit through the holes drilled in the 1-by-4. Now lay a board over the coil, and weight it to keep the tubing in place. You're ready for the soldering operation.

A small torch is handiest for this purpose, but a soldering iron will do the job too. If you aren't equipped for such work, have it done at a sheet metal shop. Solder as shown in Fig. 1 (about every six inches). Be sure to hold the tubing flat on the sheet. Heat will cause the copper to warp slightly, but it will return to its flat position upon cooling.

With the job complete, clean any excess soldering paste from the copper and paint the entire assembly with flat black paint. Apply a second coat of paint for good measure and set the copper plate and tubing aside until they're completely dry.

The coil assembly may now be slipped into the box, with the ends of the tubing carefully inserted through the 1/2-inch holes (see Fig. 2). Tack the copper sheet to the spacer blocks when you're sure it fits properly and will not have to be removed.

Unscrew the top 1-by-4 piece of wood. Slide a heavy piece of cardboard into the grooves. Trim to fit and have your supplier cut a pane of glass to this measure. Fit the glass into the slots and replace the top piece. The collector is now complete and we can begin work on the water tank.

A round, five-gallon can with a narrow, screw-top spout is used for the storage of heated water. The one here was a discarded oil container obtained from a local distributor.

Other types of containers are suitable and may be substituted if the round type shown is not available. For example, a square, lightweight can will fill the bill. This type is usually on sale at hardware and surplus stores.

Clean the can of any residue of oil or other liquid. This is done for two reasons. First, we don't want the water contaminated and, second, heat from soldering operations might set fire to the liquid. So do the cleaning carefully, and flush the container with water several times before you do any work on it.

Two short lengths of 3/8-inch copper tubing are soldered to the can. Location and correct dimensions are shown in Fig. 1. First drill a 1/4-inch hole each place a tube is to be installed. Next drive a center punch or other tapered piece of material into the opening. This enlarges the hole and also forces the metal inward. Check frequently during this flaring process to insure a snug fit of tubing. The depression formed in this way will hold more solder and make a stronger joint.

If a painted can is used it will be necessary to scrape the areas where soldering is to be done. When the metal is clean and bright, insert the tubing (which has been cleaned too). Using a torch or soldering iron, let solder flow into the depression and around the tube. This operation is easier if the can is positioned with the tube pointing straight up.

The hot-water outlet is also a length of 3/8-inch tubing, soldered to the screwed-on cap of the can. Use the "flaring" method again so that a strong joint will result. Notice that the tube is bent into a U-shape.

We are now ready to do the plumbing for the cold-water supply line. Instead of a 3/8-inch tube, use 1/2-inch tubing for this connection. Attach a simple shut-off valve to the tube, using compression-type fittings that come with the valve. Your dealer will explain how these fittings are installed. Another short length of 1/2-inch tubing extends from the valve. The free end of this tubing is soldered inside a brass garden-hose fitting of the type used with a plastic hose.

With the soldered joint made and the compression fittings tightened securely, you can connect the tank to the end of the garden hose and check for leaks. Turn on the water at the faucet, open the valve at the tank and cork the tubes that will lead to the collector. When the tank is full, water will overflow from the hot-water supply outlet. Mark any leaks, drain the tank and repair as necessary. The reservoir is now ready to be attached to the collector coil.

Our heater would be of little use if only the water in the coil itself became hot . . . this would barely be enough to wash one's hands! Fortunately there's a phenomenon called thermosyphoning which we shall make use of to heat the whole tank of our hot-water system.

If we made a very large collector, the coils would hold ample hot water. Another method would be to install a pump to circulate water between coils and tank. This would cost more money and also make our heater more complicated. Thermosyphoning is the ability of water to circulate of its own accord when heated . . . given certain conditions. For our purposes, the most important of these conditions is that the supply tank be located *above* the coil.

Fig. 3 shows the tank mounted on a wooden stand, with the bottom of the tank about on a level with the top of the collector. As the coil heats water inside it, this water rises and is replaced by cooler water drawn from the bottom of the reservoir.

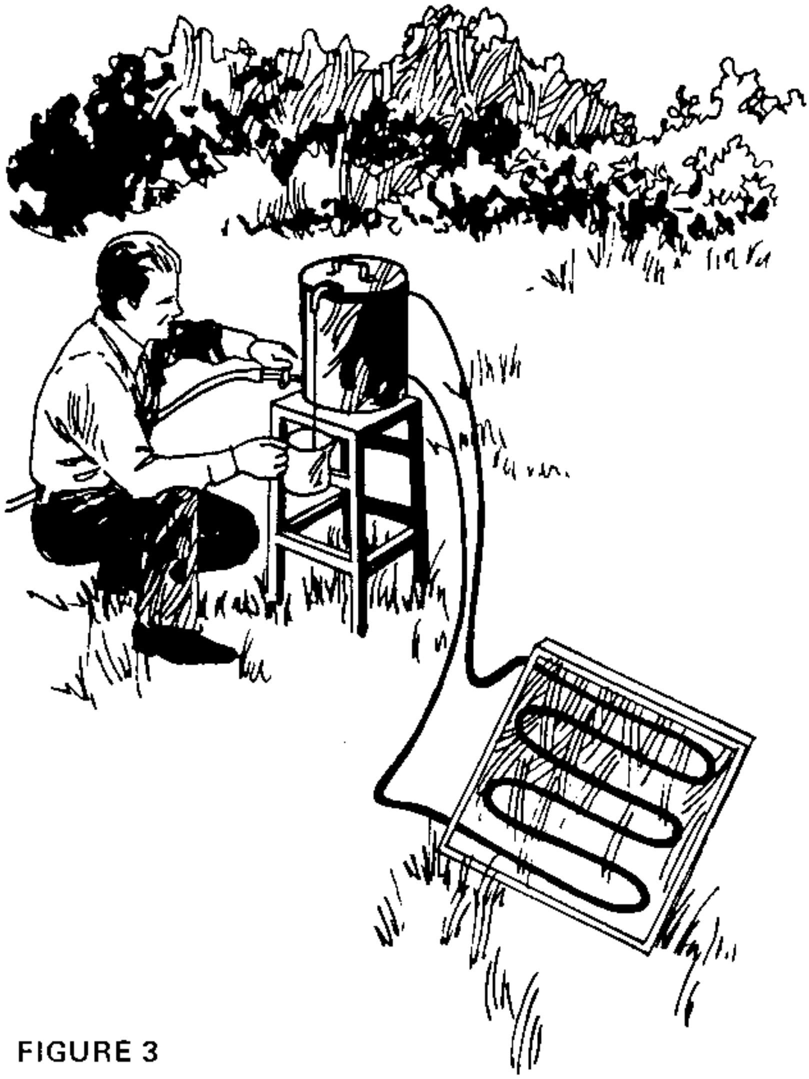


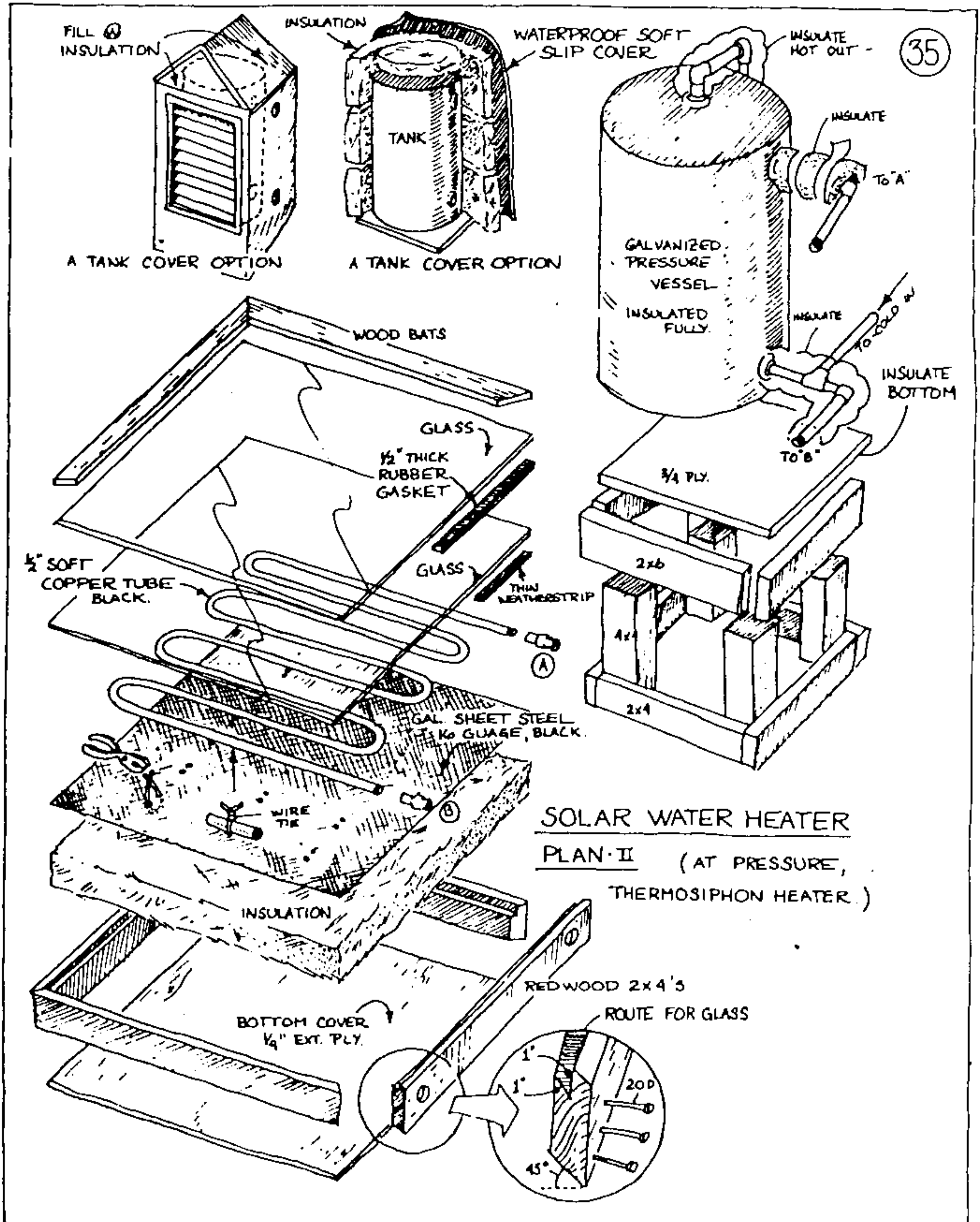
FIGURE 3

The author draws a cup of hot water from his solar water heater.

Set up the collector facing the sun (using a hinged prop on the back of the box) and place the tank on its stand to one side. Install the plastic hose between the two bottom tubes, using hose clamps for a watertight connection. Clamp one end of the second plastic hose to the upper tube of the collector, but leave the other end free.

Fill the tank. When water flows from the open plastic hose, hold it with your finger until water also flows from the top circulation tube of the tank. Then quickly slide the hose onto the tube and clamp it. This prevents air bubbles from being trapped in the lines. When the hot-water outlet overflows, close the tank valve.

Operation of the heater is simple. You will notice that the upper hose quickly gets hot, while the lower one stays relatively cool. Water is circulating now, and eventually all of it will be warmed by the coils. To draw hot water, open the valve at the bottom of the storage tank. Cold water comes in and forces hot water out the top.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FILL W/ INSULATION
INSULATION
WATERPROOF SOFT SLIP COVER
INSULATE HOT OUT
TANK
A TANK COVER OPTION
A TANK COVER OPTION
INSULATE
TO "A"
GALVANIZED PRESSURE VESSEL
INSULATED FULLY.
INSULATE
TO COLD IN
INSULATE BOTTOM
TO "B"
WOOD BATS
GLASS
1/2" THICK RUBBER GASKET
3/4 PLY.
2x6
GLASS
THIN WEATHERSTRIP
1/2" SOFT COPPER TUBE BLACK.
4x4
A
2x4
GAL. SHEET STEEL
GAL. SHEET STEEL 16 GUAGE, BLACK.
B
WIRE TIE
SOLAR WATER HEATER
PLAN · II (AT PRESSURE, THERMOSIPHON HEATER)
INSULATION
REDWOOD 2x4'S
ROUTE FOR GLASS
BOTTOM COVER 1/4" EXT. PLY.
1"
1"
20D
45°

Thermosyphon Heat Exchanger

Willson Bloch

Prior to the advent of thermosyphoning heat exchangers, designers had two choices when installing a closed-loop solar hot water system. One: they could use a storage tank with an internal or jacketed heat exchanger, or two: they could use an external tube-in-shell heat exchanger with a pump.

Internal Heat Exchanger

Solution one seemed like the best way, but it posed two problems. Heat exchanger equipped tanks were very expensive and when tank replacement became necessary, the heat exchanger went too. Secondly, because of its internal location, it was impossible to descale the mineral buildup from the heat exchanger. This rendered it less and less effective as the mineral coating grew thicker and thicker while often accelerating the deterioration of the tank itself.

External Tube-in-shell

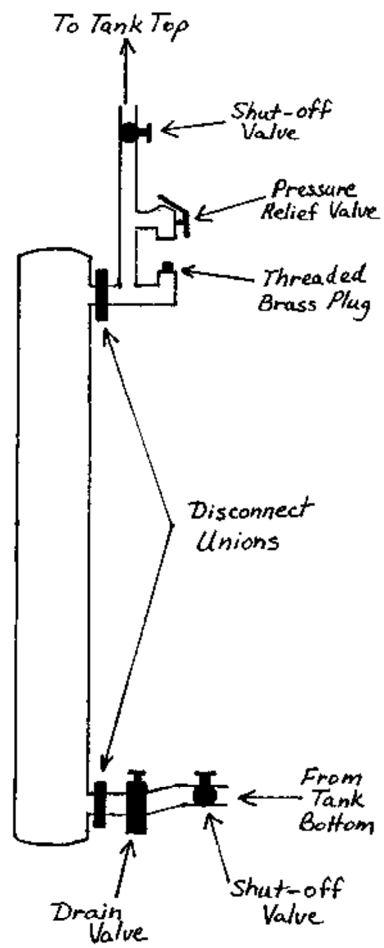
Solution two was an external tube-in-shell heat exchanger with applied pump to extract the heat from the solar fluid to return it to the storage tank. This solved both problems of the internal heat exchanger but only by adding a pump with its parasitic electrical consumption. Also, the pumped heat exchanger didn't work very efficiently because the pump always pumped at the same speed regardless of the available solar radiation and corresponding solar fluid temperature.

Thermosyphon

In 1984, Noranda Corporation released the first thermosyphoning, external heat exchanger. The design was good, but the materials used in its construction were below standard despite the International Association of Plumbing and Mechanical Officials, (IAPMO), stamp of approval. Note: Drain, waste, and vent pipe, (DWV), and test caps were approved for use in household, (150 psi), situations. Also, the set of installation instructions that were included with the heat exchanger showed that Noranda hadn't really researched their product well.

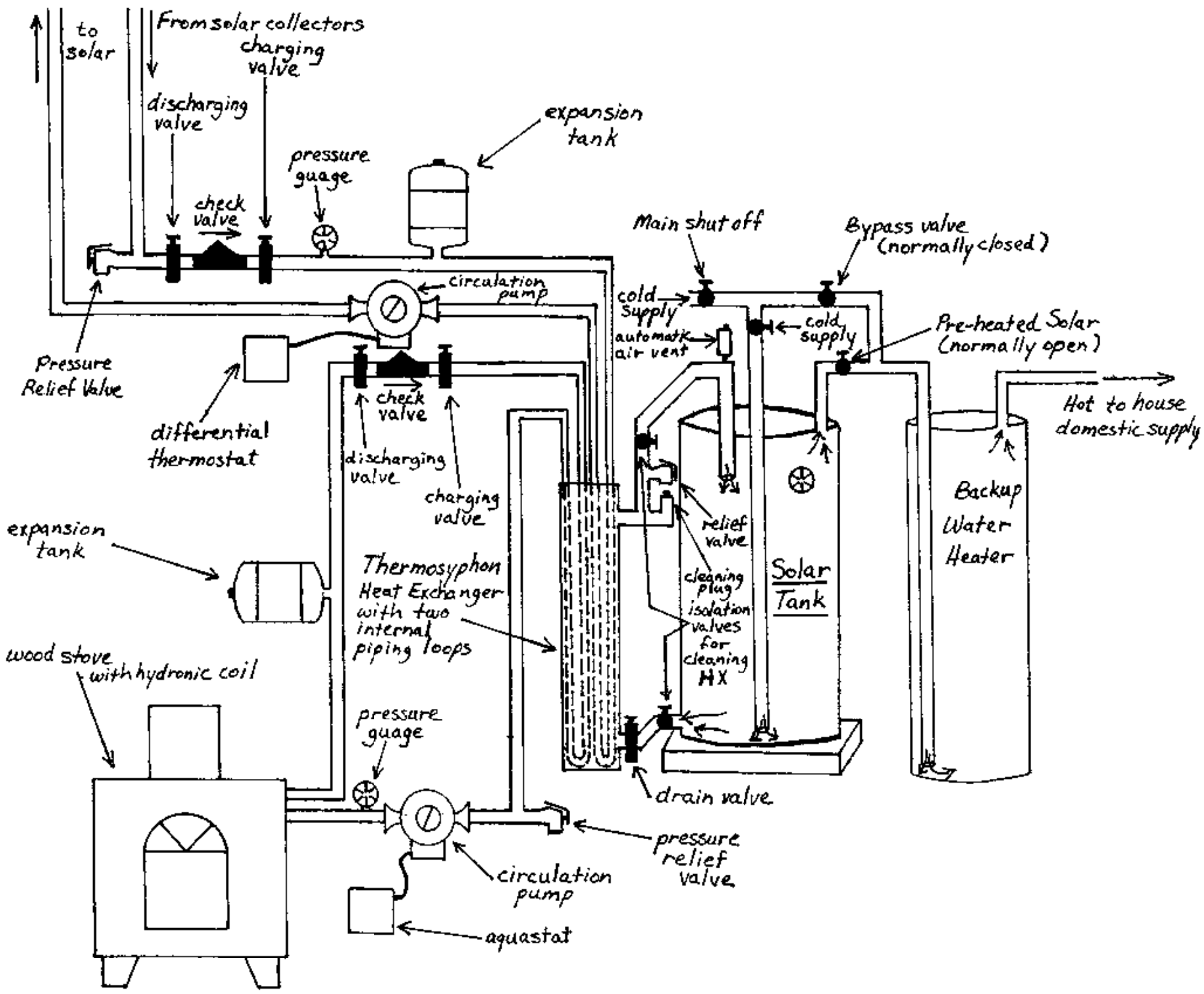
I purchased several of the Noranda exchangers and through experimentation, discovered the method of installation that produced optimum results. I especially liked the way the exchanger heated the storage tank from the top down rather than gradually bringing the whole tank up to maximum solar temperature by the day's end. The thermosyphoning method meant that hot water would be available to the user much earlier in the day. Days of marginal solar radiation would produce some useable hot water in the upper portion of the tank rather than the whole tank being lukewarm. Also, the thermosyphoning action works proportionally with the amount of available solar radiation.

With its vertical mounting position alongside the storage tank, cleaning the exchanger is a breeze when installed with two shut off valves, a boiler drain, and fill plug. A simple 30 minute task can clean off mineral build up and return the exchanger to like-new condition. This means that a properly built thermosyphon heat exchanger will last a lifetime with only miniscule care.



Homebrew

Noranda never did upgrade their thermosyphoning heat exchanger and when the solar tax credits died, they got completely out of the heat exchanger business. Another company in Florida came out with another type of thermosyphoning external heat exchanger that served as an elevating pad for the tank, but its accessibility to



cleaning didn't please me. I decided at that time to build an exchanger similar to the Noranda design but with improvements in size, efficiency, and especially in pressure-durability. It is now commercially available, and some typical installation diagrams as well as cleaning procedures follow:

Cleaning the Heat Exchanger (HX)

1. Close, (clockwise), the upper and lower shutoff valves.
2. Open drain valve at bottom and remove threaded brass plug at top to drain the water from the HX.
3. Close drain valve and fill the HX with one gallon of white vinegar. Top off with water so that HX is completely filled.
4. Reinstall the brass plug.
5. Turn on the solar system so that the solar fluid heats up the HX till it is hot to the touch, then turn the solar system off and let the HX sit for 20 to 25 minutes, (longer if the HX is really scaled-up).
6. Open the drain valve and remove the brass plug to drain out the vinegar and water solution, and then replace the brass plug.
7. Leave the drain valve open and open the upper shut-off valve to flush out any remaining vinegar and water solution, then close the drain valve.
8. Open the lower shut-off valve and you are finished. You might double-check that both shut-off valves are open to be sure that the HX can begin thermosyphoning otherwise your pressure relief valve will blow off.

Access

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Solar Hot Water

Tom Lane

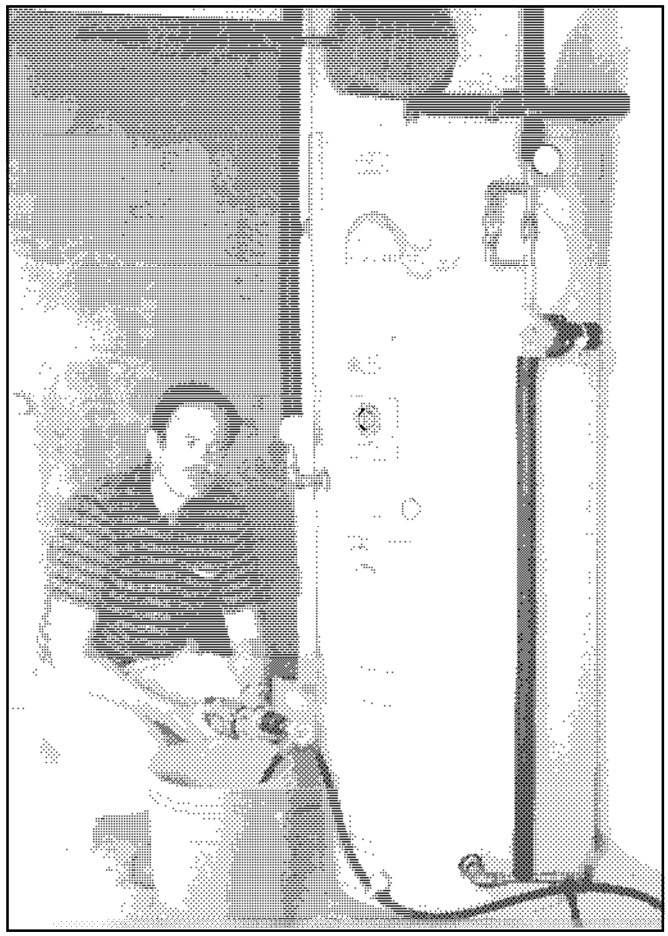
An interesting aspect of the solar industry has always been that there is little crossover between solar thermal (hot water and pool contractors) and solar electric contractors. Most solar thermal contractors have hardly any experience in photovoltaics. Conversely, solar electric contractors who are on top of "what works" in photovoltaics do not seem to have a clue about what is a value in a solar hot water system.

Why Me?
Presently I am heating water for my family of six using a 120 gallon closed loop solar tank with two 4 x 10 black chrome U.S. Solar collectors. Using a Solarex SX-20 PV module as the controller and power to run a 12 Volt March 809 DC pump for circulating the solar loop is my personal preference for this system. I like its inherent simplicity and immunity from scaling and freeze damage and low cost per square foot of collector area.

Our company, a local contracting company in Gainesville, Florida since 1977, has installed and is maintaining over 2,000 solar hot water systems in Northern Florida. I have worked in the '70s and '80s training people throughout the U.S. in installing solar hot water systems for several manufacturers.

Why You?
Solar hot water systems can be an excellent investment. However, you owe it to yourself to make sure you are getting a good investment. Your system shoud be more than just a gimmick "token" solar system that heats a little water, makes you feel "environmentally correct" but really gives no real return on your investment.

Solar hot water heating for showers, dishwashing, and laundry will cost about $110 per person if LP gas costs $1.15 a gallon, or if electricity costs $.07 a kilowatt hour. At $.10 a KWH, it costs $646 a year to heat water for four "average" people. A solar hot water system with a 120 gallon tank and 64 to 96 square feet of collector area will typically save about $500 to $600 out of the $646. Don't forget that all savings are in nontaxable income which would be equivalent to $600 to $750 that you earned and pay taxes on to the IRS to support John Sununu's and Dan Quayle's golf and ski trips. If you are heating hot water for two people or more and you are not hooked to natural gas pipelines, then you need to examine solar hot water as an investment AND LOOK FOR VALUE — total BTUs delivered into storage.



Above: Tom Lane at work on one of the 2,000 solar DHW systems he has installed in Florida.

Design Choice
There are basically two types of solar hot water systems. Open loop systems, in which the same water for your showers, etc., goes through the thermal collectors and a

closed loop system. These typically uses a glycol antifreeze or a drain back reservoir and an external heat exchanger or a heat exchanger built into the tank. The main criterion for these systems is how hard the freezing weather is where you live.

Open loop systems should be used where you get no freezes. If your local area can grow mangoes, avocados, or citrus groves without danger of being damaged by a mild freeze, then you are in an area that can directly circulate water through the collectors. If not, use a closed loop system or one day you will have a visit from Mr. Murphy. Since 95% of the U.S.'s population, including Central Florida and most of Southern California and Arizona are in areas where freezing conditions occur, I will discuss my experience with closed loop systems and solar hot water as an investment.

System Sizing

The home owner must make sure he is getting enough storage (gallons) in tank size and enough collector area to give him a real return on his investment. Plan on at least 20 gallons per person for the first four people and 15 gallons for each additional person per day. Solar hot water tanks typically come in 80, 100, and 120 gallon sizes. The 120 gallon size tank typically costs only $150 to $200 more than an 80 gallon tank and the money is well spent considering you are adding 50% more storage capacity for a small increase in dollars. Experience in photovoltaics has obviously taught solar electrical contractors the value of amp hour capacity in battery storage whose counter is gallons in storage.

You should have at least 40 square feet of collector area for the first two family members, then add 12 square feet of collector area for each additional family member, if you live in the sunbelt. In northern climates, add 14 square feet of collector area for each additional family member. Never add more than 64 square feet to an 80 gallon tank or 96 square feet to a 120 gallon tank. Keeping tank size at a ratio of 1.25 gallons or more to a 1 square foot of collector area will keep the solar system from grossly overheating in times of little demand. This assures that the collector to storage ratio is efficiently matched. Overheating a hot water tank dramatically decreases its life span. In Arizona and Southern Florida keep the ratio at least 1.5 gallons to 1 square foot of collector area.

Collectors

The typical sizes available for flat plate collectors are 4' by 8' (32 sq. ft.) and 4' by 10' (40 sq. ft.). The minimum collector area size worth investing in is one 4' by 10' in a closed loop system. I strongly suggest two 4' by 8's with at least an 80 gallon tank for more than three people. Use two 4' by 8's, two 4' by 10's, or three 4' by 8's with a 120 gallon tank for larger families. Always use thermal collectors that have ALL copper tubes AND absorber plates for collecting the solar energy, that has a tempered glass cover in front of the absorber plate. NEVER use plastics or fiberglass covers instead of tempered glass or any other material than all copper collector plates for absorbing the heat. Avoid using evacuated tube collectors for heating hot water. It is like hunting rabbits with a howitzer and can grossly overheat your tank. A 120 gallon tank with two 4' by 8' or 4' by 10' collectors is the best investment in dollar per BTU delivered into storage. Avoid solar systems with less than 40 square feet of collection. They are simply not worth the investment. All solar hot water heaters capture sunlight to heat water. No matter how exotic the bottom end of a solar water heater might be it cannot create more solar energy than falls on the collector area. Less than 40 square feet just is not enough square footage in an active open or closed loop system.

Thermosyphons

Avoid external heat exchangers that rely on thermosyphoning of heat. Thermosyphon heat exchangers that work off natural convection will typically only heat the top half of the tank NO MATTER HOW YOU PLUMB THE TANK. External heat exchangers only work well if you double pump in counter flow, also pumping the water side of the heat exchanger through the tank and back through the heat exchanger. Another serious problem for external heat exchangers is scaling due to hard water. If you have hard water, especially calcium and magnesium, DO NOT use an external heat exchanger unless you have a water conditioner or anti-scale equipment.

Closed Loop

Fortunately the two largest manufacturers of hot water tanks in the country, Rheem/Rudd, and State Industries, manufacture 82, 100 and 120 gallon solar tanks. These have closed loop heat exchangers that are bonded to the lower half of the solar tank's wall. This enables you to use a closed loop system that avoids the two biggest problems for solar hot water systems: 1) freezing and 2) scaling due to hard water. It also keeps the system incredibly simple since you need only one pump to pump the heat exchanger side of the system. The Rheem or Rudd tanks use copper tubing bonded to the exterior wall of the tank. This enables you to use Prestone II car antifreeze in a 2 gallons of antifreeze to 3 gallons distilled water mix to run through the heat exchanger. If your coldest freeze on record is above 0° F use 1 gallon of antifreeze to 2 gallons distilled water. State Industries uses an integral single wall heat exchanger that is bonded to the lower half of the outer tank wall. The State heat exchange tank works extremely well, however, you cannot use ethylene glycol (Prestone II) but must use its cousin, propylene glycol, a non-toxic antifreeze used in all soft drinks and many other foods. The mixture ratio is the same and the excellent heat transfer properties are identical for ethylene and propylene glycol. Never use hydrocarbon oils, silicone oil or alcohol as heat transfer fluid because they have low specific heat characteristics and are poor choices for heat transfer fluids. One of your local plumbing distributors can order you a State, Rheem, or Rudd closed loop solar tank. The cost is about $480 for an 80 gallon tank, and $580 for a 120 gallon tank.

Caution on Materials
The entire collector loop, all fittings and pipe, must be copper or red brass. All copper couplings must be soldered with 95/5 tin/alimony, or brazed. Never use 50/50 lead solder. The antifreeze/distilled water solution will not need to be changed for over ten years if you do not mix metals in the collector loop. NEVER use galvanized pipe, yellow brass, or any plastic pipe or parts.

Pumps & Panels
The most efficient trouble-free control and pumping system is to use the 12 Volt DC March 809 pump. Then connect it to a small solar electric module rated, at a minimum of 1.2 Amps to a maximum of 2 Amps under full sun conditions (typically a 14 to 20 Watt PV module). The solar electric module pop-riveted to the side of the frame wall of the solar thermal collector will slowly start pumping at the correct solar intensity at a variable speed.

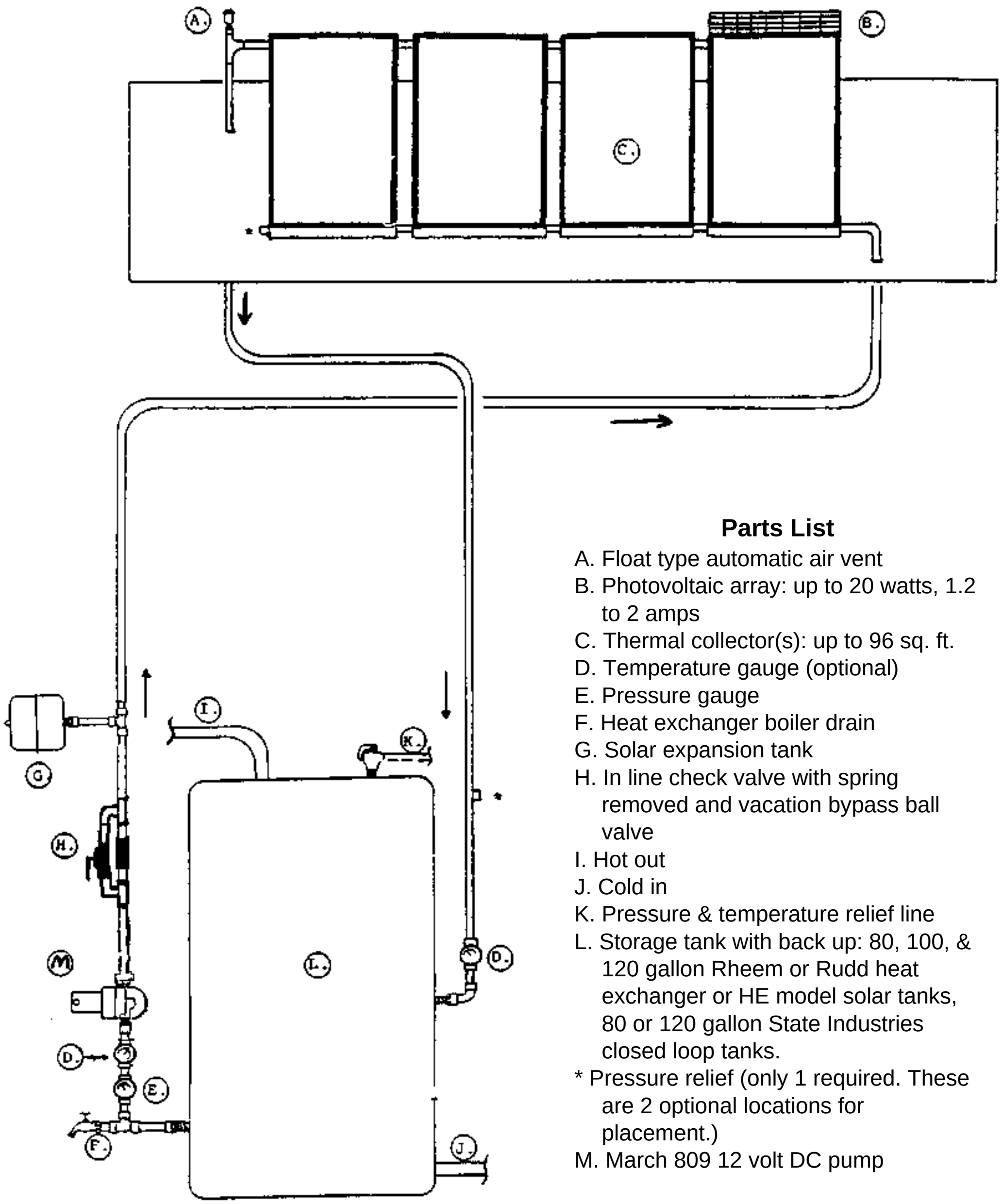
Solar thermal and solar electric energies are completely different forms of energy from the sun. However, they are always in the same proportion based on the intensity of the sunlight. The choice of a solar electric or PV module rated 1.2 to 2 Amps matched to the March 809 12 Volt DC pump enables it to provide power to run the pump. It also acts as a variable speed controller to start and stop the pump and vary the speed at the correct solar intensity. A smaller PV module (less than 1.2 Amps) will start too late and a module bigger than 2 Amps would start too early and run too long. Use only a single crystal or polycrystalline PV module - do NOT use an amorphous PV module. Just connect the positive and negative leads on the March 12 Volt 809 pump with 18 or 16 gauge stranded PVC jacketed wire. This means no sensors to fail, no differential thermostats, (which means it cannot malfunction and run at the wrong time), no AC power outages from the utilities. After the hurricane that hit Tallahassee, Florida, in 1985, the city lost utility power for several days. The solar systems with solar electric pumps were still providing hot water to their homeowners. Do not let anyone try to sell you on the obsolete differential controls with sensors and an AC pump. Tell them to send their dinosaurs back to the city dump.

Pipe
All lines in the solar loop from the tank to the collectors and back should be in type L soft and/or hard 3/4" copper pipe. Use hard type L copper around the tank and collectors and use soft type L coils on the long attic pipe runs. Insulate the lines with 3/4" thick elastomeric insulation (trade name Rubatex or Armaflex) available at air conditioning and heating distributors. Do NOT use polyethylene rigid pipe insulation! All exterior insulation exposed to sunlight must be protected from UV light. One way to do this is by encasing the insulation in PVC or ABS plastic pipe, or you can spray it with auto motive undercoating spray and touch up as needed in the future.

Safe Six
Besides the pump, there are only six simple parts in the system. 1) A pressure gauge (0-60 PSI) will let you know your system has not lost its charge of antifreeze and water. 2) A solar expansion tank (about the size of a basketball) that allows the solar solution to expand into it as a fluid heats up. 3) A check valve above the pump to prevent reverse flow thermosyphoning at night. 4) A pressure relief valve rated at 75 PSI to 125 PSI (not a pressure & temperature relief valve). 5) One boiler drain (hose bib) valve at the lowest point in the system for filling and draining. 6) A two way ball valve, to create a bypass around the check valve. This last item, #6, enables you to fill and drain from a single drain hose bib. If you go on vacation you can let the system dump all the heat back to the roof each night by reverse thermosyphoning if the ball valve bypass is open. If you vacation for a week or more and do not have a means to keep your tank from overheating , you will definitely shorten the tank's life.

Charging
Once the system is completely installed it will be time for charging. All you will need for system charging is two washing machine hoses, a drill pump for the end of a 3/8" power drill, and a bucket.

Simply add your antifreeze/distilled water mixture, to the bucket as your drill pumps the water into the washing machine hose connected to the lower boiler drain. If the collectors are extremely high, cover the collectors, remove the air vent, and slowly fill from the top with a



Parts List

A. Float type automatic air vent
B. Photovoltaic array: up to 20 watts, 1.2 to 2 amps
C. Thermal collector(s): up to 96 sq. ft.
D. Temperature gauge (optional)
E. Pressure gauge
F. Heat exchanger boiler drain
G. Solar expansion tank
H. In line check valve with spring removed and vacation bypass ball valve
I. Hot out
J. Cold in
K. Pressure & temperature relief line
L. Storage tank with back up: 80, 100, & 120 gallon Rheem or Rudd heat exchanger or HE model solar tanks, 80 or 120 gallon State Industries closed loop tanks.
* Pressure relief (only 1 required. These are 2 optional locations for placement.)
M. March 809 12 volt DC pump

funnel. Keep charging until your pressure gauge reads 20 PSI plus 1 pound of pressure for every 2 feet the solar collector is higher than your tank. One way to crank the pressure up is to connect the washing machine hose to a 100 foot garden hose that you fill with your mixture through a funnel. Connect that garden hose to a hose bib on the tank drain or an outside spigot and let your city or well water pressure crank your pressure up by forcing the extra mixture in by water pressure.

Cost & Value

An 80 gallon closed loop system with two 4' by 8' collectors and components will cost about $1688 for the equipment and save about $556 a year at $.10 KWH. A 120 gallon tank with two 4' by 10' collectors and components will cost about $1950 and save about $720 a year at $.10 KWH. A good rule is that if you are paying less than $27 a sq. ft. in collector area for the system, you are getting a good buy. Piping and insulation will cost about $1.25 a foot. The tank and heat exchanger should last 20 years with no maintenance other than to change the antifreeze mixture every 10 years. The absorber plate in the thermal collectors may need to be replaced every 50 years, about twice in the 150 year life of a good flat plate collector.

Conclusion

It is ironic, a family of four that has LP gas or high electric rates will pay for a solar hot water system in utility bills over the next 4 to 8 years, whether they get one or not. You can invest, wisely, in a solar hot water system and have something to show for your money or send the money you would have saved on solar each month to the utility company. Then you have nothing to show for your money but more NO_2, SO_2, and other airborne pollution and/or nuclear waste.

Access

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American Energy Technologies, POB 1865, Green Cove Springs, FL 32043 • 904-284-0552

Solar Development Inc., 3630 Reese Ave., Riviera Beach, FL 33404 • 407-842-8935 Rheem heat exchanger tanks, closed loop components, PV panels and DC pumps.

Radco, 2877 Industrial Parkway, Santa Maria, CA 93455 805-928-1881 Thermal collectors

Heliodyne, Inc., Richmond, CA 94804 • 510-237-9614

Introducing:

THE GRAVITY SIPHON SOLAR WATER HEATER

John Whitehead

The gravity siphon is a new way to do solar water heating, with several unique advantages. It began with a dream to create an effective system using only hardware store items, instead of specialized components. There are no pumps, and the water is kept hot in a fully-insulated indoor tank. Cold water doesn't enter the hot storage tank, which is unlike other systems. The best part is that you can build your own. Construction details will be described in an article in the next issue of Home Power.

Don't ask if it's active or passive, because it falls somewhere in between. The energy which drives collector flow comes from the cold water supply pressure. There are neither continuously-moving parts nor an extra energy source. Valves simply need to be opened and shut each morning and evening. Automatic valves and a controller may make it an active system. Consider it passive if you agree that flipping valves can be as easy as opening your mailbox or adjusting windows.

Figure 1 is a system diagram. Any flat-plate solar collector will work, including a used or homebuilt one. There's no hiding the fact that extra tanks are needed. This is the key to both pumpless operation and isolated hot storage. The rest of the system is just plumbing parts costing several dollars each, for the manual version.

How it Works

The cold water supply is connected to the upper tank. Solar heated water is stored in the lower tank. They are partly full as shown, and the remaining volume contains compressed air. This air can pass freely between the tops of the two tanks, through the air pipe shown in Figure 1. Therefore, cold water supply pressure keeps the air compressed, which in turn keeps the hot water pressurized. Each time hot water is used, the water level in the lower tank falls a little. It is replaced by air from the upper tank, which then receives fresh cold water.

The lower tank stores enough hot water for the evening and early morning. When the solar heated water is gone, the lower tank contains mostly air, and the upper tank is full of cold water. If there is extra demand, cold water overflows through the air pipe, and is delivered instead of hot water. As with any solar water heater, it makes sense to have a regular heater as a backup between the solar tank and the house.

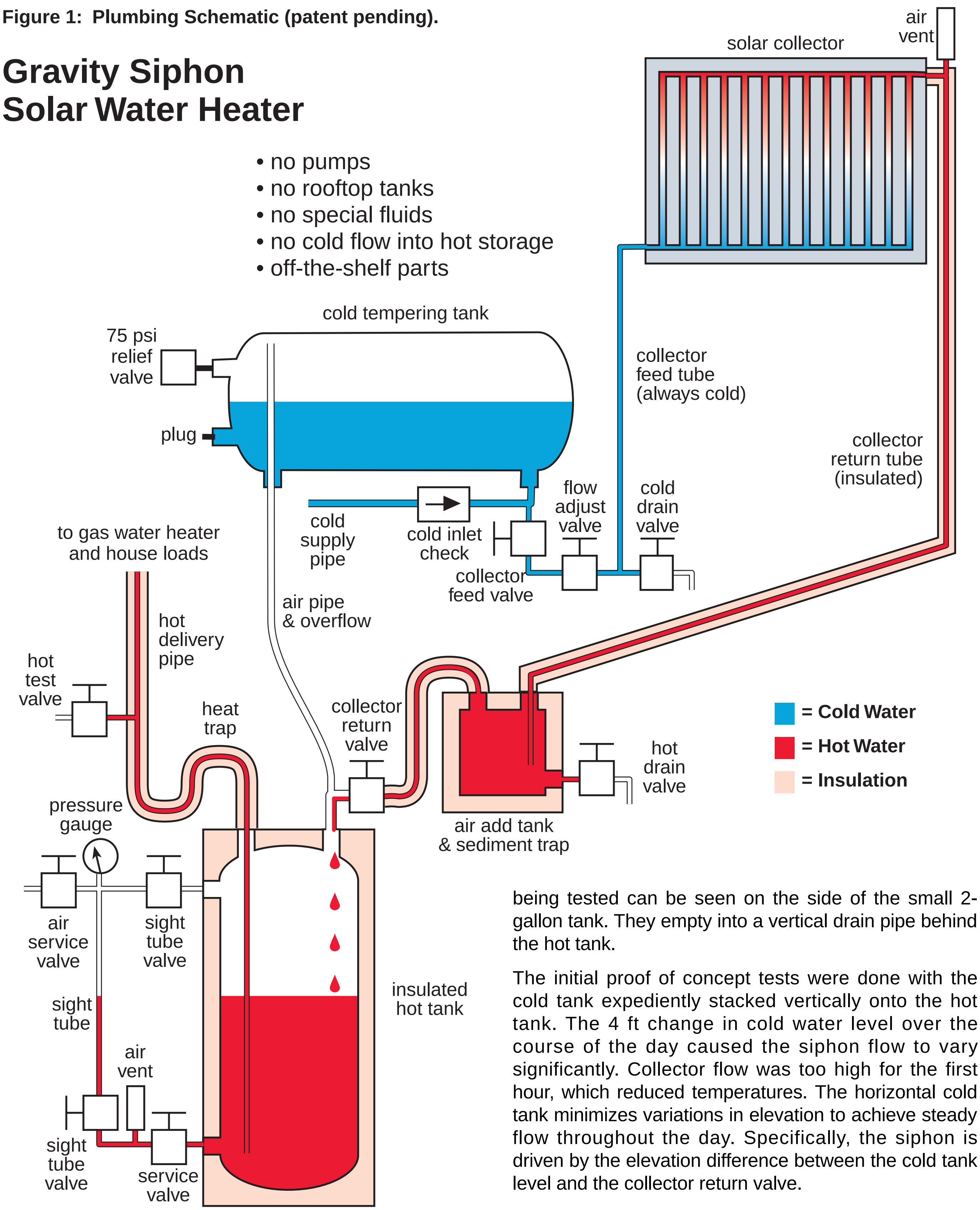
During the day the hot storage level gradually rises, as cold water is heated by the sun. The air is displaced back into the upper tank, as the cold level falls. Collector flow is sustained all day simply because the cold tank is above the hot tank. The real trick, conceived in 1993, is to run this gravity siphon inside a pressurized water system. Cold water pressure starts the siphon, and permits feeding a rooftop collector from the lowest floor with no pump. Note that a gravity siphon is just a regular siphon, as can be used to empty a fish tank, for example. The term is used here to avoid confusion with a solar thermosiphon, which is entirely different.

Afternoon shutdown does not require precise control as with systems that use pumps. The siphon flow through the collector stops passively at the end of the day, when the hot tank is full. Specifically, the water level in the hot tank rises into the air pipe to the bottom of the cold tank. When hot water is used, the level falls and collector flow can start again. To prevent collector flow at night, the collector feed valve needs to be shut anytime during the evening.

Prototype experience

The first prototype system was built and flow-tested throughout 1995, then connected to a collector in 1996. Figure 2 is a photograph of the indoor parts with refinements made in 1997. The main tanks are the cheapest 52-gallon electric water heaters purchased for $150 each. One of these was stripped down to the bare tank and painted. The plumbing is as depicted in Figure 1, except the cold tank ports are interchanged. The long copper tube in front of the hot tank is positioned to fill a bucket from the hot test valve. Automatic drain valves

Figure 1: Plumbing Schematic (patent pending).



being tested can be seen on the side of the small 2-gallon tank. They empty into a vertical drain pipe behind the hot tank.

The initial proof of concept tests were done with the cold tank expediently stacked vertically onto the hot tank. The 4 ft change in cold water level over the course of the day caused the siphon flow to vary significantly. Collector flow was too high for the first hour, which reduced temperatures. The horizontal cold tank minimizes variations in elevation to achieve steady flow throughout the day. Specifically, the siphon is driven by the elevation difference between the cold tank level and the collector return valve.

One surprise, obvious in retrospect, occurred with the earliest prototype. If the utility supply pressure is

Figure 2: The gravity siphon system.

interrupted for any reason, backflow into the cold water system could occur. After air was found escaping through faucets, the cold inlet check valve was added. A swing check valve was found to slam with the slightest pressure surges. Its replacement, a spring check valve, now operates quietly.

Another fact is that the air tends to dissolve in the water. At the tap, hot water can appear white due to microscopic bubbles, which is harmless of course. The problem was that the air in the tanks was gradually lost during the first half of 1995. A few tricks were devised to passively add air and maintain the correct amount of air in the system. This includes the 2-gallon air makeup tank, connected along the collector return tube.

Whenever the collector is drained, atmospheric air enters the makeup tank. This extra air is then compressed into the hot tank when the collector is filled with water the next morning. The small tank also can trap any sediment from the collector. The other passive air-management device is the vent valve at the lower end of the hot tank. Should the water level ever fall too low before cold overflow begins, the excess air is vented back to the atmosphere.

Transparent vinyl tubing has been extremely useful to monitor tank levels. Sight tubes were initially connected high along the air pipe, so maximum water levels could be viewed. However, flow through the air pipe created suction which sometimes invalidated the readings. The compromise settled upon (Figure 1) eliminates this problem and simplifies the plumbing.

Hot water production

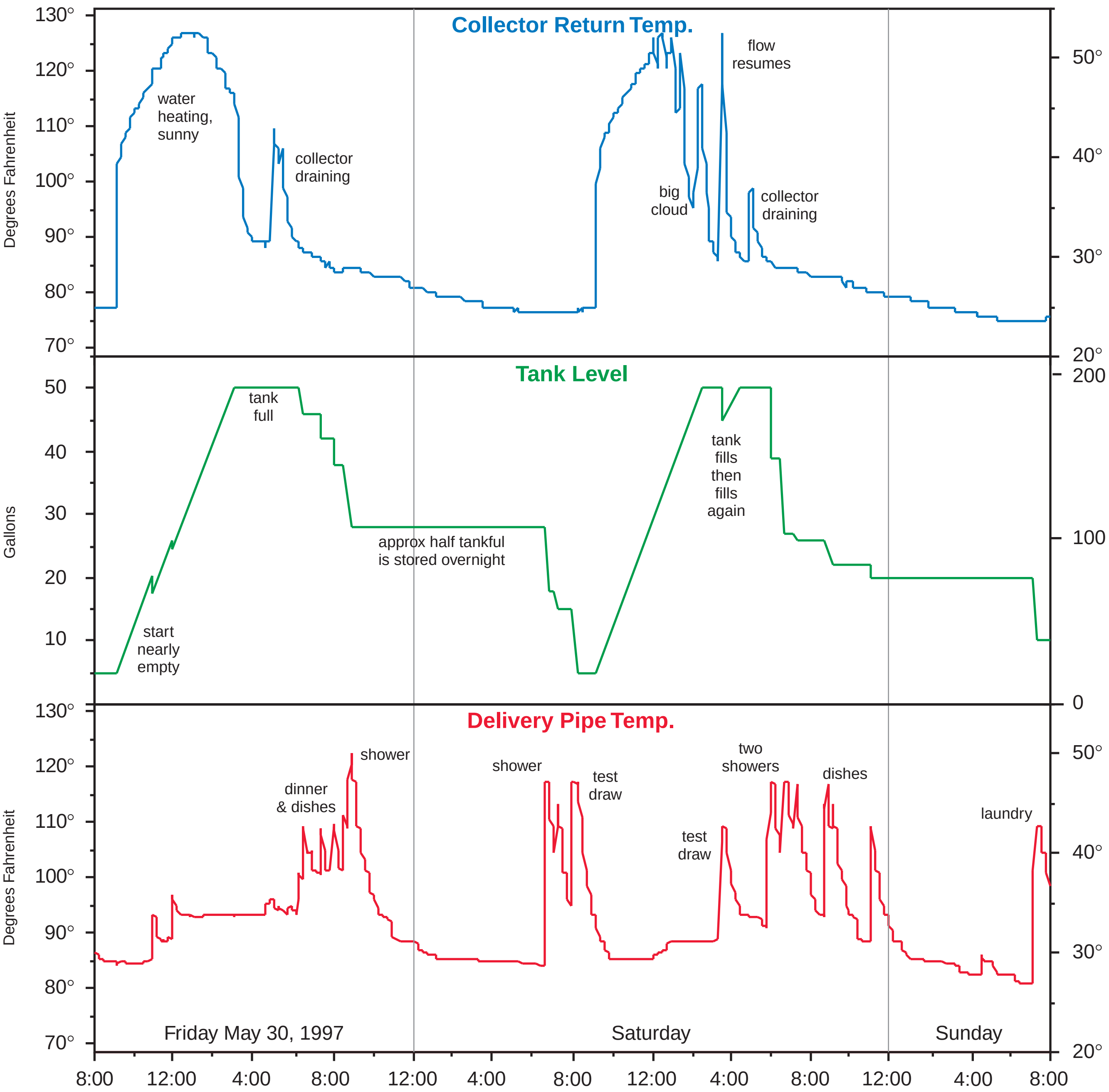
The debugged system has been found to work well, even with a single 4x8 foot homemade collector. Pictured in Figure 3, it was mounted at a 45 degree angle, which is steeper than optimum for spring and summer. A digital data logger records temperatures on both the collector return tube and the hot delivery pipe. Results for a clear spring day followed by a partly cloudy day are plotted in Figure 4. Tank level, hot water use, and clouds were carefully noted during this 48 hour period.

Over 45 gallons of hot water were collected each day, and delivered above 110°F. The data prove that solar heated water is available the next morning, with very little cooling. Actual temperatures obviously depend on the collector technology, so a professionally-manufactured collector would yield more impressive results.

The upper curve rises rapidly upon morning startup at 9 am on both days. As the sun angle improves, a midday peak is reached. On Friday, the collector return tube cooled rapidly after a full hot tank stopped flow at 3 pm.

Figure 3: The solar thermal water panel.

Figure 4. Hot water production and use data, late spring.



The blip at 5 pm resulted from evening valve switching. The gallon of warm water in the collector heated the temperature sensor on its way to the drain valve.

Solar hot water can be used anytime during the day. It just takes longer to fill the tank. The middle graph shows a pair of small draws at lunchtime on Friday. These appear as blips on a gradually rising tank level. Based on the extra time available (3–5 pm), 10–15 more gallons could have been drawn during the day. By 5 pm, a full tank would still have been stored for Friday evening.

The upper graph looks complicated on Saturday, but it is completely understandable. Several clouds passed overhead beginning at noon. A large thick cloud blocked the sun between 1:30 and 2 pm, reducing the temperature below 100°F. No hot water was used during the day on Saturday, so the tank filled earlier than on Friday. Over the next hour, the stagnant water in the collector continued to receive solar heat. At 3:30, 5 gallons were drawn through the hot test valve. The sharp collector return peak demonstrates that collector flow subsequently resumed. After 4 pm the tank was full again. The cloud-cooled collector draining blip appears on schedule at 5 o'clock.

The delivery temperature graph is tricky to interpret, since it is visually tempting to assign meaning to the area under the curve. Instead, the middle graph should be used to interpret volume information. Hot water use actually occurs over very short periods, after which it takes almost an hour for the pipe to cool down. If faucets are turned on briefly, the pipe sensor may not reach the actual water temperature. This explains numerous low temperature peaks on Friday.

Showers and washing machine operation have sufficient duration to show the actual water temperature on the lower graph. Starting late on Friday, the peaks indicate deliveries consistently above 115°F. Saturday morning deliveries were not affected by heat losses to cold water as occurs in conventional solar tanks. The clouds which rolled through Saturday afternoon reduced the Sunday morning delivery to just below 110°F.

Solar hot water was delivered all summer, but it was felt that a better test would come later in the season. Figure 5 shows similar data for two sunny days in October.

Collector flow gradually increases the tank level during the day, with temperatures exceeding 125°F in the upper graph. The return tube rapidly cools when the tank becomes full and stops collector flow. The subsequent spike each day results from stagnant water flowing past the sensor on its way to the drain valve.

The tank level falls in steps which correspond to actual hot water use. Each step lines up with its delivery temperature peak in the lower graph. For example, showers used approximately 10 gallons. On Sunday morning, the dishwasher used about 5 gallons to wash, then 4 gallons to rinse almost an hour later.

Early on Saturday morning, the tank was nearly full. The hot test valve was used to demonstrate that lots of solar heated water can indeed be delivered after overnight storage. This left the tank ready to receive freshly heated water. Saturday's production was over 45 gallons, including 5 gallons used for laundry during the day.

A greater total volume would have been heated if the tank had started completely empty. This was deliberately avoided because a tree shadow reached the collector just after 2 pm at this particular time of year. No hot water was used during the day on Sunday, so the tank filled a half hour earlier. Flow stopped while the collector was fully illuminated, which explains the precipitous drop in Sunday's collector return temperature.

Performance is good considering the time of year, although it should be noted that the 45 degree collector angle is nearly perfect for this date and latitude. Delivery temperatures were consistently above 115°F, and as high as 125°F on Saturday evening. Very efficient overnight storage was demonstrated on all three mornings in Figure 5. Outdoor ambient temperatures varied from the sixties to the seventies during the day. Cold water remained at 70°F during October.

The test data represent actual hot water use by two people. The temperatures shown represent deliveries to a backup gas heater. Additional heating was not specifically recorded, but the main burner was rarely heard. Summer gas bills and extra meter readings indicated that the vast majority of additional heat came from the pilot light alone.

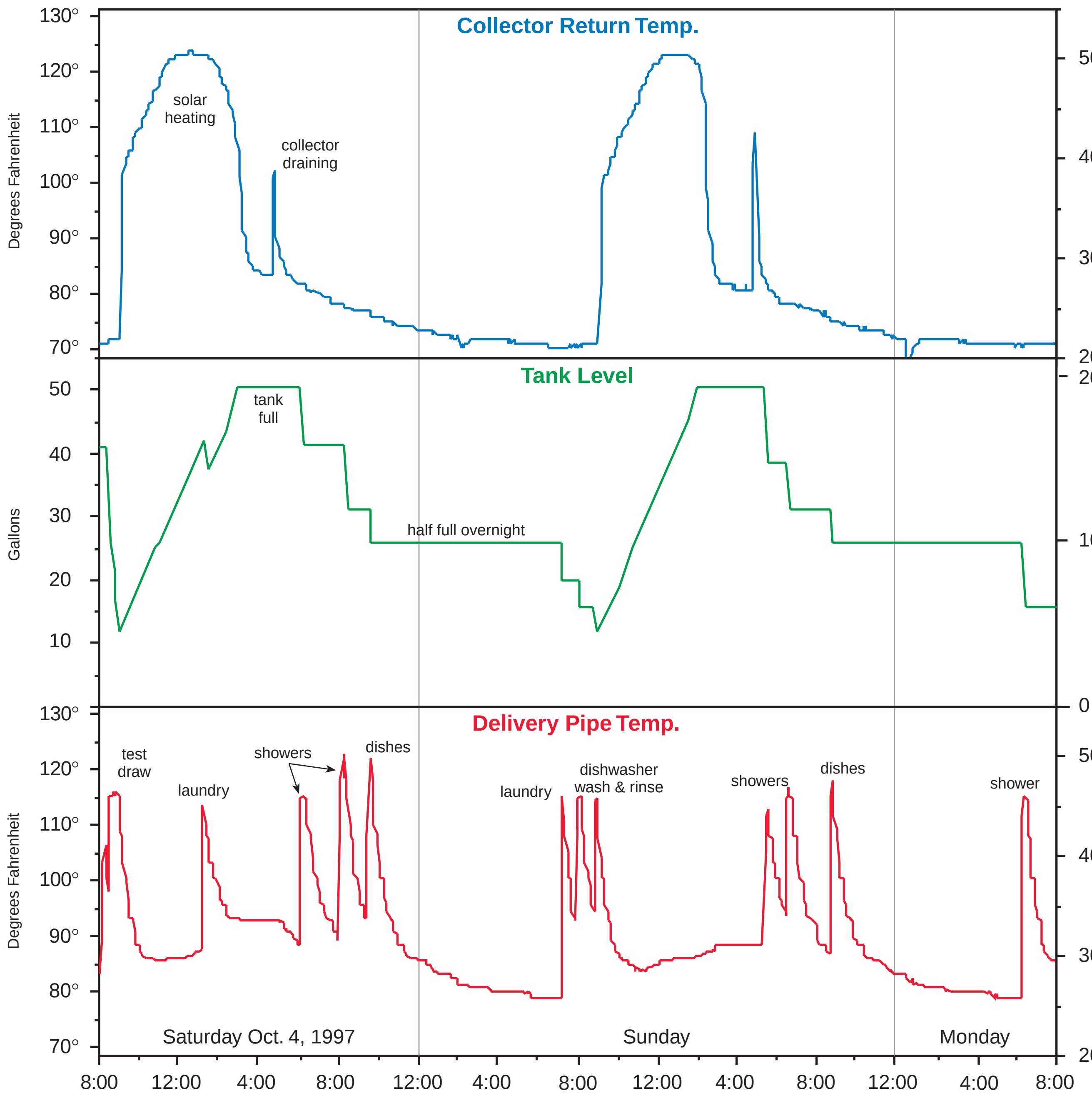
Perspective

The gravity siphon is a "once through" or "single pass" system, because heated water never returns to the collector. As another example, some heaters in developing nations have a vented hot storage tank on the roof. During the day, cold water is simply fed through a solar collector and into the unpressurized tank. In the engineering literature, these systems have been documented to be very effective. They are not well known in the United States, since high delivery pressure is considered essential here. The ideas in this article are offered as one solution. The gravity siphon system even provides a little pressurized water during supply outages.

Single pass heaters don't need insulation on the collector feed tube. The tube may even be routed through a hot attic for low temperature preheating. An air-to-water heat exchanger would maximize the effect. Similarly, a low cost solar collector can in turn feed a smaller high temperature collector. The latter would finally maximize the water's temperature after it receives most of its energy in the low tech unit. These cost-effective schemes don't work with repeated circulation, because hot water would lose heat in the attic or in the low-cost collector.

Flow rate in pumped circulating systems has been a subject of debate and detailed study. The older standard of rapid circulation increases collector efficiency early in the day, by evenly adding heat to the entire tank at low temperatures. Temperatures can be maximized because all the water receives a final pass through the collector in the afternoon. Unfortunately, this mixes the tank and destroys thermal stratification. Water used before noon is lukewarm. Draws during the afternoon introduce fresh cold water, which is then mixed in.

Figure 5. Hot water production and use data, early fall.



In recent years, it has been recognized that circulating systems should use low flow. This reduces pump power, and preserves tank stratification. Hot water floats above cold, with little mixing. Some research papers have recommended a flow of one tankful per day. Single pass systems inherently achieve this, while eliminating pumps and cold dilution entirely.

Even with perfect stratification, conventional solar tanks lose heat to cold water during the night. After evening use, there may be a half tank of hot water, floating on top of cold. The ideal situation is no liquid movement. Still, heat is conducted through the water itself and within the metal tank walls. The resulting impact on early morning solar showers is rarely considered. By coincidence with the normal workday, standardized tests only draw hot water during sunny hours.

Expensive collectors compensate for feeding cold water into the hot tank. Extreme temperatures yield acceptably hot water after mixing and conduction losses. However, temperatures above 140°F increase mineral precipitation, which can be a problem. If the house remains unoccupied, daily reheating in conventional systems produces even higher temperatures. Tank life is reduced, and mixing valves are needed to avoid scalding. Single pass operation is entirely different. Water is heated only once, to a reasonable temperature in an affordable collector. Tank overheating during vacations is impossible.

With regard to freeze protection, the gravity siphon can be classified as a drain down system. However, it differs from classic drain down systems which use pumps. In particular, automatic valves for the gravity siphon can be smaller than a conventional draindown valve. Electrical power is needed only for a small valve assembly, instead of a large valve and a pump.

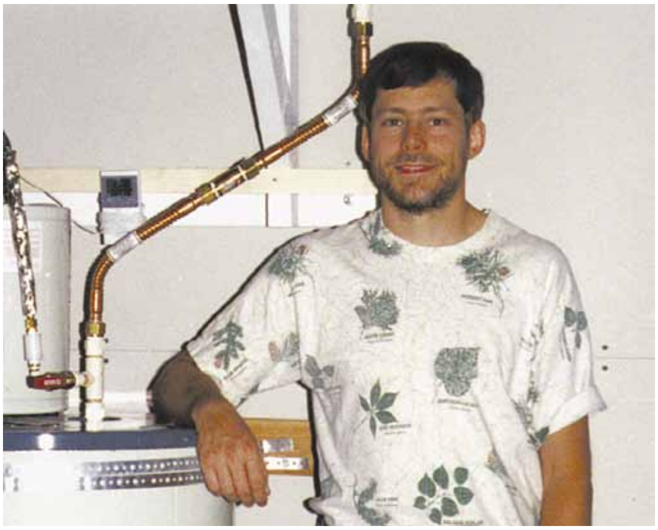
Of course the gravity siphon is not the only pumpless solar water heater. Some systems use fluid boiling action for circulation through a highly specialized collector. In more common batch heaters, the sun shines directly on the tank walls. These passive ICS (integral collector storage) heaters deliver pressurized hot water. Their plumbing is extremely simple and they require no extra indoor space for tanks. Although water flows through only once, ICS units are entirely different and classed separately from single pass systems.

Storing hot water outdoors at night obviously impairs performance of ICS heaters. The side of the tank(s) exposed to the sun cannot be insulated in the usual sense. Double glazing, high tech coatings, and even glass vacuum vessels are used to mitigate heat loss to the night sky. Homemade batch heaters without these features would be much less effective. The inherent lack of freeze protection makes ICS solar water heaters impractical in very cold climates.

A collector and tank can be manufactured into one assembly, with thermosiphon circulation. These can be recognized by the large bulge at the top of a flat plate collector. They are as passive as batch heaters, but the tanks are well insulated. Unfortunately, a horizontal tank orientation puts all the hot water in a wide shallow layer, in close proximity to incoming cold water. Even a homemade thermosiphon heater could be more effective if a vertical tank is used (see HP issue #58, p. 30). This option for pumpless circulation requires the tank to be higher than the collector, which can be inconvenient.

Conclusion

Like clotheslines, water heating is one of the most cost effective ways to use solar energy. For under $1000, a gravity siphon system can deliver 50 gallons daily at a 50°F temperature rise. This represents over 20,000 BTU, or 6 kilowatt-hours of heat energy. The same daily electrical energy consumption would require a $10,000 PV system.



Above: Author John Whitehead.

Many types of solar water heaters exist, with a wide range of advantages and disadvantages. The choice depends on factors such as budget, climate, the desirability of overnight storage, and the availability of space for tanks. The gravity siphon is a new option which is likely to be favorable in many situations. Hot water is stored in complete isolation, the system can be home built, and the collector can be high above the tanks without needing pumps. The sight tube takes the mystery out of solar water heating, by showing exactly how much hot water is produced, stored, and used.

An article coming up in the next issue, *HP64*, will explain site evaluation, tank selection, plumbing details, and operation of the gravity siphon solar water heater.

Access

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Simple Solar Water Heater

for Developing Countries

A. Jagadeesh

A simple solar batch water heater.

The sun is an energy source available to everyone—an energy source that can be used simply and inexpensively to reduce developing countries' dependence on imported fuels. A solar water heater is the simplest and most cost-effective solar application.

Solar water heaters are based on a common natural phenomenon: cold water in a container exposed to the sun undergoes a rise in temperature. A solar water heater is usually a flat-plate collector and an insulated storage tank. The collector is commonly a blackened metal plate with metal tubing attached, and is usually provided with a glass cover and a layer of insulation under the plate. The collector tubing is connected with pipe to a tank that stores hot water for later use.

When mounted on a roof or other suitable support, the collector absorbs solar radiation, and transfers the resulting heat to water circulating through the tubing. In this way, hot water is supplied to the storage tank. In many common designs, the storage tank is located above the top of the collector. The elevated position of the tank results in natural convection—water circulates from the collector to the tank.

Solar water heater technology is so simple. Why is it that developing countries do not use it very much? The reasons are not hard to find. The main constraint is prohibitive cost. For example, in India, a 100 litre (25 gallon) solar water heater costs around 12,000 rupees (Rs.), about US$300. Also, not many people living in towns and villages have access to overhead water storage tanks with a continuous supply of cold water. To overcome these barriers, I designed and tested a vertical, cylindrical solar water heater that does not require pressurized water or roof mounting.

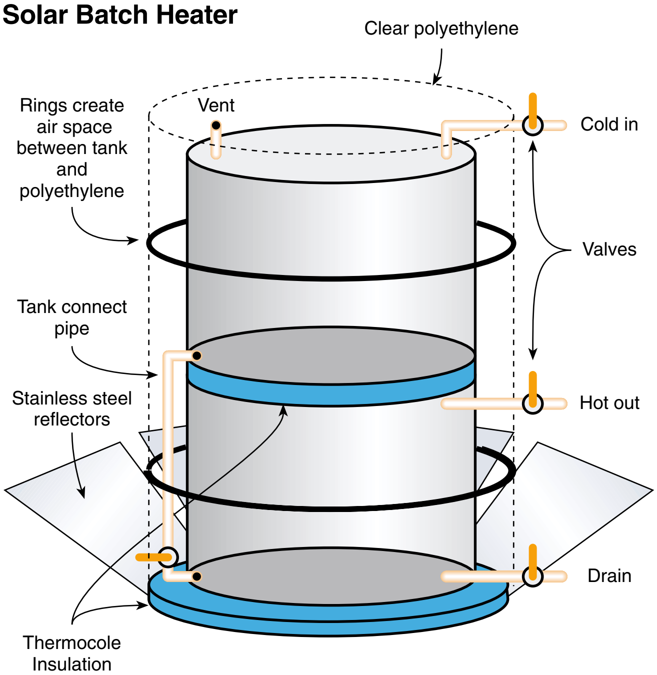
Design Details

The system consists of two stainless steel collectors (normally used in the manufacture of drinking water drums). These vertical cylinders are 0.6 m high and 32 cm in diameter (24 x 12 inches). The cylinders are placed one over the other with Thermocole insulation (made with paper) in between, as well as at the bottom, to prevent heat losses. The top tank is provided with an inlet at the top, a cap, and an opening at the bottom. This bottom opening is connected to the bottom cylinder with a pipe designed to withstand high temperatures.

There is a lever attached to this pipe to control water flow. The bottom cylinder is provided with an outlet at the top from which water is drawn. Both the cylinders have rings welded to the tanks to form a 3 cm (1 inch) gap. They are covered with high-density transparent polyethylene sheet to create a greenhouse affect.

A lotus flower shaped reflector made of stainless steel focuses sunlight on the bottom cylinder. It doesn't need

Solar Batch Heater



to be moved to follow the motion of the sun; it does its job wherever the sun is. With normal reflectors, there is a shadow in the afternoon. With this circular reflector, when one side is shaded, the other side is still working.

There is a separate insulated cover to help hold the heat overnight. It is made of a circular bamboo basket that is 1.3 m high and 45 cm (4.2 x 1.5 feet) in diameter. It is covered with 6 mm (1/4 inch) glass wool (rock wool), with a transparent polyethylene cover so that the whole setup is airtight.

Hot Design

This heater is somewhat different from the common batch water heaters you see in places with pressurized water or gravity flow systems. You might think that the lower tank is "wasted," since the hot line out is in the top of this tank. Or you might wonder why the hot line out is not where the hottest water is—at the top of the upper tank.

But consider what it takes to design a ground-mounted system with no pressurized water. Then you will see that the upper tank in this system provides a small amount of pressure and a reservoir of hot water, and the lower tank is a place for the cooler water to cycle down into.

If you put the hot line out where the drain is, you'd get the coldest water. If you put the hot line out where the hottest water is, you'd only get a little of it before you had no pressure. Tapping the hot water from the top of the bottom tank is a worthy compromise, giving you the best of both worlds. And if cold or warm water is needed, the drain from the lower tank can be tapped.

Operation

The collector is filled with potable water in the morning at 8 AM and is covered with the insulator (bamboo basket) at 4 PM. The hot water can be used either in the evening, at night or the next morning. Hot water up to 70°C (160°F) is obtainable depending on the sunshine. In fifteen hours of storage, with nighttime temperatures dropping to 25°C (77°F), I observed about 7°C (13°F) drop in the hot water temperature.

This 100 litre (25 gallon) unit costs about Rs. 6,000 (US$150) in southern India, and will be highly useful as a pre-heater for cooking, bathing, washing clothes and utensils, and for rural schools, hospitals, etc.

Advantages

- The unit is mobile, modular, and easy to install and dismantle for transporting.
- Cold water supplied through pipes is not necessary.
- There is no need for an overhead water storage tank.
- There is no need to have a separate collector; this is an integrated system.
- Since the collector is made of stainless steel, the hot water will be hygienic.
- Because of the omni-directional reflector, relatively higher water temperatures are obtained even in moderate sunshine.
- The unit occupies less space on the ground or roof, being vertical and circular.
- All the materials used in the fabrication of this simple and cost-effective solar water heater are available locally.
- The unit is durable and will last a long time, except for the polyethelene cover. It will need to be replaced about every four months, which costs just Rs. 30 (about US$0.70).
- By using pre-heated water for cooking from this unit, considerable fuel such as firewood, kerosene, gas, electricity, etc. can be conserved.

Access

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Water Preheating Panel

This solar water preheater panel is an example of a collector panel that could be used in conjunction with two other panels of the same size to supply much of the hot water required by a family of four.

It is basically a double-glazed unit that has in its interior copper pipes soldered to standard galvanized roofing. (There is some question of the long-term durability of a soldered galvanized-copper joint; thus far we have had no problems.) The blackened surface of the galvanized iron heats up and transfers its heat to the copper pipes attached to the sheet. Water flowing through the pipes carries away the solar energy collected. Cold water enters the collector via the bottom header and flows evenly through each of the risers, exiting, after heating, from the top header. Providing water flow rates are not too high, the collector can easily produce water at 120°–140°F.

The double glazing and insulation in the collector help keep heat losses to a minimum. These losses are further minimized by using silicone to mount the collector plate in position. The use of silicone mounting also allows for free expansion and contraction of the collector plate.

Materials Required

1 4-by-8-foot sheet of ¾-inch plywood

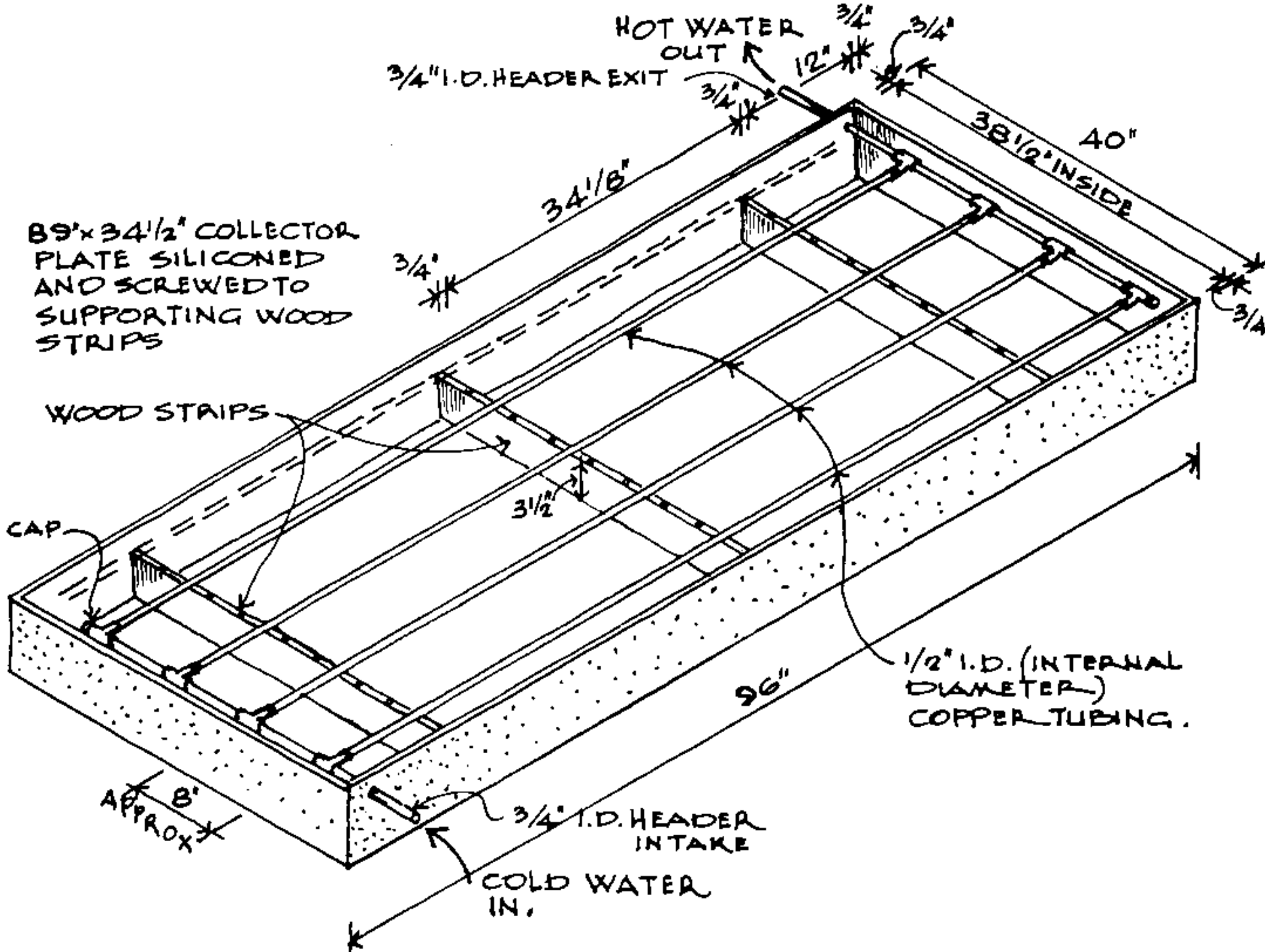
1 2-by-8-foot piece of 3/4 inch plywood

24 feet of 16-inch-wide R–12 (4 inch) fiberglass batt insulation

1 8-foot sheet of standard galvanized roofing

1 96-by-38½-inch sheet of Mylar or Tedlar

1 96-by-40-inch sheet of Kalwall premium



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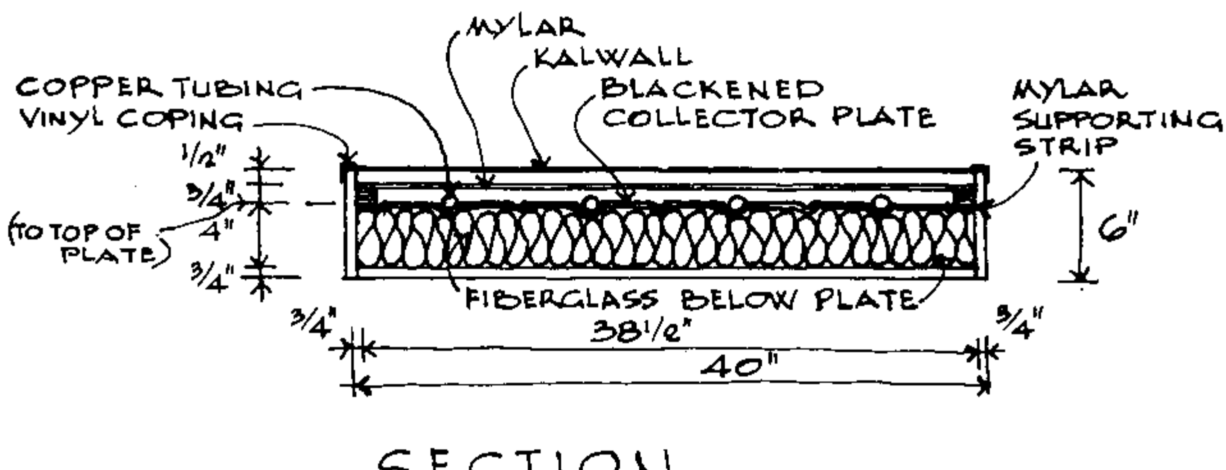


SECTION.

32 feet of ½-inch I.D. hard copper tubing

8 feet of ¾-inch I.D. hard copper tubing

8 ¾-by-¾-by½-inch copper tees

2 ¾-inch copper caps

24 feet of 7½-inch-wide light-gauge galvanized sheet metal (to flash collector-box edges)

1 4-by-8-foot sheet of light-gauge galvanized sheet metal (if required)

24 feet of ¾-by-¾-inch vinyl coping

24 feet of ¾-by-¾-inch redwood to support inner glazing

½ pound of 1½-inch galvanized finishing nails

24 ⅜-inch sheet metal screws

1 can flat black heat-resistant paint

1 tube of clear silicone sealant

1 small can of contact cement

waterproof glue

wood preservative

Collector Plate Supporters

Cut three collector plate supporters ¾ by 3½ by 38½ inches and install them in the collector box: one at the center and the other two 12 inches from either end of the box. Firmly glue and screw the supporting strips in place. Mylar supporting strips should also be secured on the inside of the collector box ½ inch from the top. Two of the strips are 94½ inches long, the other two 37 inches. Paint all wooden surfaces completed with two coats of wood preservative.

Collector Plate

The actual collector plate, 96 by 34½ inches (i.e. standard galvanized roofing), is reduced in length to 89 inches by cutting with tin snips. Four ½-inch-I.D. straight copper tubing pieces are cut, each 87 inches in length. Thoroughly clean the surface of the galvanized sheet and copper with steel wool before soldering the copper tubes in place. When soldering use a paste-type flux and 50:50 solder.

Soldering the Tubes

The best method of accomplishing the soldering is to clamp the copper tubes in place using a steel tube, placed across the collector, which is clamped on either side. A short length of each copper tube is then soldered and allowed to cool, after which the steel tube and clamps are moved further down the collector and the process is repated. A 2-inch section at both ends of each copper tube should be left unsoldered. Bend these short sections slightly upwards to accommodate the T's which may then be slipped over them.

Measure the exact distances between the ends of each copper tube and cut ¾-inch-I.D. copper sections to fit in the header configuration. Solder the first T at the end of one pipe and then proceed to build up the whole header configuration. Do not put all the T's on at first otherwise you will not be able to fit the other straight sections in between. Put a 2-inch extension on the end of each header, as illustrated, and cap them.

Drill 1-inch holes to allow the inlet and outlet pipes to enter and leave the collector; these holes should be drilled once you know precisely where they are to go in relation to the rest of the header arrangements.

Installing Insulation and Collector Plate

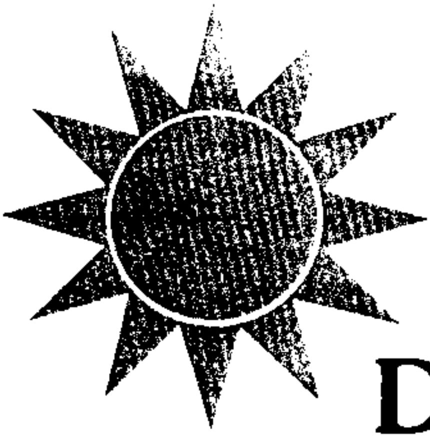
Using 4-inch industrial fiberglass, pack the bottom of the collector and the sides and ends. Silicone the top of each plate supporter; then, using sheet-metal screws, secure the plate to the supporters. Twenty-four hours later remove all screws except the middle ones so that the plate can move without buckling during expansion and contraction.

Then solder the copper inlet and outlet tubes in place. Measure these tubes so that they extend at least two inches outside the box.

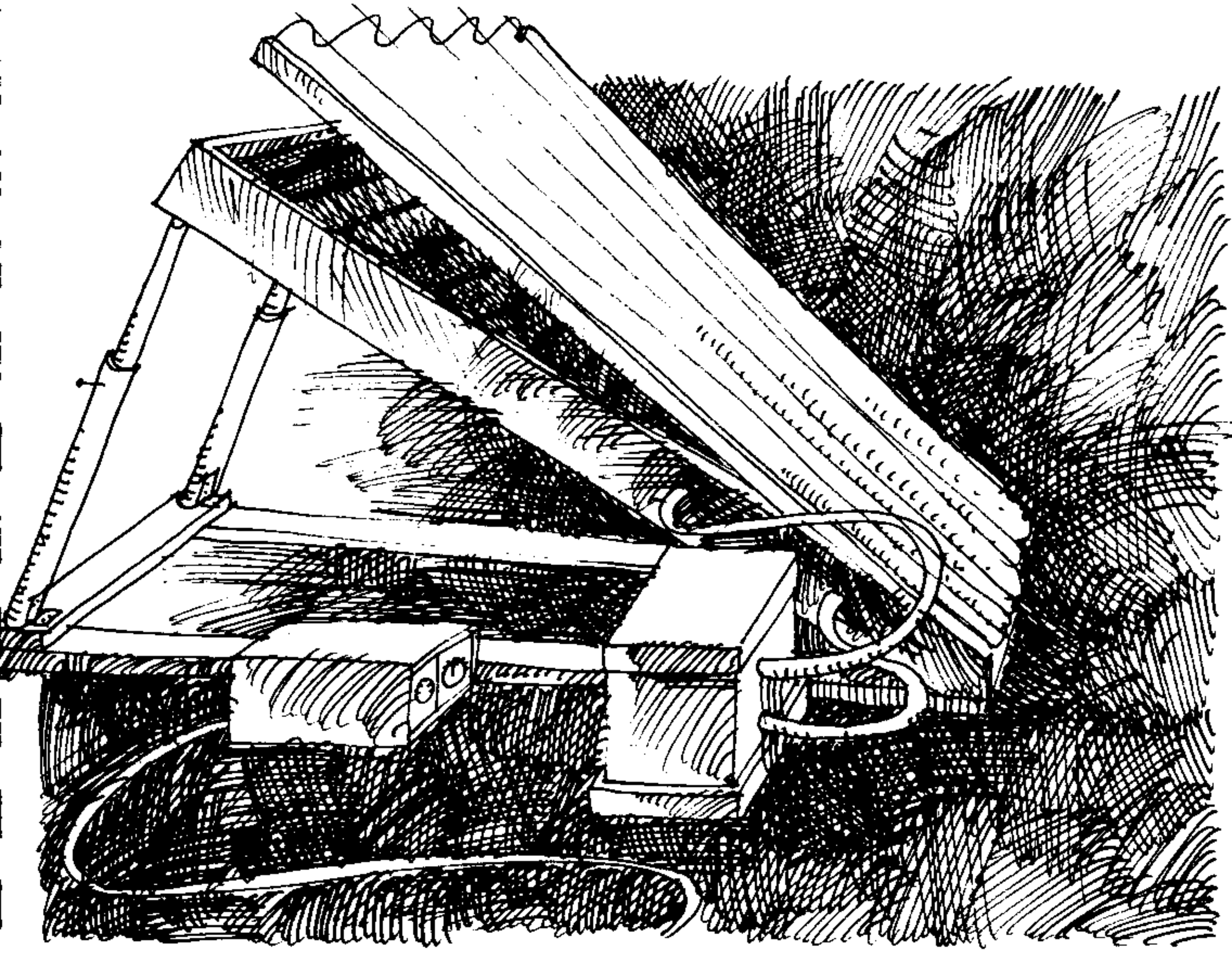
Glazing

Now for the glazing. Silicone and staple a Mylar sheet to the supporting strips already in place. Make sure that this sheet is stretched as tightly as possible to prevent later sagging. To complete the glazing, use Kalwall premium siliconed in position and futher secured by heavy-duty vinyl coping.

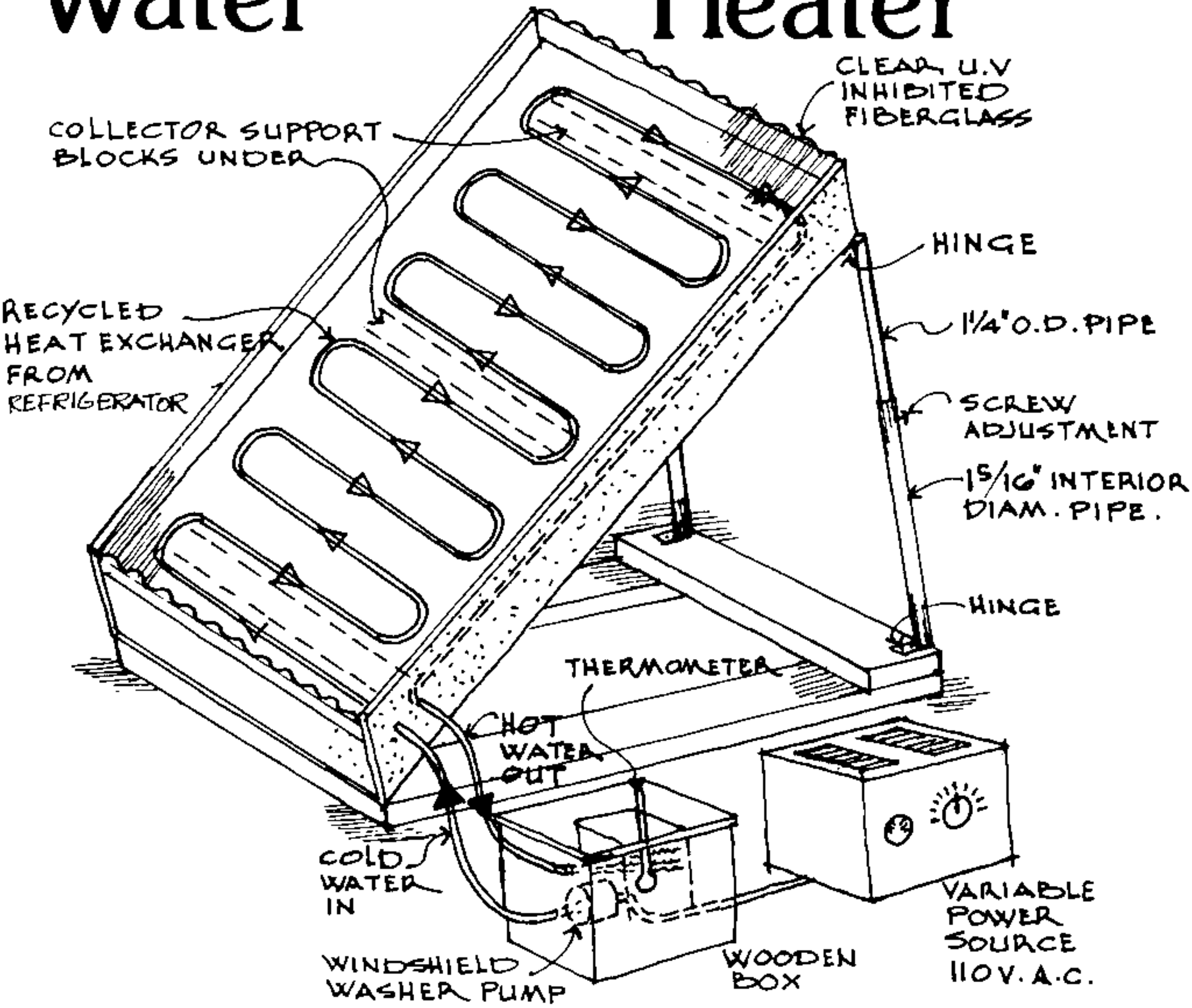
To complete the project the collector should be caulked, flashed with galvanized steel, and then thoroughly painted with a premium-quality paint.



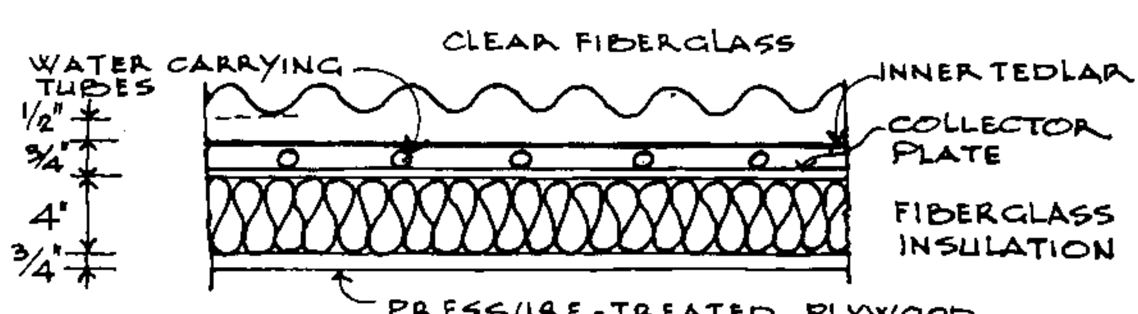
Demonstration Hot Water Heater



Demonstration Hot Water Heater



CONSTRUCTION DETAIL.



TYPICAL SECTION

The original idea for the construction of a demonstration hot water heater, using a refrigerator heat exchanger and windshield washer pump, came from Tom Walton, physics lecturer at Cariboo College, Kamloops, Canada.

This hot water heater is a unit that is ideal for use in science fairs or as a general unit for demonstrating many basic principles involved in collector design. The basic design consists of heat exchanger coils from a refrigerator that form a collector when painted with a heat-resistant flat black paint. Removable double-glazing is placed over the collector. Insulation behind and at the sides of the collector reduces heat losses. Adjustable pipe supports are used to alter the inclination of the collector. The windshield washer pump is used to circulate the water through the collector coils. The flow rate can be changed by the use of a variable power source.

It is possible to test many variables because of the flexible nature of the basic design. Specific construction details are not possible as the heat exchanger available will vary in dimensions; however, generalizations concerning the design may be made.

Materials Required

1 sheet of 4-by-8-foot pressure-treated ¾-inch plywood

1 recycled heat exchanger from a refrigerator

Glazing: Outer, U.V.-inhibited fiberglass; Inner, Tedlar

12 feet of 2-by-4-inch softwood

1 4-foot 1¼-inch O.D. steel tube

1 4-foot-15/16-inch I.D. steel tube plus 2 adjustment screws (see illustration)

1 windshield washer pump

1 12-v d.c. variable power source (110-v a.c. supply)

4 2-inch hinges plus screws

1 4-by-2-foot (approximately) piece of 4-inch (R–12) fiberglass insulation

10 feet of self-adhesive foam weatherstripping

6 feet of rubber tubing (sized to fit heat exchanger tubes)

1 small can of flat black heat-resistant paint

½ pound of 1½-inch galvanized nails

2 dozen 2½-inch galvanized nails

waterproof glue   paint

Collector Box and Plate

Pressure-treated plywood is an ideal material from which to build the collector box; ¾-inch material is recommended. The collector plate is silicone mounted (for thermal insulation) on three supporter struts which are placed one at the center and two close to either end of the collector. These supporters should be 4 inches deep, ¾ inch thick, and the width of the collector. Industrial fiberglass (4-inch) is packed behind the collector plate and 2 inches to either side of the plate.

Glazing

A gap of approximately ¾ inch is left between the collector plate and a removable frame holding du Pont Tedlar. The outer glazing is ultraviolet-inhibited corrugated fiberglass which is mounted on a hinged frame that is weather stripped and held in position by hooks and eyes.

Supporting Base

The supporting base consists of a 2-by-4-inch framework which is hinged at the front and rear, the latter hinges being welded to tubular inclination adjusters. The two pipes comprising the adjusters fit inside one another, which allows the angle of the face of the collector to be easily adjusted. When the desired angle is obtained, a screw adjustment threaded into the outer pipe secures the inner pipe. Hinges welded to the top of the adjusters and screwed into the rear of the collector complete the stand's structure.

Pump and Storage Tank

The pump and storage tank are placed in an insulated box. Water is pumped up the collector's serpentine tubing and back down the side of the collector. Pumping upwards ensures that all tubing is full of water and virtually eliminates the possibility of hot spots caused by air pockets in the tubing. A variable power source, as previously mentioned, may be used to control flow rate.

A variety of experiments can be performed using the collector by varying the glazing, the angle of inclination of the collector, the flow rate through the collector, etc. A great number of different variables may be tested while other factors are kept constant.

Barling's Barrel Bread-Box Heater

A do-it-yourself bread-box heater can be a low-technology solar water heater that is relatively simple to build. At the same time it is a very cost-effective structure that produces large volumes of hot water. The description of this heater does not give specific construction details, but rather gives details of a conceptual model that is going to be built by the author.

This bread-box heater is both a collector and hot water storage area in one. Basically the structure consists of a shoe-box-shaped device that is oriented west to east along its long axis. The well-insulated box (R–20) is double-glazed on both its top and its south-facing side. Sunlight enters the box directly or is reflected off the reflector panels into the box. The light entering the bread box strikes the blackened drums or reflective aluminum box lining. The drums heat up, when the light is absorbed, and transfer heat to the water inside them.

Barrels: 5 used 45-gallon fiberglass resin drums

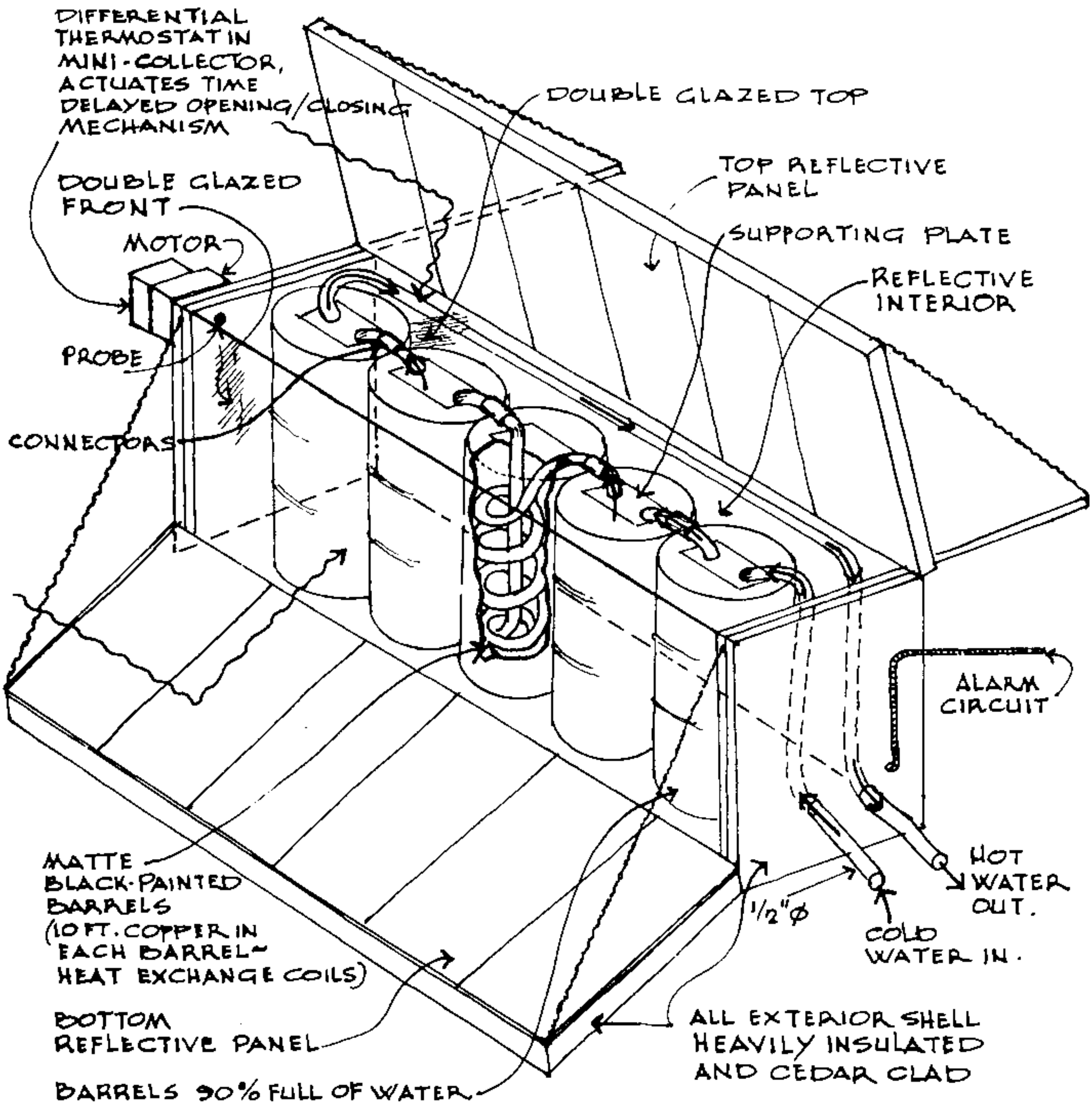
Sheathing: ½-inch pressure-treated plywood

Reflective material: highly polished used aluminum printing plates

Glazing: Outer, Kalwall premium or tempered glass; Inner, Tedlar

Insulation: 4-inch (R–20) Styrofoam on reflector panels; 6-inch (R–20) fiberglass in walls of bread-box

Copper tubing: 70 feet of ½-inch I.D. soft copper tubing



CONSTRUCTION DETAIL.

Collector and Storage

Each of the steel 45-gallon fiberglass resin drums (cost about $2) is 90 percent filled with water and nontoxic propylene glycol antifreeze. The air space at the top of each barrel is to allow for expansion of the water.

Running through each barrel is a ½-inch-I.D. copper tube. In each barrel is a 10-foot coil of the copper to achieve good heat exchange. The water in the coils is under pressure and enters from the house plumbing. The cold water running through the coils is progressively heated and leaves the bread box, where it travels directly into the hot water pipes, or alternatively into a conventional water heater. An air-filled expansion tube should be fitted into the piping to allow for expansion as the water is heated if there is a pressure-reducing valve located where cold water service enters your home.

The coils are removable from each drum because each is soldered to a galvanized sheet which is siliconed and screwed into position in the top of each drum. Each coil has a coating of tar on its exterior to avoid any potential long-term galvanic reaction with the iron of the drum.

If the bread box is not used in the winter, the copper coils can be emptied by blowing compressed air through them, followed by hot air (e.g., from a hair-dryer). The antifreeze would then protect the drums from freeze-up damage. (Check to see that your local code allows the use of antifreeze next to pipes containing potable water).

Throughout spring, summer and fall, the bread-box heater should provide hot water reserve supply (200 gallons) for two cloudy days, for a family of four. The percentage of hot water a system such as this could supply would depend on the climate and many other variables.

Reflector Panels

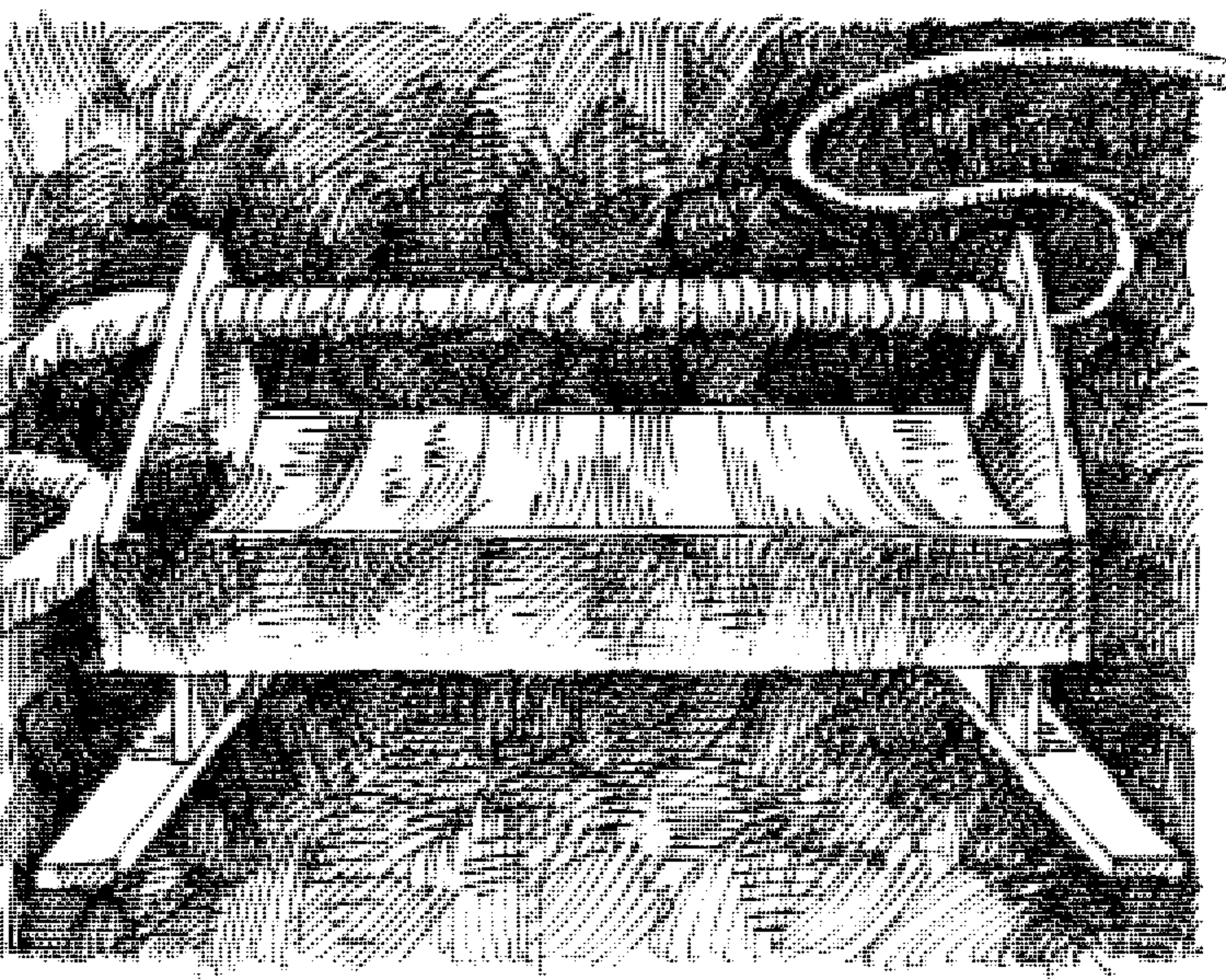
The reflective panels above and below the bread box reflect light into the bread box during sunny weather. During poor weather and at night, the closed panels reflect heat back into the interior, and the heavy insulation in the whole structure further helps to retain heat.

The opening and closing of the reflector panels could, if desired, be made fully automatic by coupling each panel to an electric motor that would be controlled by a differential thermostat. One probe of the thermostat would be housed in the actual bread box and the other would be externally mounted in a mini-collector. Once the temperature was 10°F. higher in the mini-collector than in the bread box, a time-delay relay would activate the motor and open the reflectors. Conversely, as soon as the temperature in the mini-collector dropped 10°F. below that of the bread box the reflector panels would automatically close. The mini-collector would have less insulation than the bread box to make the probe in it more responsive to temperature drops, and so the reflectors would be closed fairly quickly, reducing unnecessary energy losses.

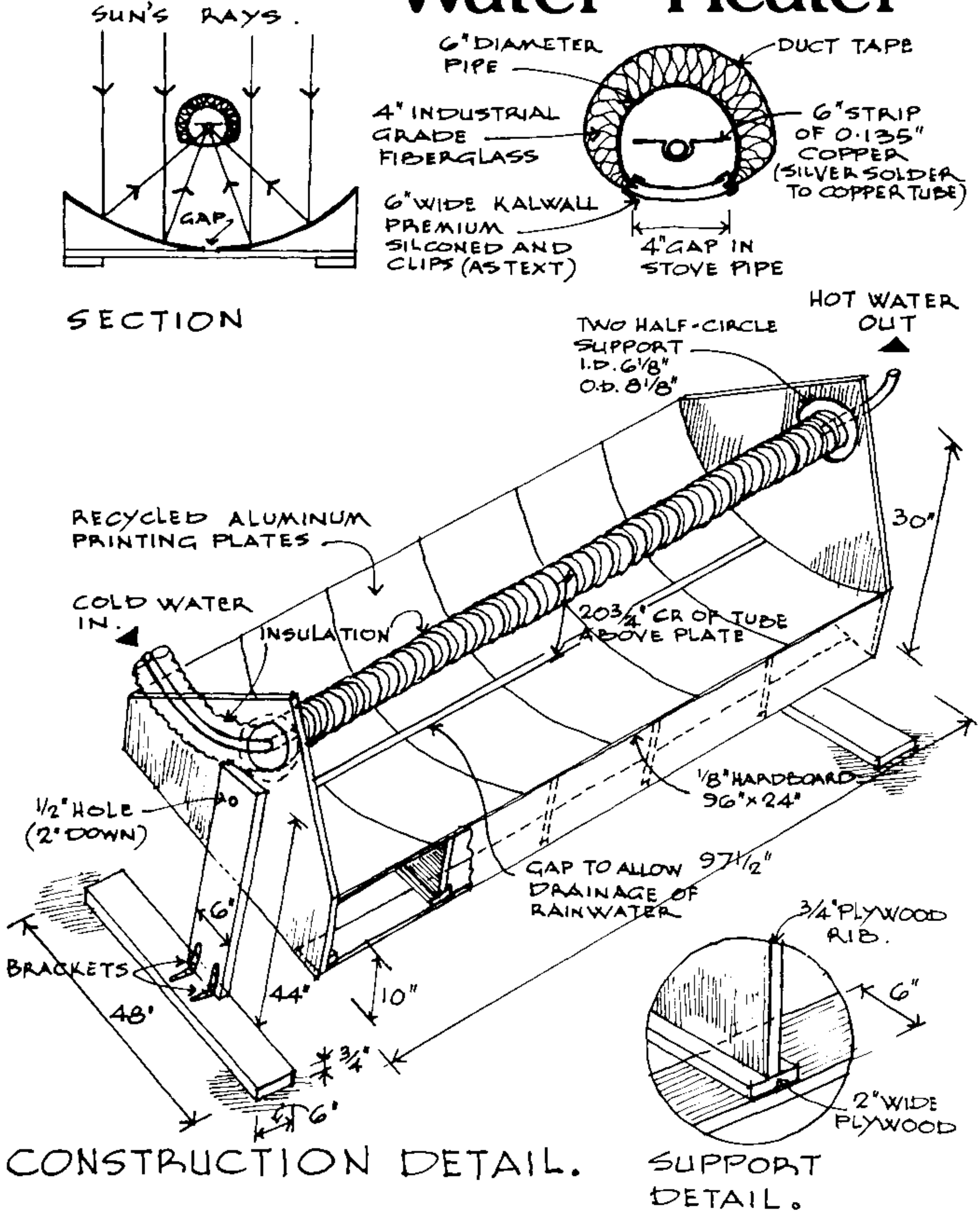
The steel drums in the bread-box should last at least 20 years, providing the metal is not continuously exposed to oxygenated water. As long as the drums are not opened, any oxygen that was already dissolved in the water will react with the iron of the drum and then further rusting will be limited. If a leak should occur, the water released would complete a circuit and sound an alarm in the adjacent home.

I believe that this bread box heater has considerable potential as an inexpensive, practical source of domestic hot water.

Experimental Concentrating Water Heater



Experimental Concentrating Water Heater



This experimental concentrating water heater was built in the course of a series of experiments to see how efficient such designs actually are. An automatic tracking system would be necessary to make this heater really practical for heating domestic hot water.

Flat-plate collectors are generally more appropriate for heating water than concentrating collectors. However, concentrating collectors do have the advantage of not requiring as much expensive glazing material as flat-plate collectors.

Light striking the highly polished aluminum surface of the collector reflects light through a rounded double-glazed fiberglass window. The light is then absorbed by a copper tube soldered to a strip of copper; both are blackened. Water flowing through the pipe absorbs heat, while the glazing and the insulation surrounding the collector tube reduce heat losses.

Materials Required

3 4-by-8-foot sheets of ¾-inch plywood

1 4-by-8-foot sheet of ⅛-inch hardboard

1 8-foot-long piece of 6-inch-diameter stove pipe (or, alternatively, thin-walled asbestos pipe)

1 8-foot strip of 6-inch wide 0.135-inch copper

1 12-foot piece of ¾-inch hard copper tubing

8 feet of 16-foot wide, 4-inch thick (R–12) fiberglass insulation

6 strips of Kalwall premium fiberglass 30-by-5½-inches

4 6-inch steel brackets

2 2-inch bolts, ½-inch diameter

1 pound of 1¼-inch galvanized finishing nails

½ pound of 1-inch plasterboard nails

1 caulking tube of clear silicone sealant

1 can of flat black heat-resistant paint

paint

glue

silver solder

flux

dilute hydrochloric acid

First cut six pieces of ¾-inch plywood 10 inches wide and 48 inches long. Mark parabolas on these pieces, 48 inches wide and having a focal point of 18 inches (see instructions for the hot dog cooker). Cut out the parabolas using a jig- or bandsaw.

Cut six 2-inch-wide strips of ¾-inch plywood, 48 inches long; glue and nail these to the bottom of the six parabolas. These strips should be attached on center to four of the parabolas, the other two parabolas (which will be placed at either end of the collector) should be attached off-center, with one edge of the strip level with the side of the parabola in question.

Cut three strips of ¾-inch plywood, 96 inches long and 6 inches wide. Glue and nail the parabolic ribs of the collector to these three plywood pieces, one at either end of each rib, the other one at the center. Leave a gap of 16 8/10 inches between the base of each rib.

Cut two pieces of ⅛-inch hardboard, 24 inches wide and 96 inches long. Glue and nail these pieces to the parabolas in place, as shown in the illustration. Make sure the smooth side of the hardboard faces upwards.

To the collector attach end pieces of 3/4-inch plywood, the base of which should be 48 inches, sides 10 inches high, and above a triangular shape with its top 30 inches above the base (see illustration).

Drill ¾-inch holes in the end pieces of the collector, 20¾ inches above the center of each piece. Extend each hole 3 inches in two directions, by cutting horizontally with a jigsaw, for later admission of the collector's copper tube and copper strip. Also drill a ½-inch hole, 8¾ inches below each of the holes already drilled, to accommodate the bolts that will connect the collector to each stand.

Stands Stands are made from ¾-inch plywood. Cut two pieces ¾ by 6 by 48 inches and two others ¾ by 6 by 44 inches. Using brackets, assemble the stands as illustrated. Join the stands to the collector assembly by placing ½-by-2-inch bolts through the holes already drilled.

Reflective Surface The collector surface is covered with aluminum printing plates that are first cleaned with white spirits followed by dilute hydrochloric acid, using great care. Attach the plates with contact cement. Self-adhesive aluminized Mylar or strip mirrors may be used instead of aluminum plates if you want to produce a surface with excellent reflective properties.

Pipe Collector The pipe collector assembly is fabricated next. A 6-inch stovepipe, or an asbestos tube, is cut so that three openings are produced in line with one another, each one being 30 inches long and 4 inches wide. This leaves a 1½-inch piece of metal or asbestos before and after each opening to help strengthen the pipe collector. (Note: If asbestos is used, wear a respirator over nose and mouth to avoid inhaling the dust while cutting. Do not allow asbestos dust to contaminate your clothing, and clean work area thoroughly at once.)

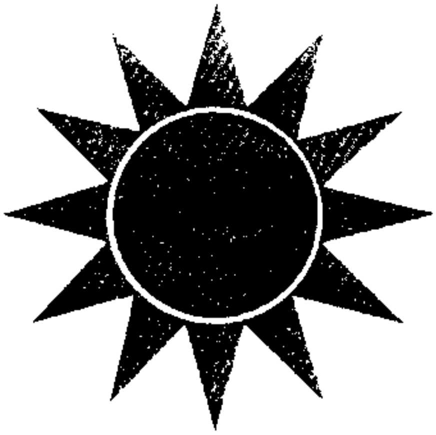
Glazing Six strips of Kalwall premium 30 inches long and 5½ inches wide are bent and are then clipped in place after a liberal application of silicone under and above the glazing (see illustration). It is essential that the glazing does not touch the metal tube.

Insulation of Collector Industrial fiberglass, 4 inches thick, is wrapped around the collector pipe and duct tape is carefully wrapped right around the fiberglass and collector glazing. A ½-inch strip of galvanized metal is screwed along the edges of the glazed area to secure the tape. The duct tape is then removed from the glazing area by carefully using a razor blade. Half-circle supports of ¾-inch plywood are used to secure the collector tube in place. These supports should be 2 inches wide and have an inner diameter of 6⅛ inches and external diameter of 8⅛ inches.

Copper Tube and Strip A 6-inch-wide strip of 0.135-inch copper 96 inches long is crimped over a 12-foot straight length of ¾-inch copper pipe. The pipe is then silver-soldered to the middle of the strip.

Spray the side of the copper tube and strip that will face the glazing with flat black heat-resistant paint. Slide the copper tube and strip through the openings left in the two ends of the collector; then bend the protruding copper pipe as required.

Your concentrating water heater is ready for experimental or practical use.



Solar Swimming Pool Heater

A solar swimming pool heater is typically an unglazed flat-plate collector capable of efficiently collecting solar energy and transferring it to the pool to be heated.

The aim of the system is to raise the temperature of a large volume of water so that on average its temperature is about 10°F. higher than it would be without the system.

Water flows through the collectors at high flow rates and is heated up to 5°F. on each pass. Because the water in the collectors is not much higher in temperature than that of the ambient air temperature, heat losses are relatively low. For this major reason glazing is largely superfluous. Glazing also reflects a high proportion of sunlight when the sun is low in the sky, so that glazed collectors would actually collect less solar energy in the early morning and evening than an unglazed system would.

Materials Required

Plumbing to heater

Schedule-40 plastic piping or schedule-160 (N.B. schedule-40 more durable). Diameter of plastic pipe 1½ or 2 inches, dependent on size of system (see text)

1 vacuum-relief valve

Controls

Manual or automatic (see Panel and Plumbing Layout)

Materials necessary for template and form construction

2 4-by-8-foot sheets of ½-inch plywood

½ 4-by-8-foot sheet of ¾-inch plywood

glue

Materials necessary per panel

1 4-by-8-foot sheet of ½-inch plywood

1 4-by-8-foot sheet of ¼-inch hardboard

25 feet of heavy-duty U-configuration vinyl coping

2 2-by-8-foot sheets of 0.135-inch copper

2 16-foot lengths of ½-inch soft copper tubing (N.B. approximately 2/3 of 50-foot coil)

2 4-foot lengths of 2-inch low-pressure copper drainage pipe (2/3 of 12-foot standard length)

4 CxM threaded copper adapters (thread to fit 9/16-inch hole in header; open end to accommodate ½-inch riser tube)

1 caulking tube of clear silicone sealant

1 quart of Rustoleum flat black paint

contact cement

cold tar

50:50 solder

flux

steel wool

Collector Location and Tilt

The panels of the system should be placed on a south-facing roof or a rack custom-made for the job. The tilt of the panels should be latitude minus 10° to 15° to optimize the collection of energy from the summer sun.

As a very rough rule of thumb the panel area for the particular pool should be about 50 percent of the surface area of the pool, providing roof pitch, orientation, wind factor, etc., are optimal. Systems using a small area of panels are of little use because they are not effective when they are needed most, i.e., at the beginning and end of the heating season.

Collector Panel

Copper was chosen as the recommended collector material for both the tubes and the flat plates because of its reliability and compatibility with chlorinated water. Aluminum is totally unsuitable for this particular use, as it corrodes far too quickly. A combination of copper tubes and aluminum flat plates produces the inevitable problem of galvanic action, which can result in sacrificial dissolving of the aluminum. In addition, the problem of satisfactorily bonding the copper to the aluminum is hard to solve in a do-it-yourself system. Iron was not used because it also presents potential corrosion problems over the long term.

Each 8-by-4-foot panel consists of copper sheet with a header at either end and two serpentine riser tubes linking the headers. The tubes are soldered to the underside of each sheet. The copper is then bonded to a plywood frame and painted flat black to absorb sunlight. The individual panels are then linked together and plumbed into the pool's existing plumbing.

Design Considerations

In determining the overall design of the pool heating system a number of factors have to be taken into consideration. Using the specific system first built as an example: The volume of the pool was 27,300 U.S. gallons. The size of the pool was 18 by 36 feet, with a surface area of 648 square feet. The existing pump was a ¾-h.p. Jacuzzi. It was desired to achieve a swimming temperature of 80°F. The wind factor was not considered to be a major problem in the particular location. The angle of the roof was 20°. The optimum angle for summer use = latitude − 15° = 50° − 15° = 35° for the particular latitude in question. (N.B. Tilt can be up to 20° from optimum and 90 percent of maximum insolation is still received.)

Design calculations for pool described*

a) Volume of the pool = 27,300 U.S. gallons

b) Circulation pump circulates approximately one pool volume every 10 hours (typical). Flow rate through total solar heating system = $\frac{27{,}300}{600}$ = 45.5 gallons/minute (G.P.M.).

c) The number of tubes = 2 per collector. On 10 collectors there are 20 tubes.

d) Tube size = ⅜ inch nominal diameter (½ inch external diameter)

e) G.P.M. per tube = $\frac{45.5}{20}$ = 2.275

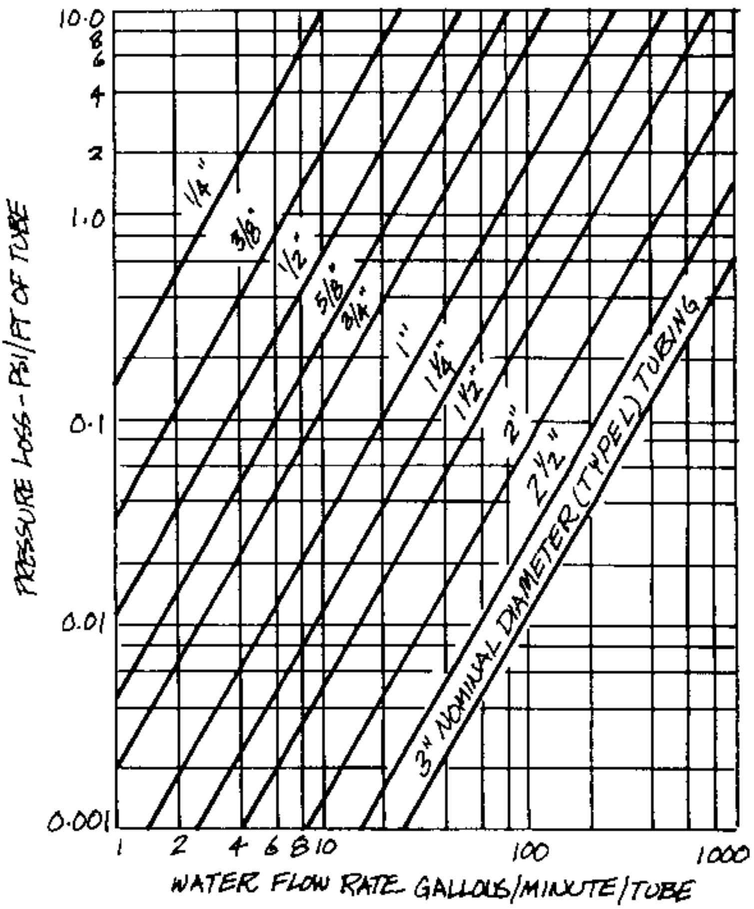
f) Flow length = 15 feet + 9 inches for each bend (9 inches added on to compensate for frictional loss due to bend; with 10 bends, therefore, 7.5 feet extra). Equivalent flow length for each riser = 22.5 feet

g) Pressure drop = pressure drop per foot × length (see accompanying graph)

$= 0.175 \times 22.5$

$= 3.9375$

$= 3.94$ lb./in.^{2} (correct to 2 decimal places)



HOW PRESSURE DROP PER FOOT OF TUBE VARIES AS A FUNCTION OF WATER FLOW RATE AND TUBE DIAMETER *

*OPTIMUM SPACING OF RISERS ON COPPER SHEET.

Copper Sheet Description		Optimum Spacing of Collection Tubes	
Weight	**Thickness**	**Unglazed**	**Glazed**
10 oz.	0.0135 in.	7¾ in.	8½ in.
14 oz.	0.0189 in.	8¼ in.	9¼ in.
16 oz.	0.0216 in.	8½ in.	9½ in.
20 oz.	0.0270 in.	8¾ in.	10 in.

Design Guidelines

In designing a heater for your own specific pool carefully consider the following:

> *Pool Plumbing*—If you have a small or medium-size pool, use 1½-inch tubing for the plumbing, if the pool is large, use 2-inch tubing, if it is very large, you should determine the diameter necessary.
>
> *Collector Tube Spacing*—With thin sheet material, you might use a spacing of 8 inches, for thick material either 8 inches or 10 inches, depending on the width of sheet material you are able to buy. Use tubes of ⅜-inch nominal diameter, i.e. of ½-inch actual outside diameter.
>
> *Number of Tubes*—Do not use less than about 10 heater tubes in parallel. If you use relatively few, use ½-inch tubing (i.e., ⅝-inch actual outside diameter). If you use about 15 tubes or more you might use ⅜-inch tube (i.e., ½-inch actual outside diameter).
>
> *Length of Tubes on Collector*—On a combination heater/roof the length of the tubes should not be more than about 30 feet. On a heater which does not have a roofing function you can build it longer if you wish, but you should allow for thermal expansion, and run through some pressure-drop calculations.*

Following the guidelines outlined should prevent any potential disasters in your own system.

* Courtesy of Copper Development Association Inc.

Construction

Sequential sketches illustrating the construction of each individual swimming pool heater panel follow. To facilitate construction, the description and sketches should be followed simultaneously. To save time, it is advised that all panels be constructed at the same time rather than individually.

Laying Out Serpentines

On an 8-by-4-foot sheet of exterior-grade plywood, very carefully draw the twin serpentine arrangements, as illustrated. The accuracy of each serpentine can be checked by using a piece of string 16 feet in length. A 50-foot length of soft copper ½-inch-O.D. (⅜-inch-I.D.) can later be conveniently cut into 16-foot lengths with some room left for error.

Cutting Out Serpentines

Once the 16-foot-long lines of the serpentines have been drawn, take a compass set open at 2 inches and mark out two lines, one on either side of each serpentine line, so that two tracks, 4 inches wide, are produced. Using a saber saw, cut out the two 4-inch-wide serpentine tracks by following the lines drawn. These tracks will later accommodate the copper tubing. (The first ½-inch plywood sheet marked and cut out may now be used as a guide for marking all future serpentine tracks.)

Laying Out Serpentines on Copper Sheet

Place two 2-by-8-foot sheets of 0.0135-inch copper under the serpentine tracks. The copper sheets should overlap ½ inch and thus be ¼ inch away from each side edge of the plywood. Using a felt-tipped pen, mark out the serpentine tracks on the copper ready for later soldering.

Bonding Hardboard to Plywood

Roll contact cement onto the plywood and also onto the smooth side of an 8-by-4-foot sheet of ¼-inch hardboard. Make sure that plenty of cement is used. When the cement has dried somewhat, test to see if a piece of paper will stick to it; if it won't it is ready for use. Firmly press the hardboard to the plywood to make a good bond. Walk over the panel to ensure complete adhesion.

Forming the Copper Tubes

Next, a form is made in order to bend the copper pipe required for each panel. The form can conveniently be made on a 2-by-8-foot sheet of ½-inch plywood. Mark out a serpentine track identical to that originally drawn. Then mark and cut pieces of ¾-inch plywood to produce the individual semicircular pieces of the overall form. Bear in mind that these individual pieces of plywood must be cut ¼ inch away from the serpentine (N.B. the serpentine line represents the midpoint of the ½-inch tube). The individual forms should be firmly glued and screwed in place.

Twenty 16-foot lengths of ½-inch-O.D. copper tubing are then bent into shape, taking care not to kink the tubing. The tubing is then cut to length with a tubing cutter. The end of each tube is carefully cleaned to remove burrs and the ridge left by the tubing cutter. Two or three people can bend the tubing together much faster than one person. Surprisingly, it only takes about two minutes to bend each tube!

Headers

Using 2-inch low-pressure copper drainage pipe, cut twenty 4-foot pieces of copper that will be the headers on each collector. Try to borrow a large tubing cutter from a cooperative plumbing shop; a tubing cutter is easier to use than a hacksaw and produces a more professional finish. Remove burrs and ridges at either end of the tubes. With a centerpunch, mark spots 6 inches and 27 inches from one end of each header. Then carefully drill holes 9/16 inch in diameter and thread each hole with a ⅜-inch tap to accommodate a CxM adapter, the C opening being ½ inch I.D. After thorough cleaning, the adapters are fluxed with a good-quality paste flux, screwed into position, and soldered with a 50:50 solder. The procedure is repeated with all the other headers.

Soldering the Copper Tubes to the Copper Sheets

Next the copper tubes are soldered to the copper sheets. The sheets are first drilled to produce two holes, 9/16-inch in diameter, 5 inches from the edge of the copper (as illustrated).

The copper is then cleaned with steel wool and fluxed along the track previously marked out with a felt-tipped pen. The copper tube is then placed on the fluxed track after it also has been cleaned and fluxed. The tube is held in place by means of two iron tubes 2 feet long and 1 inch square in cross-section. The iron tubes (or equivalent) are clamped in place across the copper tube and the section in between the pipe braces is soldered with 50:50 solder. The soldering is then continued section by section. Remember to feed the ends of the tube through the holes in the copper sheet prior to soldering close to either end of the sheet.

Installing the Copper Sheets

Once the copper tubes are soldered in place the copper sheets and tubes are ready to be placed in the plywood tracks. Contact cement is applied to a 4-inch margin around the perimeter of the underside of each copper sheet and the corresponding areas on the plywood pieces with the tracks cut out. Firmly bond the copper and plywood together once the contact cement is dry. Remember to offset the 2-by-8-foot sheets so that they overlap by ½ inch at the center. The middle area of each 2-by-8-foot copper sheet is not glued to allow for a certain degree of expansion and contraction of each copper sheet and tube.

The four corners of each panel are cut off with a saber saw, using a fairly fine-toothed blade. Then ¾-inch heavy-duty vinyl window coping (U-configuration) is applied to all the edges of each panel, using clear silicone, and to ensure a tight seal a few rough-galvanized large-headed nails are also used to secure the coping. Silicone all areas of the panel that might conceivably leak at some future date; better safe than sorry!

Installing the Headers and Risers

Place the headers in position, clamp to the panel and solder the risers to the connectors in the headers. Caulk where the header touches the collector along both sides of the header (see illustration). Where the copper risers come through the copper panel to meet the headers, apply further silicone. Leave the silicone to dry for at least twenty-four hours before removing the clamps holding the headers in place.

Painting the Collector Panels

Roughen the surface of the copper with emery cloth, making sure that all the surface is properly cleaned and roughened. Apply a high-quality flat black paint to the panel. (A heat-resistant paint is probably unnecessary since very high temperatures are not experienced with this type of collector. I have found Rustoleum flat black paint to be quite satisfactory.) The back of each panel is thoroughly painted with cold tar to ensure that it will be impervious to water. Several coats may be necessary.

Mounting the Panels

The individual panels are mounted so that all the top and bottom headers of each panel are in line with one another and are absolutely horizontal with reference to the ground. A chalk line may be conveniently snapped on the roof or mounting rack to achieve this. The collectors should be as high on the particular roof as possible to prevent snow build-up above them.

The specific mounting instructions are as follows: six ⅜-inch-diameter holes are drilled through each panel; two at the top, middle, and bottom of each panel, away from the internal piping.

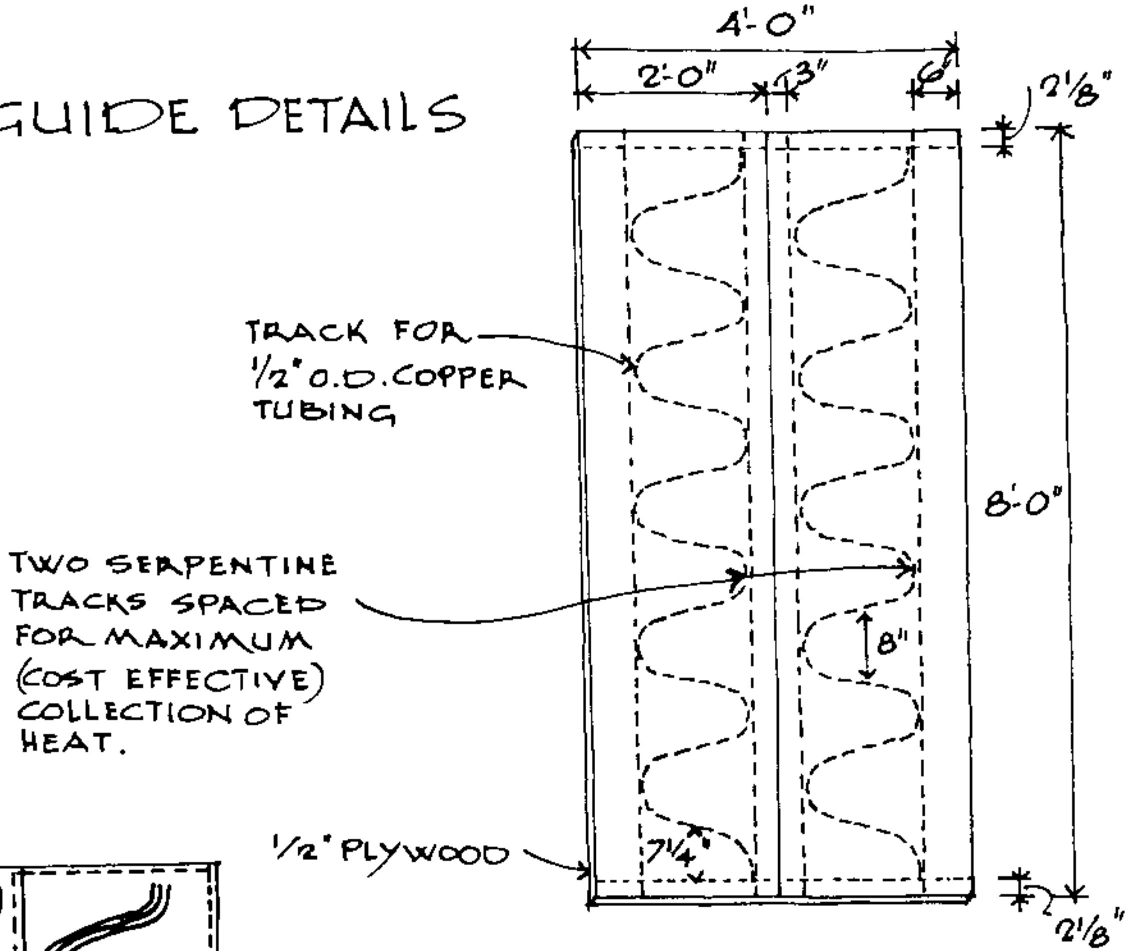
The holes are elongated in a horizontal direction to allow for expansion or contraction of the mounted panel. Silicone or polysulphide sealant is injected into the holes and the lag bolts are firmly screwed into the roof. On a shaked roof, or wherever considered necessary, the panels may be raised from the roof surface by mounting them on three wooden slats running parallel to the headers. The slats are bolted to the roof before the panels are in turn attached to them.

The panels are set about 4 inches apart and are linked to the next panel by means of high-grade rubber piping that fits snugly over the ends of the headers. At least 1½ inches of the rubber should cover the protruding ends of each header. The rubber hose is secured by the use of two stainless steel clamps at each end.

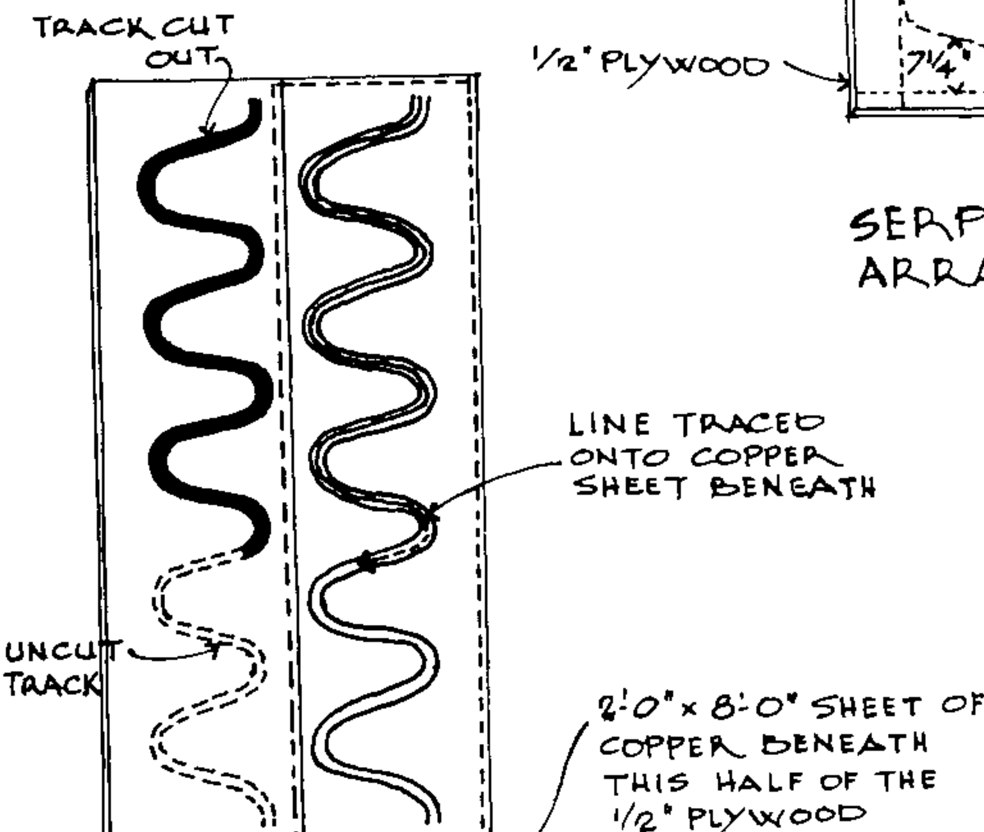
The rest of the plumbing is completed as per enclosed diagram, using schedule 40 or 160 plastic piping.

Pool Heater

TRACK GUIDE DETAILS

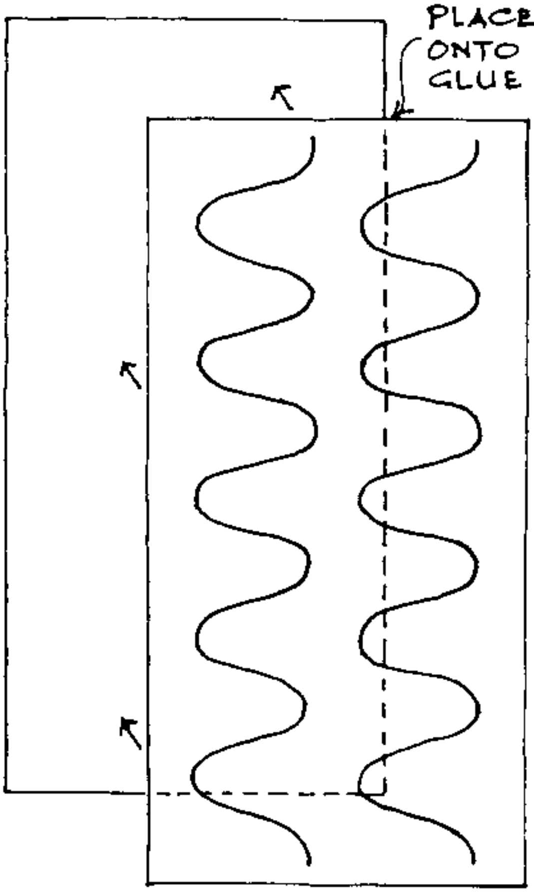


SERPENTINE ARRANGEMENT

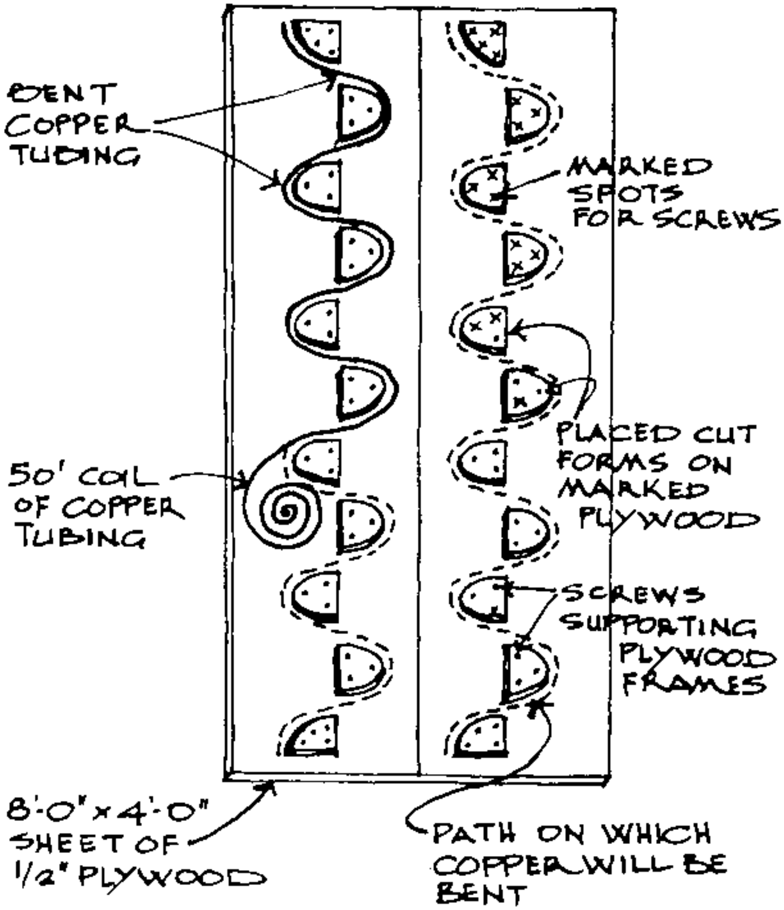


TEMPLATE FABRICATION

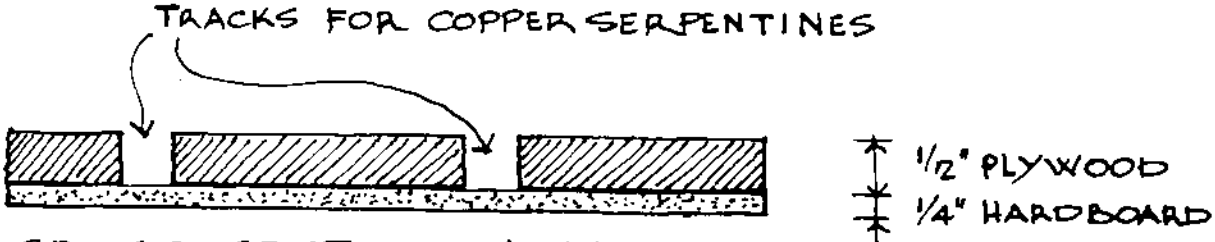
USE OF TEMPLATE



BONDING HARDBOARD TO PLYWOOD.

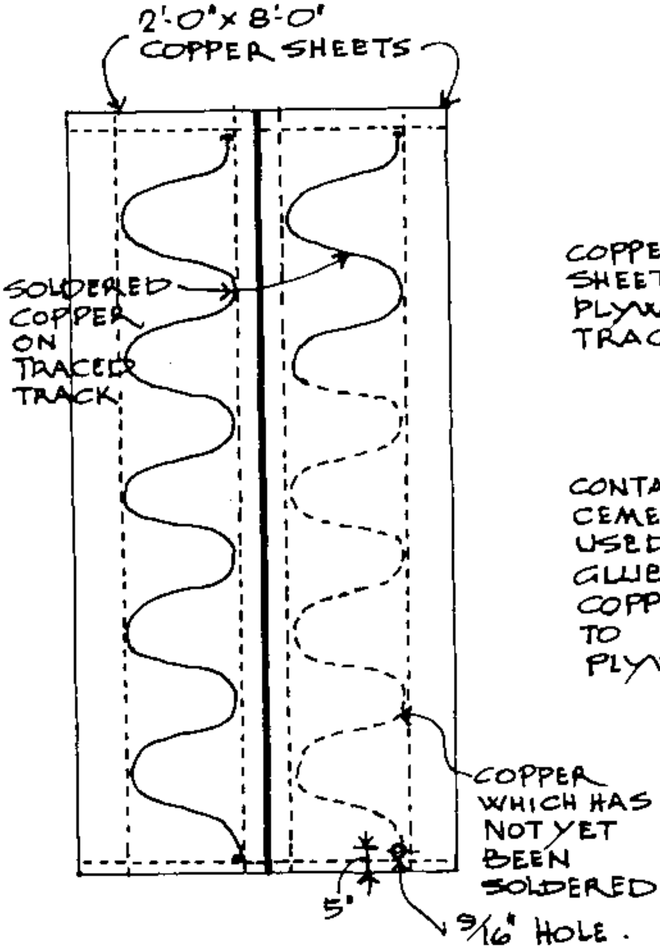


USE OF FORM. FORM CONSTRUCTION

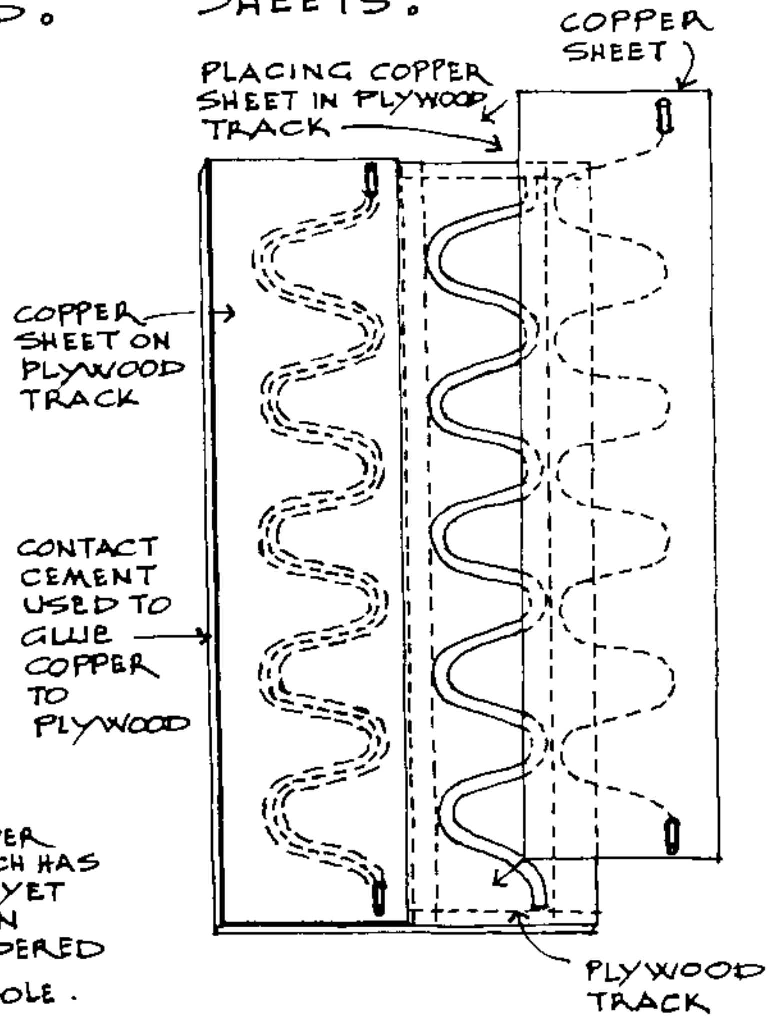


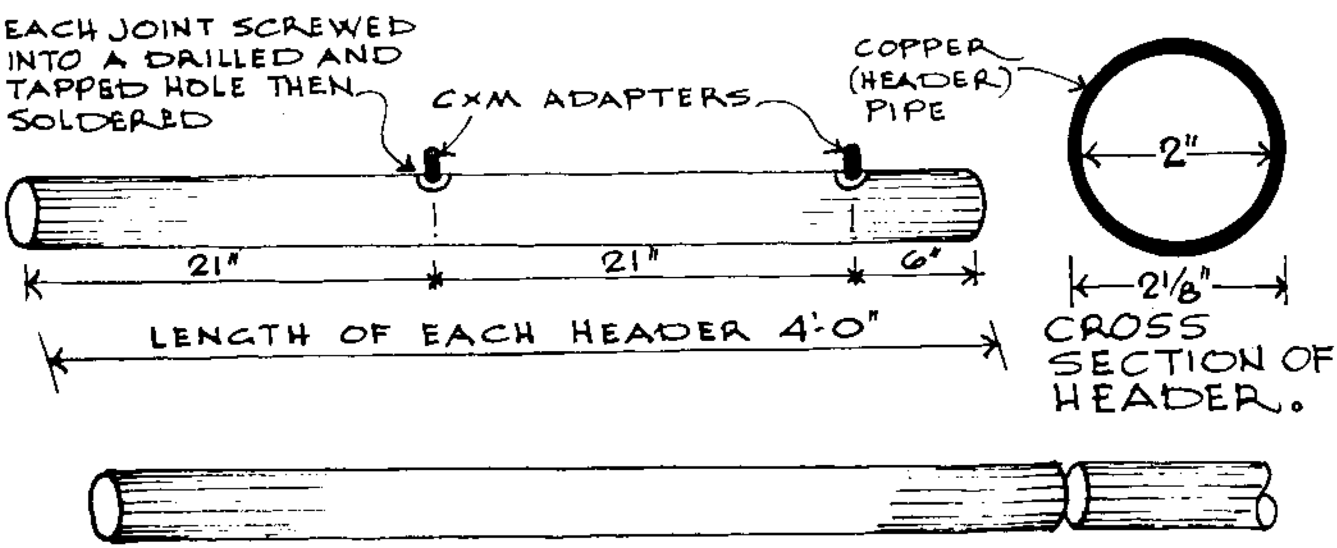
CROSS SECTIONAL VIEW.

SOLDERED COPPER SHEETS.

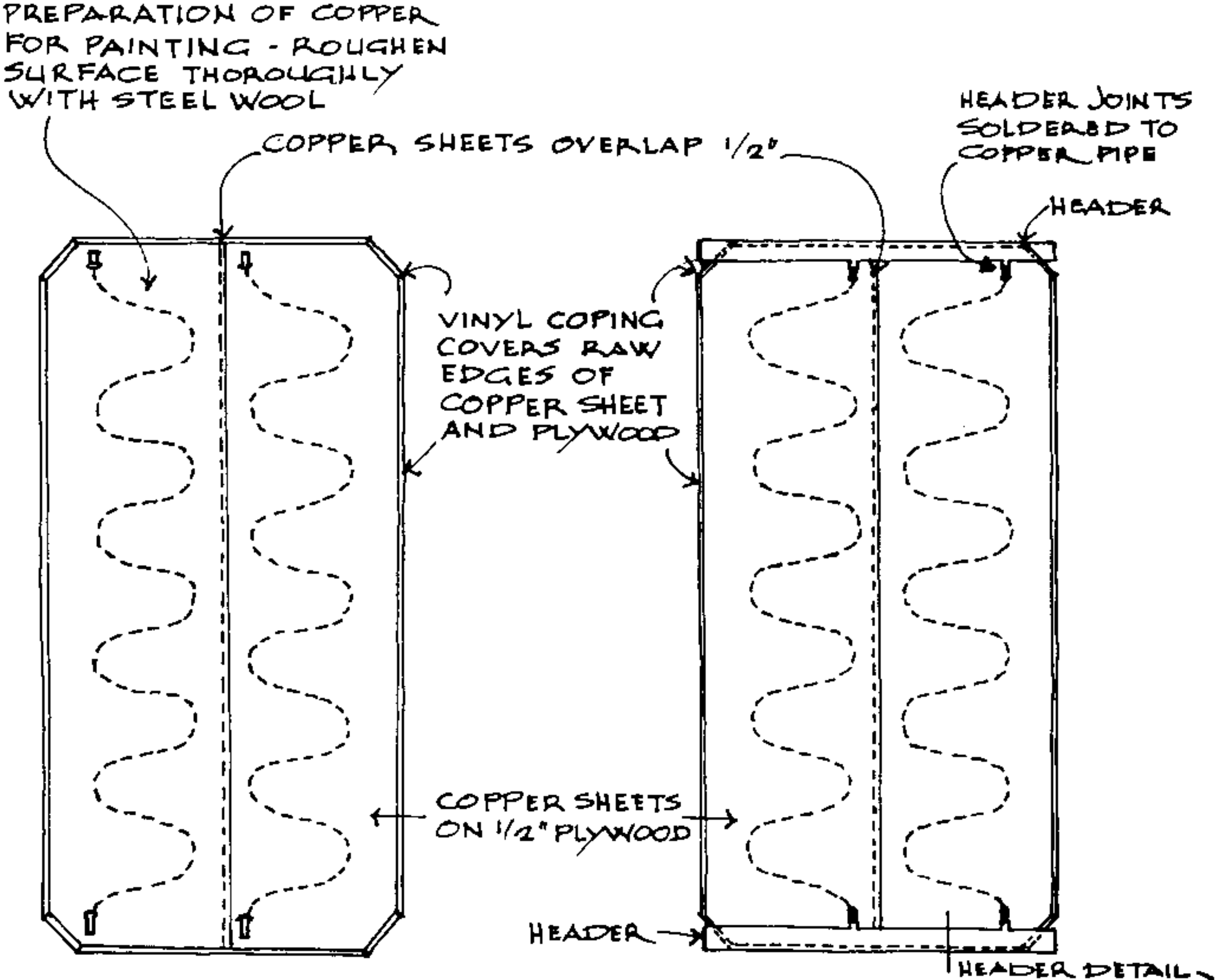


PLACEMENT OF COPPER SHEETS.



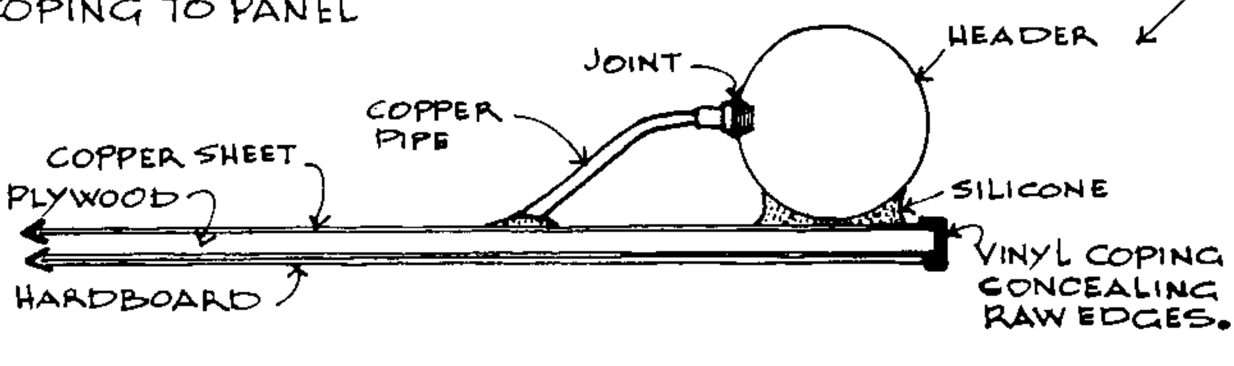


HEADER CONSTRUCTION.

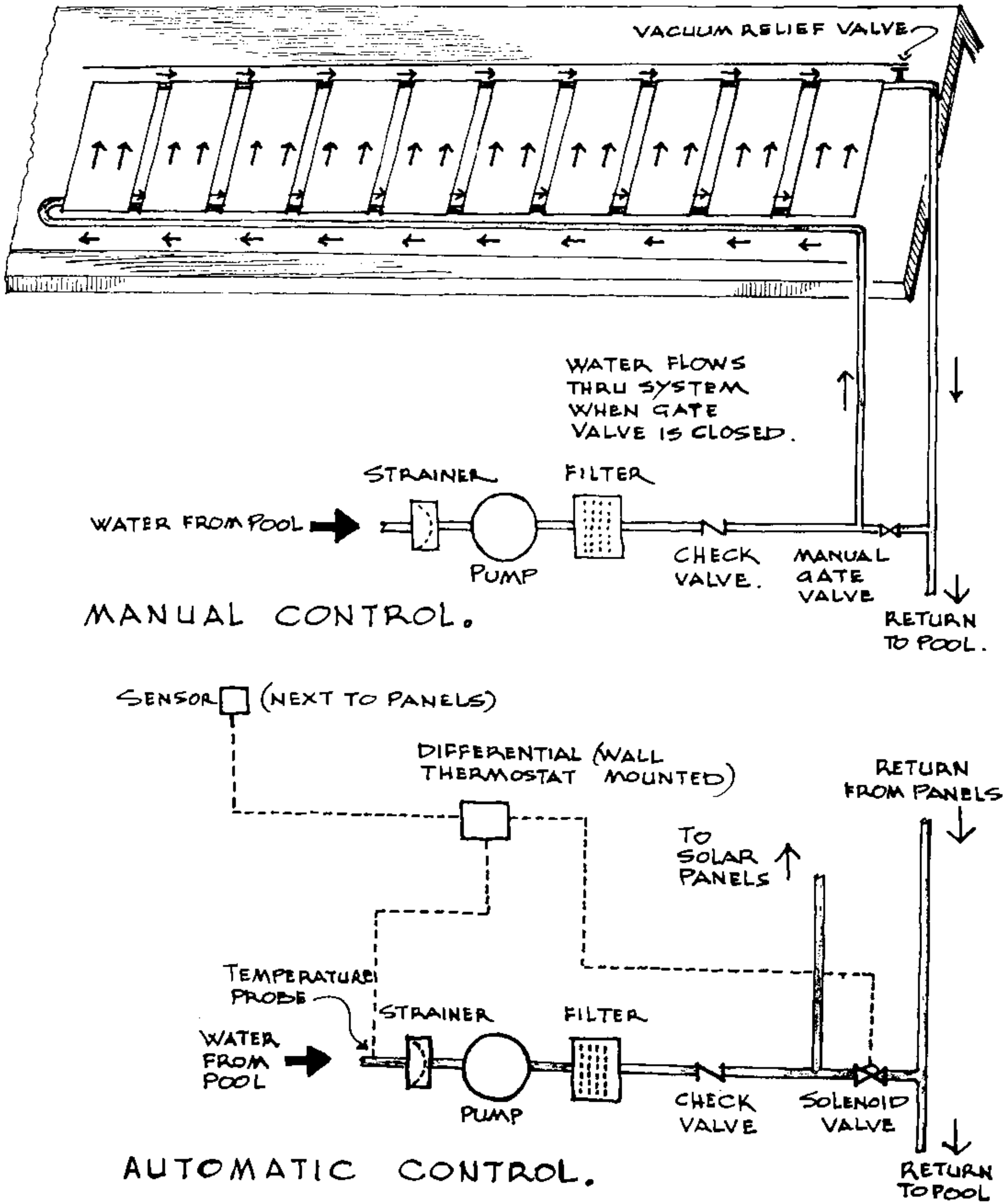


APPLICATION OF COPING TO PANEL

COMPLETED PANEL.

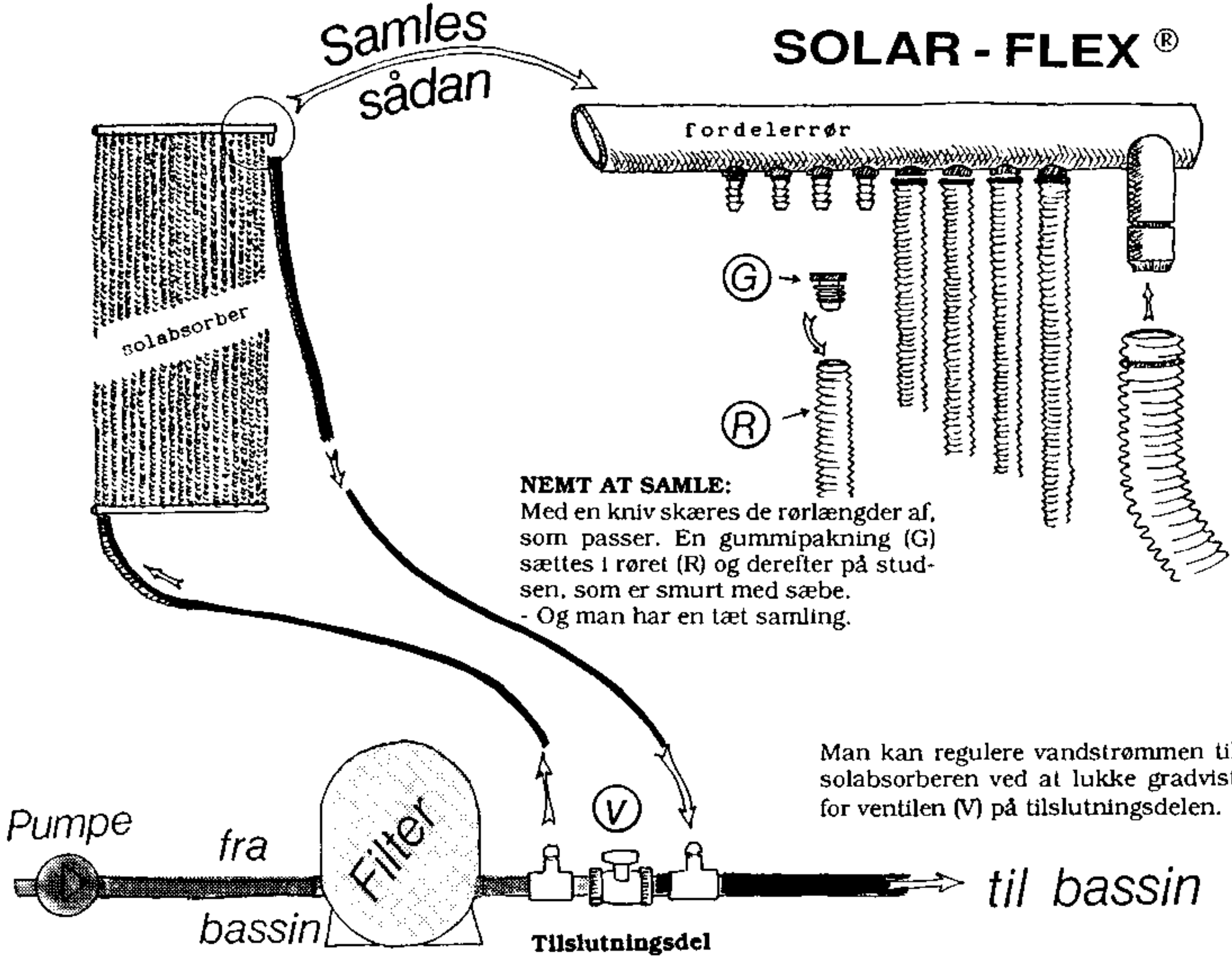


HEADER DETAIL.



PANEL AND PLUMBING LAYOUT

SOLAR - FLEX ®



NEMT AT SAMLE:
Med en kniv skæres de rørlængder af, som passer. En gummipakning (G) sættes i røret (R) og derefter på studsen, som er smurt med sæbe.
- Og man har en tæt samling.

Man kan regulere vandstrømmen til solabsorberen ved at lukke gradvist for ventilen (V) på tilslutningsdelen.

Low-Cost Air Heater

This air heater utilizes scrap printing plates for the fabrication of low-cost collector plates. The collector plates consist of corrugated aluminum over polished flat aluminum. The upper corrugated surface is painted matte black and absorbs sunlight that falls on its surface, heating it. Air flowing over the plates and through multiple holes in their surface then flows under the plates and out of the collector. The flow of air above and below the plates helps to minimize loss of heat from the collector and to maximize its efficiency.

Materials Required

1 4-by-8-foot sheet of ¾-inch plywood

1 2-by-8-foot piece of 3/4-inch plywood

8 3-by-2-foot, 0.009-inch used aluminum printing plates

Suggested glazing

Outer, Kalwall premium or tempered glass, 26½-by-1 90½-inches; Inner, Tedlar 3-by-8-feet (to be trimmed)

Galvanized metal

1 4-by-8-foot sheet (only if back of collector is to be flashed)

General

1 20 foot piece 9-inch-wide metal strip

2 boxes of 3-by-3-by-32½-inch (open at one end)

1 20 foot piece of fiberglass, 16 inches wide, 4 inches thick (R-12)

1 caulking cartridge of clear silicone sealant

2 cans of flat black heat-resistant paint

½ pound of 1¼-inch galvanized nails

3 dozen ½-inch aluminum screws

½ pound of ⅜-inch sheet metal screws

waterproof glue

paint

Materials The major materials required for this project are ¾-inch plywood, 4-inch-thick fiberglass batts, eight 3-by-2-foot used printing plates (0.009 inch thick), galvanized flashing, and glazing materials as described.

Collector Box From ¾-inch plywood cut out the base of the collector box, a rectangle 96 by 32½ inches. Cut two pieces of ¾-inch plywood 7¼ by 96 inches. Nail and glue these two pieces of plywood onto the top of the base, along its edges. Cut two pieces of ¾-inch plywood 5¾ by 31 inches; glue and nail these air intake and exit dividers in place 6 inches from either end of the collector box.

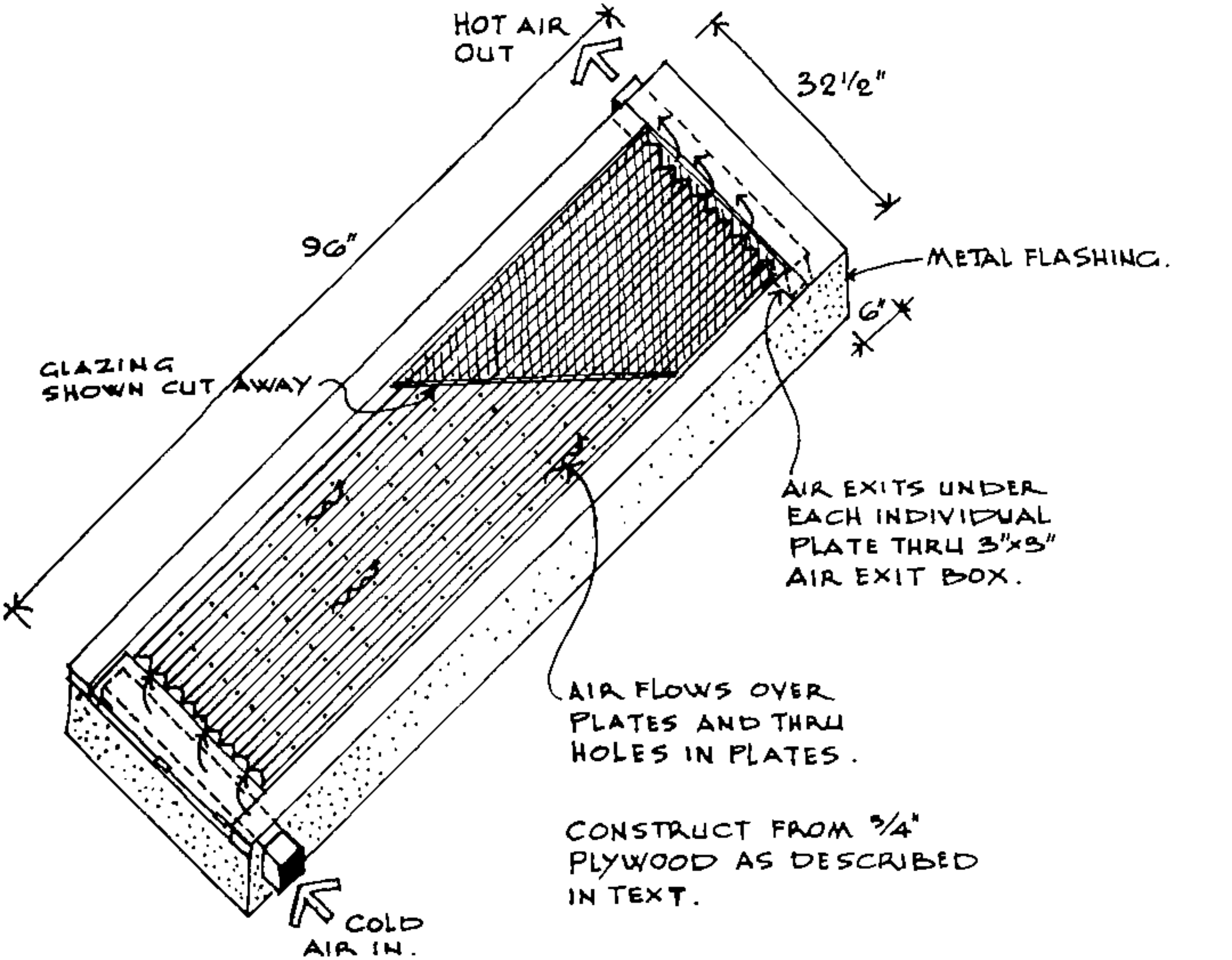
Intake and Exit Boxes Either fabricate, or have made, two oblong galvanized boxes, 3 by 3 by 32½ inches, each having one end open. Mark and cut out holes to accommodate these boxes; use the actual boxes as guides to mark out holes in the plywood sidepieces.

Use sheet-metal screws to attach both intake box and exit box in their respective places. Make sure the open end of each box protrudes 3 inches beyond the edges of the collector.

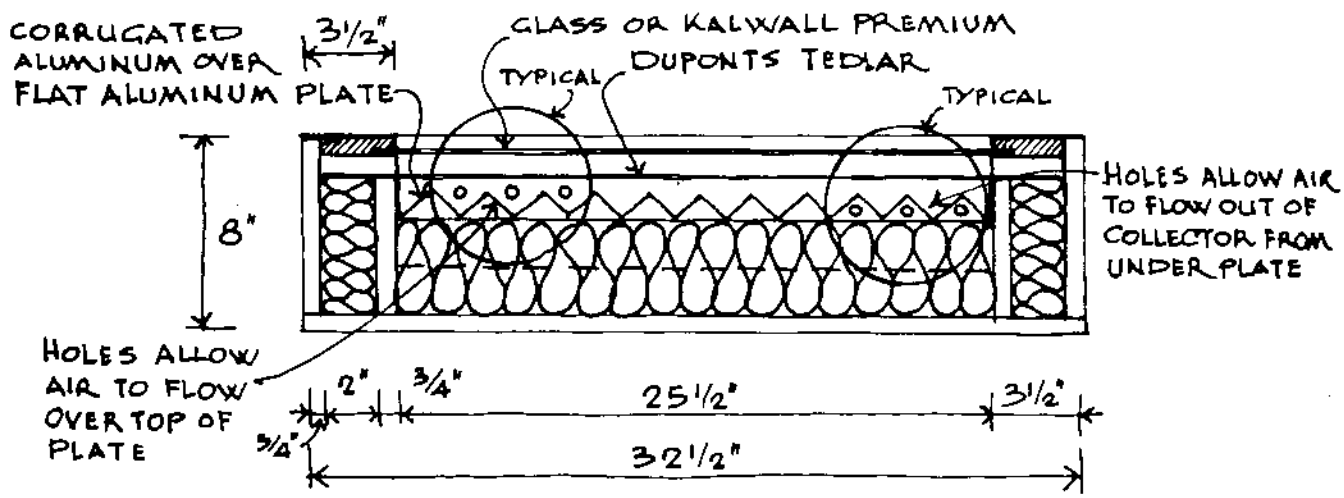
Collector Plate Supports Rip out, from ¾-inch plywood, side collector plate supporters 5¾ by 82½ inches and glue and nail them to the base and intake and exit dividers so that the inward-facing surface of the plywood is exactly 3½ inches from the outer edge of the collector box.

Cut five collector plate supporting struts out of ¾-inch plywood, each one 2 by 25½ inches. Attach one of these to the air intake divider and one to the exit divider so that the upper edge of the struts is 4 inches from the inner surface of the collector's base. Glue and nail the other plate supporters at equal intervals inside the collector box.

Insulation Pack the whole of the interior of the collector's structure with 4-inch-thick batts of fiberglass, making sure that all areas to be insulated are thoroughly stuffed. (Don't pack the fiberglass too tightly, however, or you will reduce its insulating properties.)



CONSTRUCTION DETAIL.



CROSS SECTION.

Collector Plates

Take eight printing plates 3 by 2 feet in size, and clean them with white spirits. Bend V-shaped corrugations parallel to the 2-foot sides of four of the cleaned plates; each side of each V should be approximately 1½ inches.

Halfway up each V, punch a hole with a 1-inch finishing nail through the aluminum. Repeat on either side of the V's at 4-inch intervals along the entire length of the plates. These holes will later allow airflow from one side of the plates to the other.

Assembling the Collector Boxes

Drill ½-inch holes from the interior of the collector box into the air intake box and into the exit box, bearing in mind that air goes into the collector above the plates and exits below the plates. Use the corrugated shape as a guide in determining the positions of the holes. Glue and screw the two ends of the collector box (31 by 6½ inches, made of ¾ inch plywood) into place.

Reflector Plates

Fix four flat plates of shiny polished aluminum with aluminum screws and silicone, with the 3-foot length across the box. Trim after bending and securing these reflective plates to the inner sides of the collector plate supporters.

Finishing and Installing Absorber Plates

The corrugated absorber plates should be sprayed on both sides with "hibachi flat black" or an equivalent heat-resistant paint. When the paint has dried use more screws and silicone to fix the painted corrugated sheets above the flat plates, making sure that 1½-inch strips are left on either side. These are then bent up the sides of the collector side supporters and are fixed in position. Overlap the plates as they are placed in the collector.

Glazing

Depending on the glazing to be used, either follow the drawing details (for an inner cover of Tedlar and outer glazing of Kalwall) or adapt them according to whatever other materials are available.

Finishing the Collector Box

The whole collector box can be painted or preferably clad with galvanized iron sheeting. Use clear silicone to thoroughly caulk all areas where leaks could occur.

Giant Experimental Reflector

This project is for experienced solar enthusiasts, not beginners. A giant experimental reflector was constructed so that a group of highly motivated students could build one of the largest (if not the largest) solar furnaces ever built by students of their age. Certainly this furnace has the potential to provide sufficient power to drive a Stirling engine or other engine dependent on a fairly high temperature source. The basic structure of this giant experimental reflector is essentially the same as that of the parabolic concentrating reflector described previously.

Highly polished recycled aluminum printing plates or self-adhesive aluminized Mylar provides the reflective surface for the collector. This surface can be inclined at different angles by adjusting the inclination of the swiveling collector. Rotational movement is achieved by moving the base (this movement could be facilitated by mounting the base on wheels).

The whole structure is susceptible to wind damage and therefore is intended primarily for intermittent rather than continuous use.

Materials Required

2 4-by-8-foot sheets of $\frac{3}{4}$-inch plywood

4 4-by-8-foot sheets of $\frac{1}{2}$-inch plywood

$1\frac{1}{2}$ 4-by-8-foot sheets of $\frac{1}{8}$-inch hardboard

48 feet of 2-by-8-inch softwood

46 feet of 1-by-1-inch softwood

50 square feet of self-adhesive aluminized Mylar mounted on hardboard or highly polished recycled aluminum printing plates

4 12-inch steel brackets

6 2-inch-long, ½-inch diameter bolts

1 11-foot heavy-duty chain

1 pound of 2½-inch rough-galvanized nails

1 pound of 1½-inch galvanized finishing nails

1 3-inch screw-threaded hook

½-inch staples

waterproof glue

paint

dilute hydrochloric acid

Furnace Base The base of the furnace structure is made in two separate halves which are then joined when they are completed. This allows the structure to be disassembled and moved through standard-size door openings.

First start the construction of the collector itself. Place two 4-by-8-foot sheets of ¾-inch plywood side by side on a flat surface. Using a straight piece of wood 50 inches long, hammer two nails in the wood, 1 inch from either end of the wood, making sure that the nails are exactly 48 inches apart. Using this as a compass, scribe out a circle on the plywood having a radius of 48 inches.

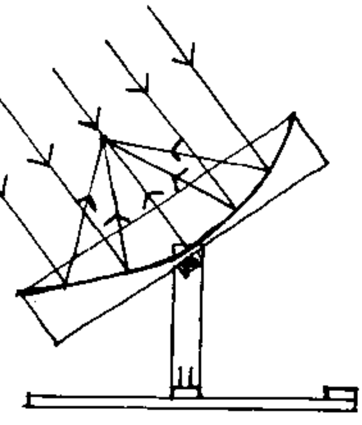
Two pieces of ¾-inch plywood are ripped 96 inches long and 18 inches wide. Mark out on these pieces a complete parabola having a width of 96 inches and a focal point of 36 inches. (Use the method of parabola formation described earlier for construction of the hot dog cooker.)

Taking one piece of the plywood furnace base (previously marked out with the semicircle on it), attach one parabola along its edge. A 1-by-1-inch wooden strip should be nailed to the base and parabola to give additional support to the parabola. The process just completed should be repeated with the other half of the furnace base.

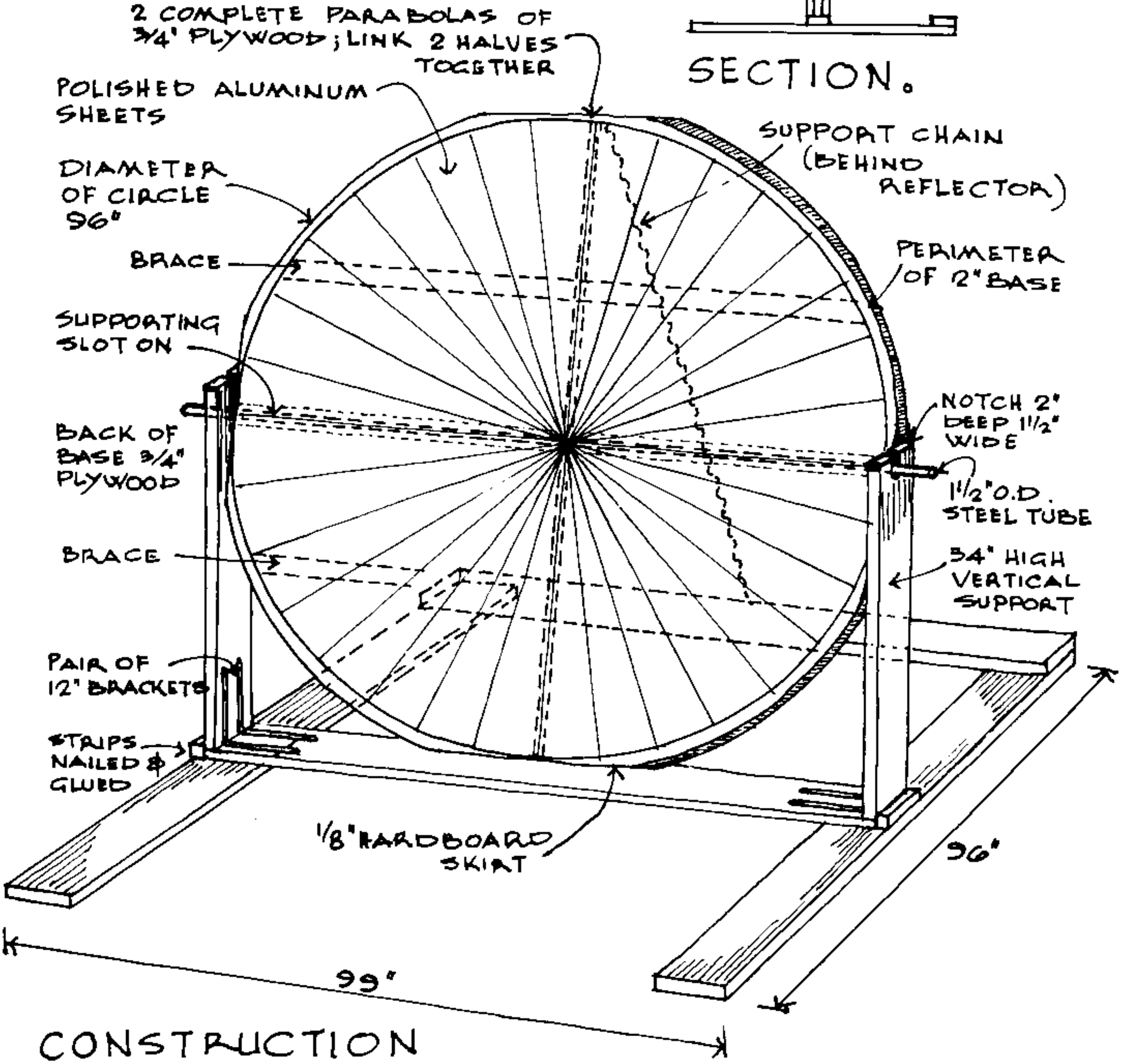
Reflector Shell Using ½-inch plywood, cut thirty half-parabolas, 4 feet wide and having a 36-inch focal point. Glue and nail 1-by-1-inch strips to one side of the base of each of these half-parabolas. Then attach them radially, as illustrated, placing them 9-4/10 inches on center. Many of the half-parabolas will require cutting short on their narrow ends in order to fit on the collector base. The central

Giant Experimental Reflector

WHEN REFLECTOR IS AIMED TOWARDS SUN, LIGHT REFLECTS OFF POLISHED ALUMINUM SURFACE TO A FOCAL POINT 36" FROM THE CENTER OF THE REFLECTOR.



SECTION.



CONSTRUCTION DETAIL.

area of the collector may be filled in with wooden blocks which when attached can be belt-sanded to match the remaining parabolic shapes. Two or three 1-by-1-inch bridging struts can be glued and screwed between each two ribs to help stabilize them.

A U-shaped supporting slot, to accommodate the 1½-inch-O.D. steel tube which will support the collector and allow adjustments is fabricated from ¾-inch plywood. Cut one piece 1½ inches wide and 96 inches long, and another two pieces 3 inches by 96 inches. Glue and nail the 3-inch-wide strips to the sides of the 1½-inch strip. Reduce the 96-inch-long structure to two 48-inch-long pieces by cutting it in half. Glue and nail these 48-inch-long slot-shaped plywood structures to the middle of the back of the collector, across the joint in the furnace base, as illustrated. Make two other braces of a shape similar to the one completed and attach them to the furnace base, parallel to the slot already in place, and 21 inches away from it. Trim the braces to length.

Lining the Reflector

Cut around the circumference of the 96-inch-diameter plywood base, leaving an extra 2 inches of plywood beyond the outer circumference where possible. Thoroughly clean 3-by-2-foot aluminum printing plates with white spirits, followed by dilute hydrochloric acid. Wear rubber gloves and protective glasses and use great care when carrying out this procedure. Use the plates to cover the whole inner surface of the parabolic reflector shell. Start from the edge of the collector, gluing and stapling the plates between adjacent ribs. Then trim each plate and continue fixing them in place until the shell is completed.

Perimeter of Reflector

Hardboard, ⅛ inch thick, should be cut into 18-inch-wide strips; you will require approximately 30 linear feet. These pieces are then glued and nailed to the perimeter of the reflector assembly, i.e., to the 18-inch-wide end of each half-parabola. Leave gaps between the two halves of the furnace, between the two large parabolas, and between the first adjacent half-parabolas on either side of the two full parabolas to allow access when joining the two halves of the furnace together.

Assembling the Furnace

Place the two halves of the furnace next to each other and drill at least three ½-inch holes at either side in the central parabolas. Use ½-by-2-inch bolts to securely link the two halves together.

Support Base

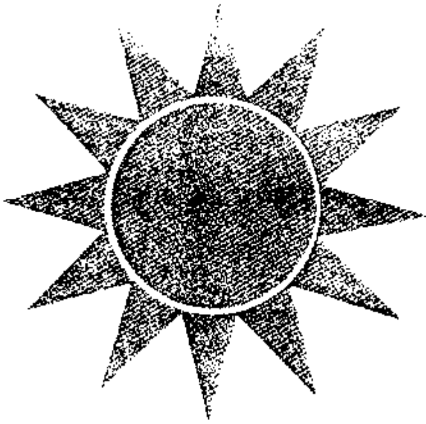
The support base is made from 2-by-8-inch fir (actual dimensions 1½ by 7½ inches). Cut two sidepieces 1½ by 7½ by 96 inches. Glue and nail a rear crosspiece, 1½ by 7½ by 99 inches, to join the sidepieces together. A central crosspiece, 1½ by 7½ by 96 inches, is attached between the sidepieces of the base. This crosspiece should form a span between the midpoints of the two sidepieces.

Two 1½-by-7½-by-54-inch vertical supports are then cut; notches 2 inches deep and 1½ inches wide are cut into the top of the supports. Then glue and nail the supports in place. Supporting blocks, 1½ by 7½ by 1½ inches, are attached to strengthen the verticals (see illustration). Two 12-inch brackets are then attached to each of the vertical supports to further strengthen them.

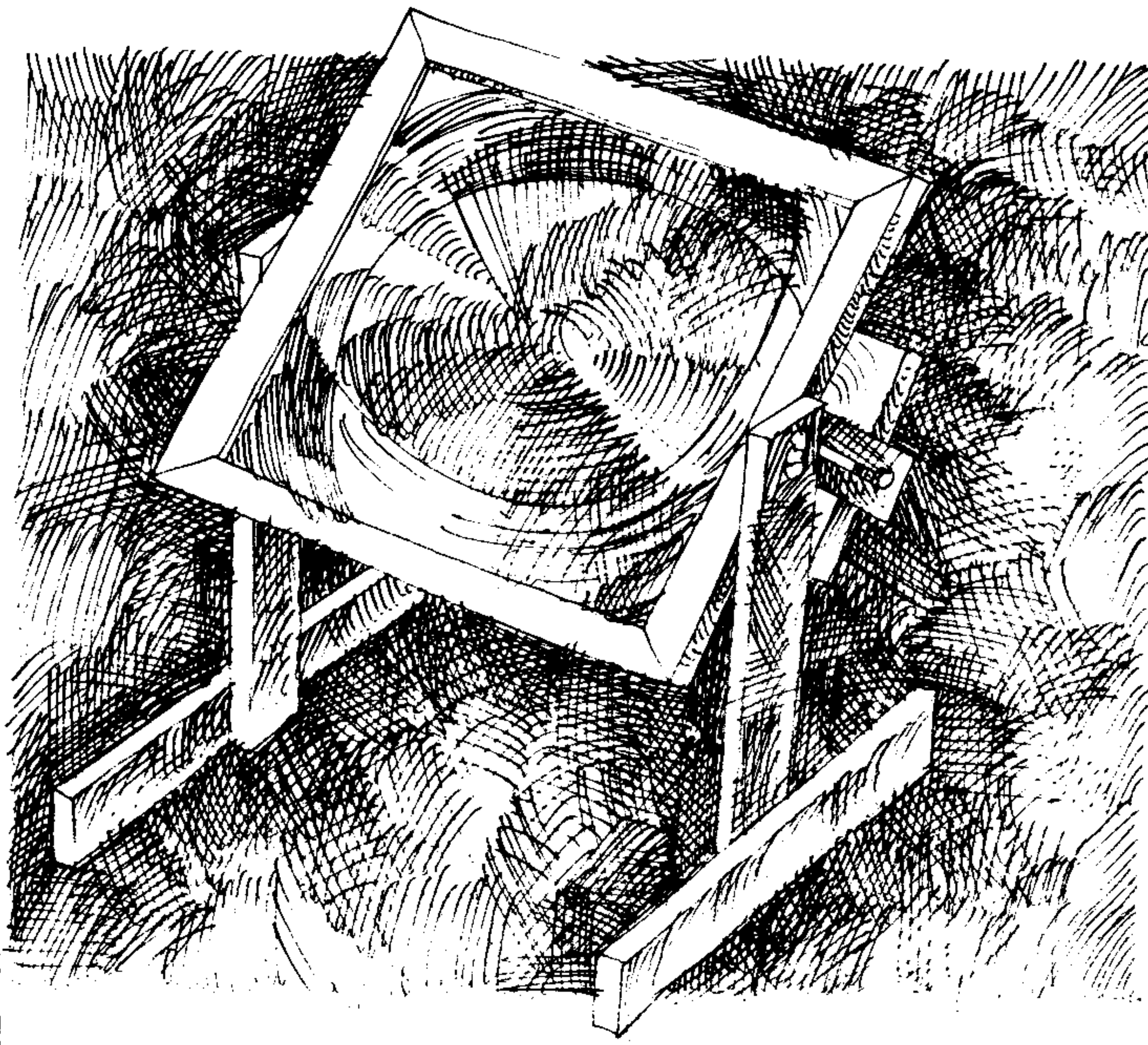
Pivot Shaft Into the notches at the top of the vertical supports, place a steel tube 107 inches long and having an outside diameter of 1½ inches.

Adjustment Chain A stout chain 11 feet long is attached to the base of the collector and to a hook on the rear strut of the stand to make it readily adjustable.

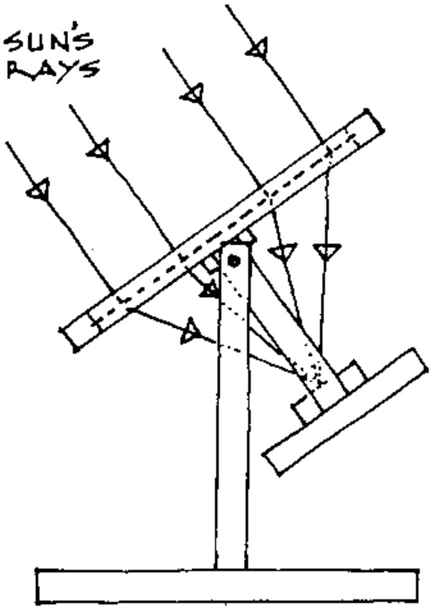
Find many friends to help mount the collector in place; then you are ready to experiment!



Fresnel Lens Concentrator

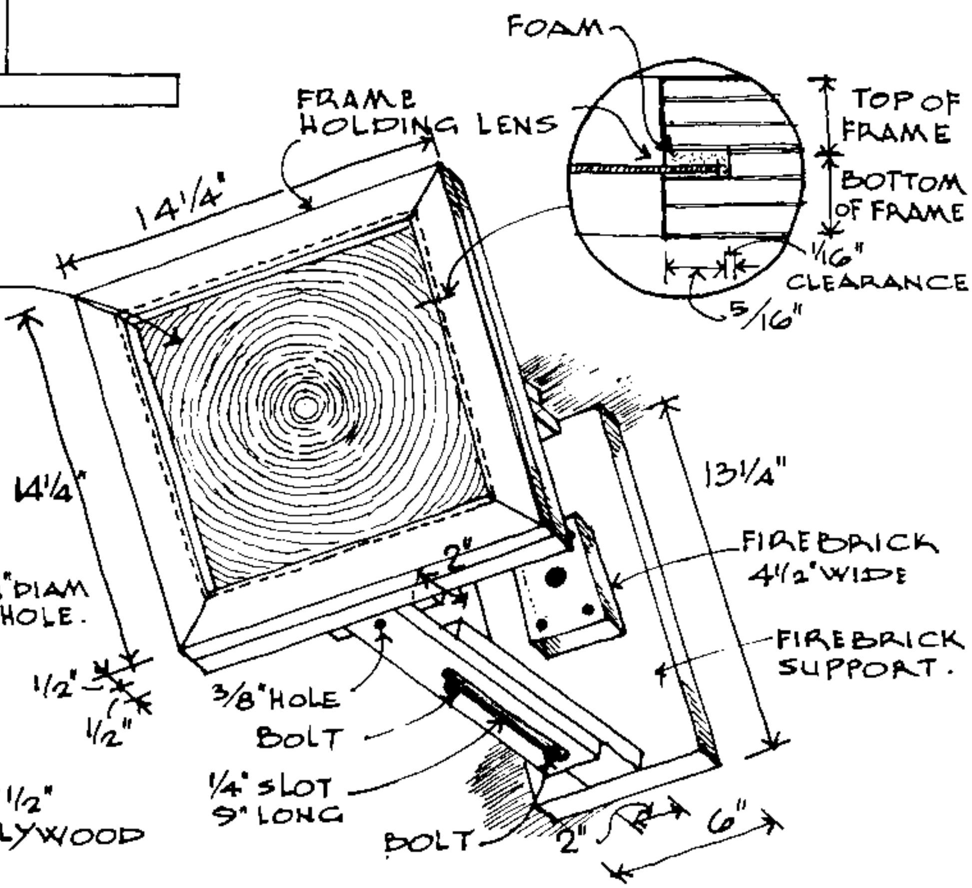


Fresnel Lens Concentrator

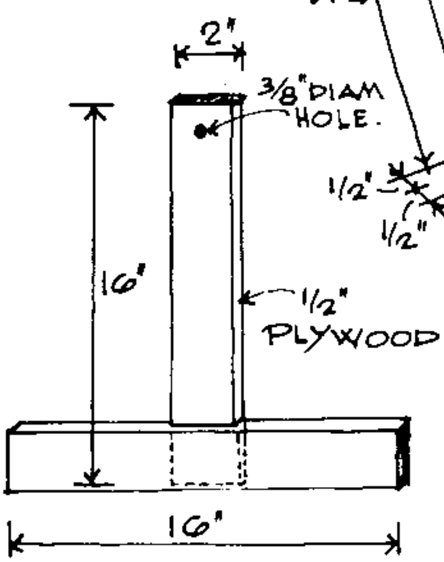


AN EXPERIMENTAL DEVICE FOR ACHIEVING HIGH CONCENTRATION FACTORS, AND THUS HIGH TEMPERATURES.

FRESNEL LENS FOCUSES LIGHT ONTO TARGET PLACED ON FIREBRICK.



LENS HOLDER AND FIREBRICK SUPPORT CONSTRUCTION DETAIL.



LEG DETAIL

The Fresnel lens concentrator illustrated is capable of producing temperatures in excess of 2000°F., sufficiently high to melt many common metals. It is a project whose value is largely that of providing a demonstration and producing an experimental unit rather than an object of any very practical value. The lens may be used to concentrate light onto photovoltaic cells, providing the cells are placed closer to the lens than the focal point. One has to be careful not to deteriorate the cells by overheating them.

Materials Required

1 Fresnel lens (see text)

¼ 4-by-8-foot sheet of ½-inch plywood

1 13¼-by-6-inch piece of ¾-inch plywood (firebrick support)

12 inches of 2-by-2-inch clear fir

2 1¼-by-¼-inch bolts with washers and butterfly nuts

2 2½-by-⅜-inch bolts

4 feet of self-adhesive foam weatherstripping

4 No. 10 1¾-inch wood screws

½ pound of ¾-inch finishing nails

waterproof glue

Lens The Fresnel lens itself (which may be obtained from Edmund Scientific*) consists of a rigid plastic sheet which has multiple grooves very accurately cut into its surface. When parallel rays of light pass through the lens the light is refracted and meets to form a small intense focal point. Objects to be heated and melted are placed on a movable firebrick and support, which can be positioned closer to or farther from the lens to focus the light.

*Edmund Scientific Co.: 101 East Gloucester Pike, Barrington, NJ 37646; 3500 Bathurst St., Toronto, Ontario, M6A2C6

Lens Frame The lens-holding frame can be conveniently made from ½-inch plywood. Cut eight pieces of plywood 14¼ by 1¾ inches; miter each corner at 45°. Four of the pieces should have grooves rabbeted along their inner edges, ¼ inch deep and 5/16 inch wide (see illustration). The bottom frame should be glued, nailed, and clamped together and the same process repeated with the top frame. Make sure each frame is perfectly flat and square. A thin strip of self-adhesive weatherstripping foam is placed opposite the ¼-by-5/16-inch groove (see illustration). The foam will hold the lens firmly in place when mounted. Eight screws may be used to fasten the two frames together. These can be withdrawn if the lens has to be removed at any time.

Lens Frame Support Arms

The slotted side arms, which support the lens frame and join it to the firebrick support arms, are fabricated next. Two 1-by-2-by-2-inch blocks are cut and each is glued and nailed to one end of two 12-by-2-inch strips of ½-inch plywood. Slots ¼ inch wide and 9 inches long are cut into the side arms. The cut for each slot should be started 2 inches from the lens frame. Follow the illustrations in conjunction with the text. A ⅜-inch hole is drilled in the slotted side supports 1 inch from the lens frame. The slotted side supports are then glued and nailed to the bottom lens frame holder.

Firebrick Support

Next the firebrick support is fabricated from ¾-inch plywood and a half firebrick (4½ by 4½ by 1¼ inches when cut). The firebrick support is cut 13¼ by 6 by ¾ inches. Then two side arms should be cut, 2 by 10 by ½ inches; set these into the middle of either end of the firebrick support. Slots should be cut into these side arms to match the slots in the frame supporting arms.

Mounting the Firebrick

Using a carbide-tipped drill, drill four ⅛-inch holes through the firebrick; ensure that each hole is at least ½ inch from the edge of the firebrick. In the middle of the firebrick a depression may be made using a ½-inch carbide-tipped bit. Fix the firebrick to the firebrick support using 1¾ inch screws. Two 1¼-by-¼-inch bolts and butterfly nuts are placed through each of the slots in the firebrick and lens support arms to make the whole structure fully adjustable.

Stand Legs

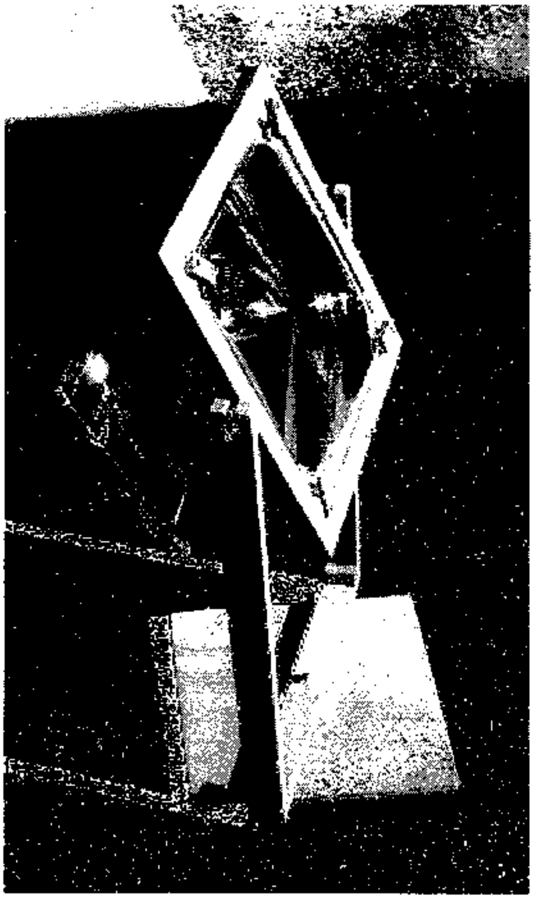
Finally, two stand legs are constructed. The base of each leg is made from wood 16 by 3½ by 1½ inches. At the midpoint of each base piece a ½-by-2-inch recess is cut to accommodate a 16-by-2-by-½-inch plywood vertical support (see illustration). Before each vertical support is fixed in position a ⅜-inch hole is drilled in the middle of the support, 1 inch from the top of the support. Glue and nail the vertical supports into place. Attach the stand legs to the rest of the concentrator already constructed with 2½-inch-long ⅜-inch bolts.

The project is then ready for very hot action!

FRESNEL SOLAR STAND

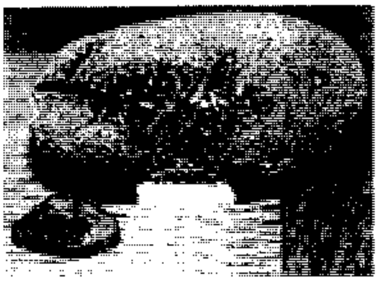
Modified on 3/19/97

The Fresnel lens is a powerful light magnifier. This 11 1/2" x 11 1/2" lens melts rocks in seconds, boils water in a soup can in minutes and will melt most metals. The key for this lens is that it focuses sun light into a pin point. With the right adsorbing plate, temperatures reach over 2,000 degrees in seconds. Fresnel lenses are used in light houses, overhead projectors, big screen TV's and stage lighting to name just a few.



This fresnel solar stand is made out of oak.

WARNING!!!! When the light is focused on to an object it is extremely bright. Use gas welding glasses with shade 8 or higher. The lens are so dark that it is hard to see through them on a bright sunny day. I started by using four pairs of sunglasses but that was not enough.



This stand is very close to the one that they advertise in Edmund Scientific but this has many more features.

1. 1) Adjustable attachments for holding different size objects. Objects can be held from top to bottom or left to right.
2. 2) Different attachments. The picture shows a universal clamp. (also solar camp cooker, solar furnace energy kiln, etc.)
3. 3) Temperature varying by adjusting the distance from the focal length with all attachments.
4. 4) The lens is removable. This allows for different lens, ease of cleaning and storage (in cloth folder)
5. 5) Disassembles down to 1 1/2" tall, 15 1/2" wide, and 22" long for storage or packing.
6. 6) Swivel base and frame that tracks the sun all times of the day and year.

Fully detailed plans, instructions and parts list are $10 US. Order by e-mail at ajones@intercomm.com. All the parts to build one of these stands can be found at any hardware store for ~$15 US.

The lens can be purchased At Edmund Scientific for $19.95 US. The order number is A52,833

OTHER FRESNEL SITES:

Fresnel Lenses and Zone Plates (Shows how a fresnel works, very technical)

Random Destructive Acts via Focused Solar Radiation

AGD Antics and Mayhem Page

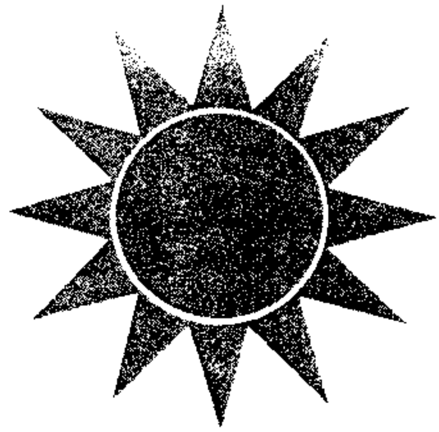
MY HOME PAGE

Drop me a line ajones@intercomm.com

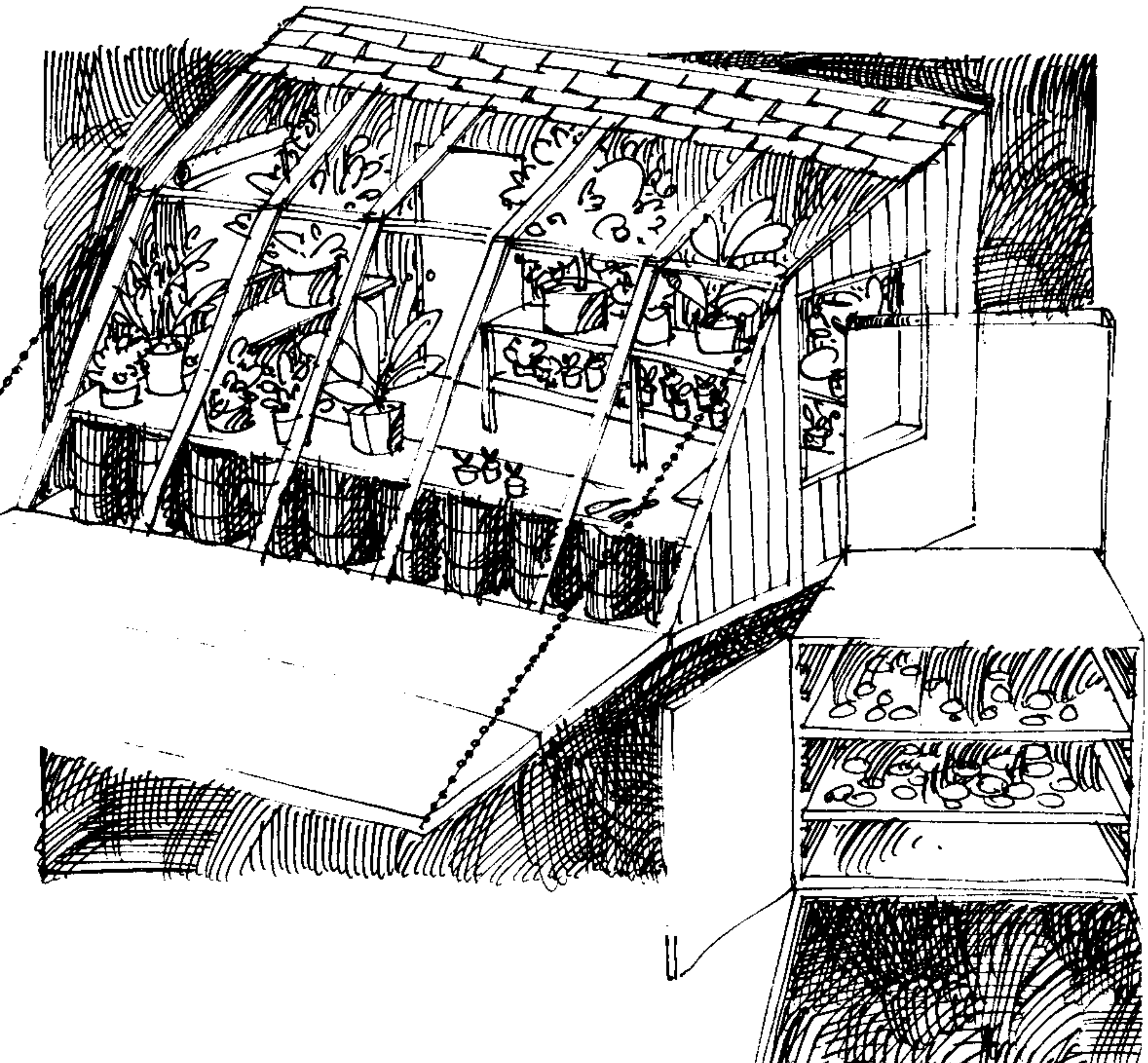
Snail mail to:

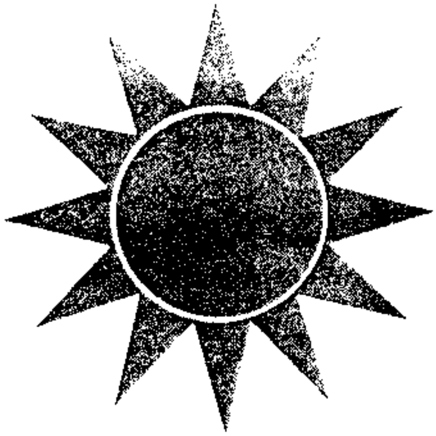
8175 South Virginia #850-301

Reno, Nevada 89511



Food-Producing Devices





Solar Cold Frame

In the spring this solar cold frame can provide developing plants with at least two months of extra protection from possible frost damage.

Light passing through the clear (translucent) fiberglass cover of the cold frame heats water-filled sealed cans which warm up during the day. At night the closed cover, the insulation in the walls of the cold frame and the roll-over insulated blanket help retain heat and prevent frost damage. The translucent cover can be propped up to vent away excess heat during particularly warm weather. The roll-over blanket probably is not necessary except when frost is actually anticipated.

Again, ¾-inch plywood (preferably pressure-treated) is used for the majority of the construction of this project.

Materials Required

2 4-by-8-foot sheets of pressure-treated ¾-inch plywood

1 10-foot-long piece of U.V.-inhibited clear corrugated fiberglass

220 used quart-size oil cans (half to be used to obtain tops)

8 2-by-3-foot used aluminum printing plates

90 feet of 1-by-2-inch redwood or cedar

1 insulating blanket made from fabric and 4-inch fiberglass (finished blanket 46 by 44 inches)

1 4-by-8-foot sheet of 2-inch Styrofoam

1 4-by-4-foot sheet of 2-inch Styrofoam

2 gallons of antifreeze

1 caulking tube of clear silicone sealant

1 can of flat black paint

2 3-inch butt hinges

2 dozen 3½-inch screws

1 quart of cold tar

1 pound of 1¼-inch galvanized nails

18 feet of self-adhesive weatherstripping

Styrofoam glue

waterproof glue

½-inch staples

Box Construction

Cut out a base 49½ by 46¾ inches, then cut out the two sidepieces (as illustrated); base length 49½ inches, sides 18 inches and 30 inches. The top edge should be approximately 51¼ inches. Glue and nail sides onto the base.

Using ¾-inch plywood, cut out the front end, 18 by 45¼ inches, and back end, 30 by 45¼ inches. Glue and nail the ends in place.

Cover Supporting Frame

On the inside of the top of the box, fabricate a frame that will support the cover. This should be made from 1-by-2-inch cedar or other weather-resistant wood. Two pieces of 1-by-2-by-49¾-inch cedar should be angled at either end and then glued and nailed in place. Then cut two pieces 1 by 2 by 43¼ inches and glue and nail in place on the top of either end of the cold frame. Apply self-adhesive weatherstripping to the opening of the completed box to prevent possible air infiltration.

Insulation

The whole of the interior of the cold frame should be insulated with 2-inch-thick Styrofoam. The Styrofoam is marked and cut with a long-bladed utility knife. Use readily available Styrofoam glue to secure the Styrofoam in place. If the Styrofoam is cut slightly oversize, friction will help hold it in place while the glue sets.

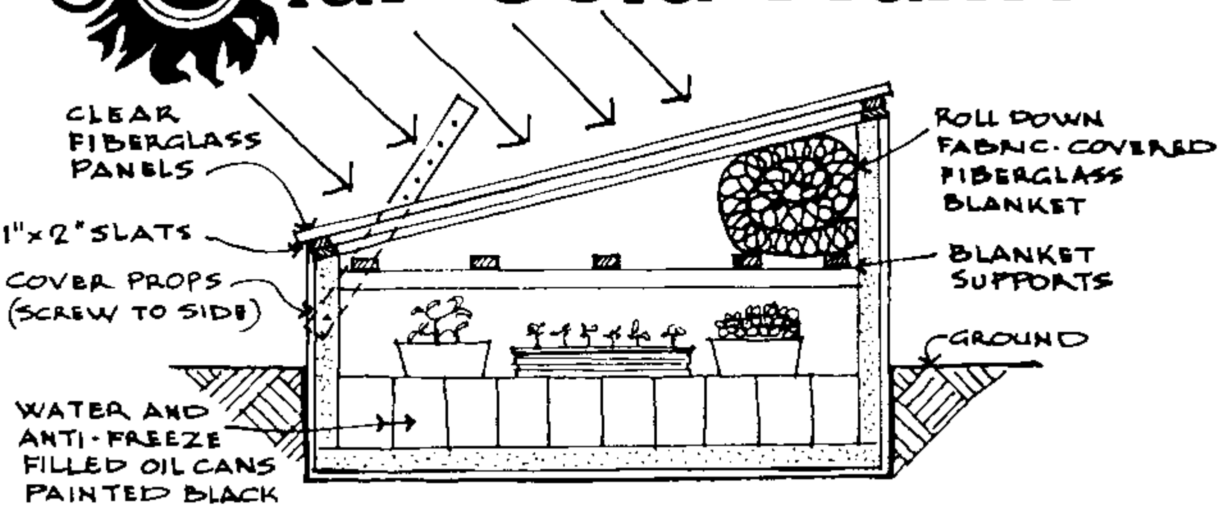
Blanket Supports

Two blanket side supports should be cut from 1-by-2-inch cedar, 44 inches long. These should be secured in place with thin 3½-inch screws driven into the outside of the box. Five movable slats made of 1-by-2-inch cedar are cut 41¼ inches long.

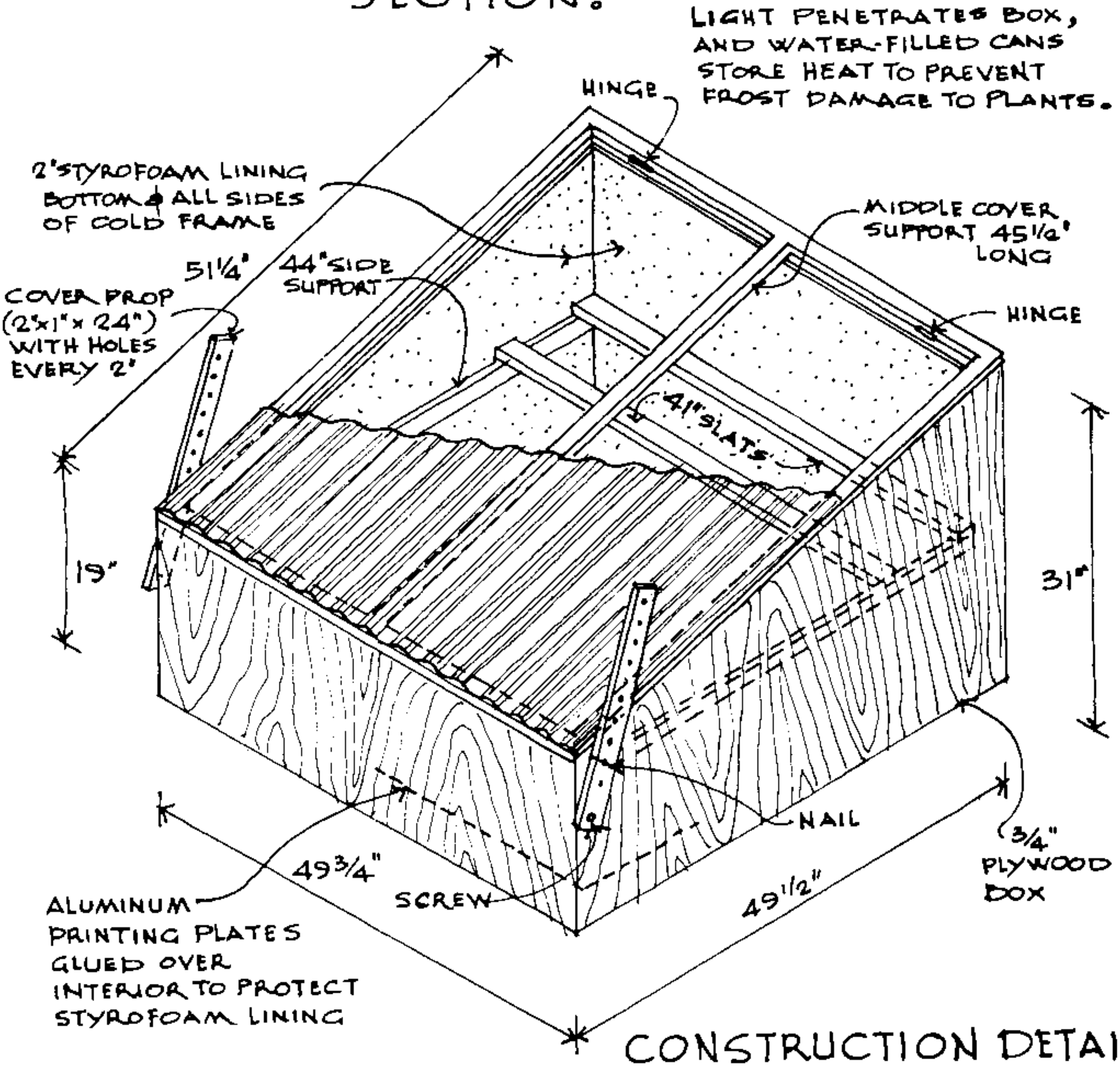
Aluminum Liner

The whole of the interior is then lined with aluminum printing

Solar Cold Frame



SECTION.



CONSTRUCTION DETAIL.

plates to protect the Styrofoam lining. Fix the plates in place with long staples and Styrofoam glue.

Cover Frame and Glazing

The top cover frame is made from 1-by-2-inch cedar fabricated as shown in the illustration. A middle cover support 47¼ inches long is cut and then glued and nailed into place in order to brace and strengthen the frame.

A 10-foot piece of standard clear greenhouse-quality corrugated fiberglass is necessary to complete the fabrication of the cover. Cut the sheet of fiberglass in two and fix into place using large-headed ring nails. Ready-made corrugated wood supports under either end of the cover, together with an ample quantity of clear silicone, completely weatherproofs the cover.

Two strong hinges are fixed to the rear of the cover frame and two hooks and eyes to the front to hold the cover and frame tight against the weatherstripping. Two cover props are made from 2-by-1-by-24-inch cedar which have ⅛-inch holes drilled in them at 2-inch intervals. They are then screwed in position onto the exterior of the cold frame. Nails hammered into the cold frame box as pegs make the props fully adjustable.

Blanket

A blanket is made from sheeting sewn into a pillow shape approximately 46 by 44 inches. This is stuffed with 4-inch-thick fiberglass batts and is then sewn up. The completed blanket is then rolled into its stored position at the back of the cold frame.

Storage Cans

About 110 one-quart cans (automobile oil cans) are necessary to fill the bottom of the cold frame. Each can has one end removed and is 90 percent filled (a gap is left to allow for expansion and contraction) with water and antifreeze and is then resealed by siliconing a top removed from another can. After thoroughly cleaning the tops of the cans, spray them with a heat-resistant flat black paint.

Waterproofing

The exterior of the cold frame is waterproofed by painting it with cold tar or an equivalent waterproofing material.

Installation

The whole cold frame is embedded in the ground to a depth of about 10 inches and your seeds are ready to go!

Model Solar Greenhouse

The solar greenhouse illustrated is a conceptual design that has not as yet been completed in full-scale form. However, basic design features to be incorporated into the full-scale version of this greenhouse are outlined below.

Conventional greenhouses are very adequately illuminated during daylight hours, but unfortunately their structures do not normally encourage good heat retention. During very cold weather greenhouses usually suffer massive heat losses and the maintenance of proper growing temperatures requires large quantities of expensive fuel.

A solar greenhouse provides an economically justifiable alternative to the typical greenhouse. In designing it, two somewhat opposing factors have to be considered: allowing the entrance of sufficient light for healthy growth while minimizing heat losses. Through its construction a solar greenhouse is in effect a combination solar collector and heat storage area. It not only serves as an area to grow food and provide controlled humidity for the adjacent home, but also provides supplemental heat.

Materials Required

Exterior and framing

Cedar or redwood

Thermal Storage

Water in used 45-gallon fiberglass resin drums plus 1½-inch-diameter rocks (under greenhouse)

Glazing

Outer, Kalwall premium

Inner, Tedlar or clear heavy-duty vinyl (not as durable as Tedlar)

Ventilating structures
Fan plus two large opening windows

Reflective panels
4 inches of Styrofoam covered with polished used aluminum printing plates

Structure

The specifics of the proposed design are as follows. Ideally, the greenhouse is built onto the south-facing wall of a house. The whole structure of the greenhouse is insulated to R-20 in the walls and R-28 in the roof. It has windows on its south-facing front, half of its roof and part of each of its west and east sides.

To avoid spindly growth because of the reduced areas of glazing, the whole of the interior of the greenhouse, apart from heat-storing structures, is painted white to reflect as much light as possible. Lights are used to extend daylight hours, and during particularly cold weather all glazing is covered and growth is maintained solely by using electric light rather than natural illumination.

A number of features help to retain heat and serve to control the intensity of light entering the greenhouse. The side windows have roll-down insulating blinds fabricated from canvas which sandwiches fiberglass batting. The inward-facing side of the canvas is finished with a thin film of reflective Mylar. Velcro fasteners around the edges of the blinds seal them to the window frame.

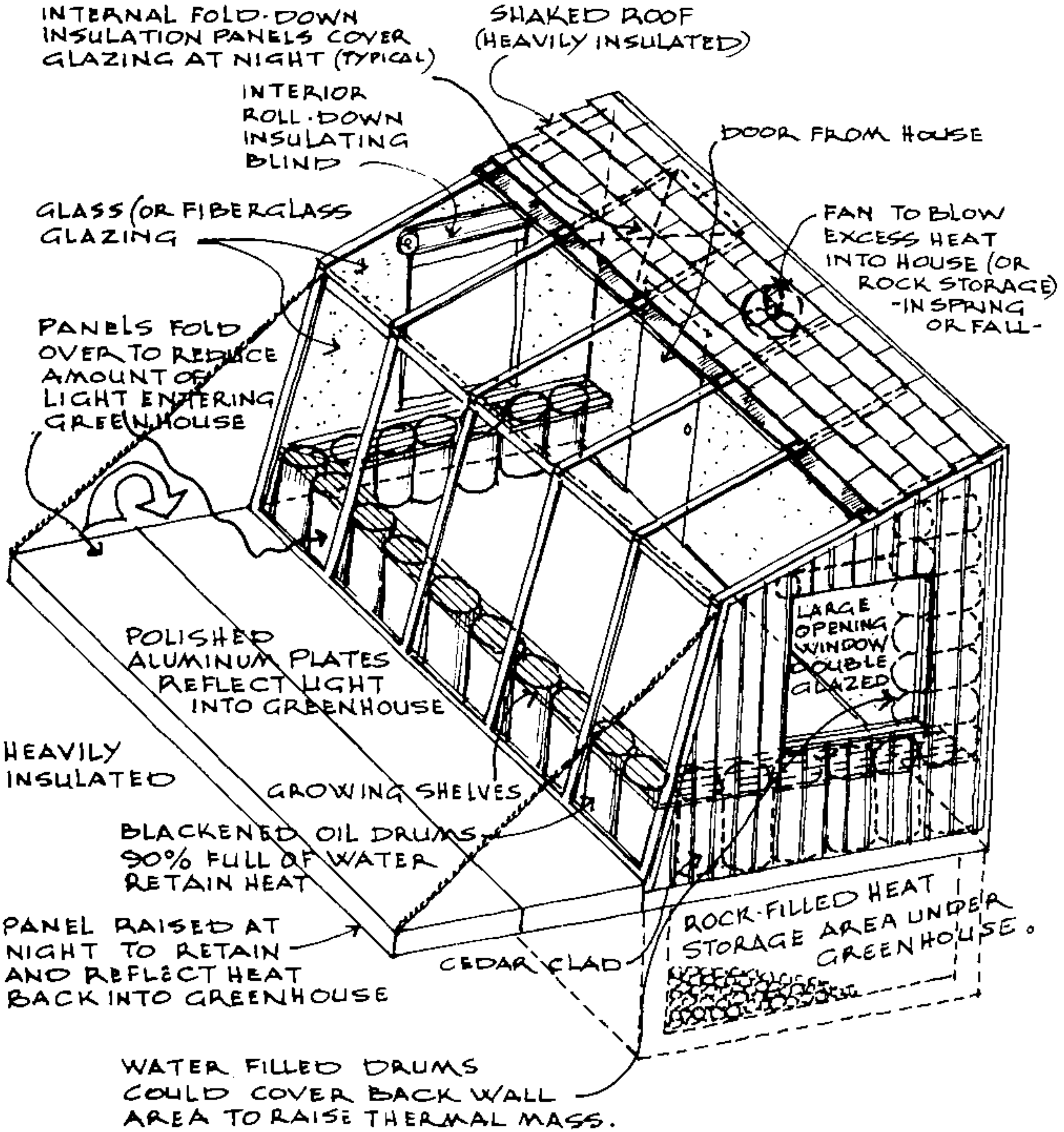
Reflecting Panel

A reflecting panel, faced with polished aluminum printing plates, boosts the light entering the south window during the winter, early spring, and late fall. If the intensity of light becomes too great, then the reflecting panel may be folded in two to eliminate its reflective function. The whole panel could be opened and closed by utilizing an electric motor linked to nylon ropes attached to the panel. At night the insulated reflective panel is closed and helps to reflect heat back into the interior of the greenhouse. In summer possible overheating of the greenhouse is reduced by using roll-down bamboo or vinyl shades over the south-facing windows; the side windows could also be opened.

The thermal mass of the greenhouse should be as high as possible in order to absorb and retain heat for as long as possible.

Storage Drums

Used fiberglass resin or oil drums, filled with water to 90 percent of capacity (an air space is left to allow for expansion of the


INTERNAL FOLD-DOWN INSULATION PANELS COVER GLAZING AT NIGHT (TYPICAL)
SHAKED ROOF (HEAVILY INSULATED)
INTERIOR ROLL-DOWN INSULATING BLIND
DOOR FROM HOUSE
GLASS (OR FIBERGLASS GLAZING
FAN TO BLOW EXCESS HEAT INTO HOUSE (OR ROCK STORAGE) -IN SPRING OR FALL-
PANELS FOLD OVER TO REDUCE AMOUNT OF LIGHT ENTERING GREENHOUSE
LARGE OPENING WINDOW DOUBLE GLAZED
POLISHED ALUMINUM PLATES REFLECT LIGHT INTO GREENHOUSE
HEAVILY INSULATED
GROWING SHELVES
BLACKENED OIL DRUMS 90% FULL OF WATER RETAIN HEAT
ROCK-FILLED HEAT STORAGE AREA UNDER GREENHOUSE.
PANEL RAISED AT NIGHT TO RETAIN AND REFLECT HEAT BACK INTO GREENHOUSE
CEDAR CLAD
WATER FILLED DRUMS COULD COVER BACK WALL AREA TO RAISE THERMAL MASS.

The all-glass still illustrated on the previous page is designed to produce distilled water even when weather conditions are not optimal.

Brackish water or tap water (*not* alcohol—it's illegal!) is placed in the central compartment. Diffuse or bright sunlight passing through the cover glass penetrates the water and glass and then hits the undercoat of tar. This absorbs sunlight, producing heat, which then helps to evaporate the water. Experimental evidence suggests that having the black layer under the glass maximizes heat output.

The evaporating water condenses on the upper glass cover and slowly but steadily drips into the two side troughs. These distilled water troughs have a layer of white silicone on their bottom surface which helps to reflect light and minimize reevaporation of the collected water. The inert nature of silicone prevents contamination of the distilled water.

The water collected is ideal for use in steam irons, for topping up lead-acid cells, for making pure chemical solutions or for drinking purposes.

The water is withdrawn when required by removing the two rubber stoppers and siphoning out the water with a rubber or copper tube. The 4-inch-diameter inspection hole is sufficiently large to permit thorough cleaning of the interior should it become necessary. Water is not lost through this inspection hole as it is well sealed by the weatherstripped glass plate covering it.

The still is almost entirely built out of glass which is joined and sealed with clear silicone. (Having built over twenty aquariums with students, I am a great believer in silicone.)

Materials Required

3/16-inch glass

- 1 2-by-3-foot base piece
- 2 24-by-20-inch top pieces
- 4 23⅝-by-3-inch trough dividers and end pieces
- 2 side pieces, 3-foot base, 1 foot high at center, 3 inches high at ends

1 7-by-6-inch inspection hole cover

1 2-by-1-inch (handle)

2 feet of 1-by-1-inch redwood or cedar

44: Instituto Technológico y de Energias Renovables - Teneriffe.

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Instituto Tecnológico y de Energías Renovables

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http://www.cabtfe.es/iter/inver.html

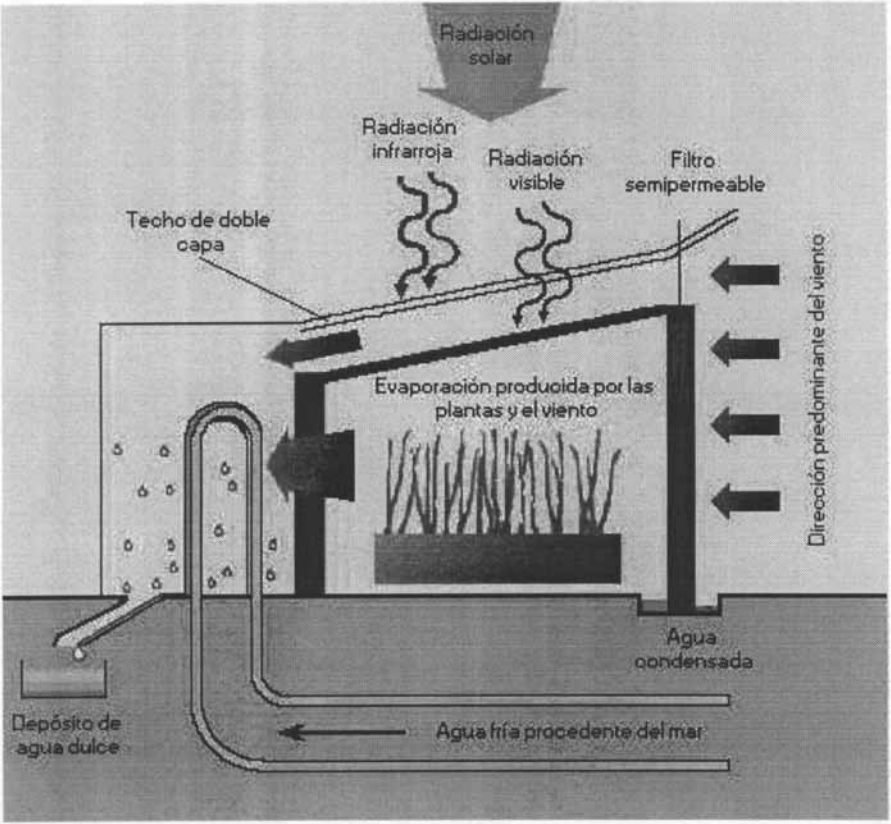
SEAWATER GREENHOUSE FOR ARID LANDS

The object is to design and build a controlled greenhouse, in which both desalination and optimised conditions for copproduction could be combined.

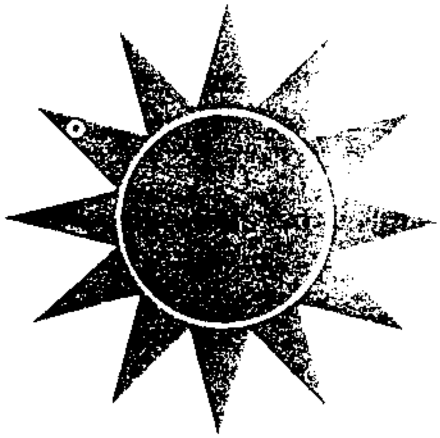
The design of the structure exploits the high levels of solar radiation and prevailing wind to drive most of the processes. In addition, the structure will provide shelter and water for an outdoor planting scheme.

The greenhouse uses heat from both the atmosphere and the sun to evaporate sea water, providing a cooled environment in high light conditions for optimum plant growth, particularly for salad vegetable crops. Pure water evaporates from salt water, cooling and raising the humidity of the air. The water vapour in the ventilation air and that transpired by the plants produces virtually saturated air. Fresh water condenses out of this air as it passes across the cooled surface of a heat exchanger.

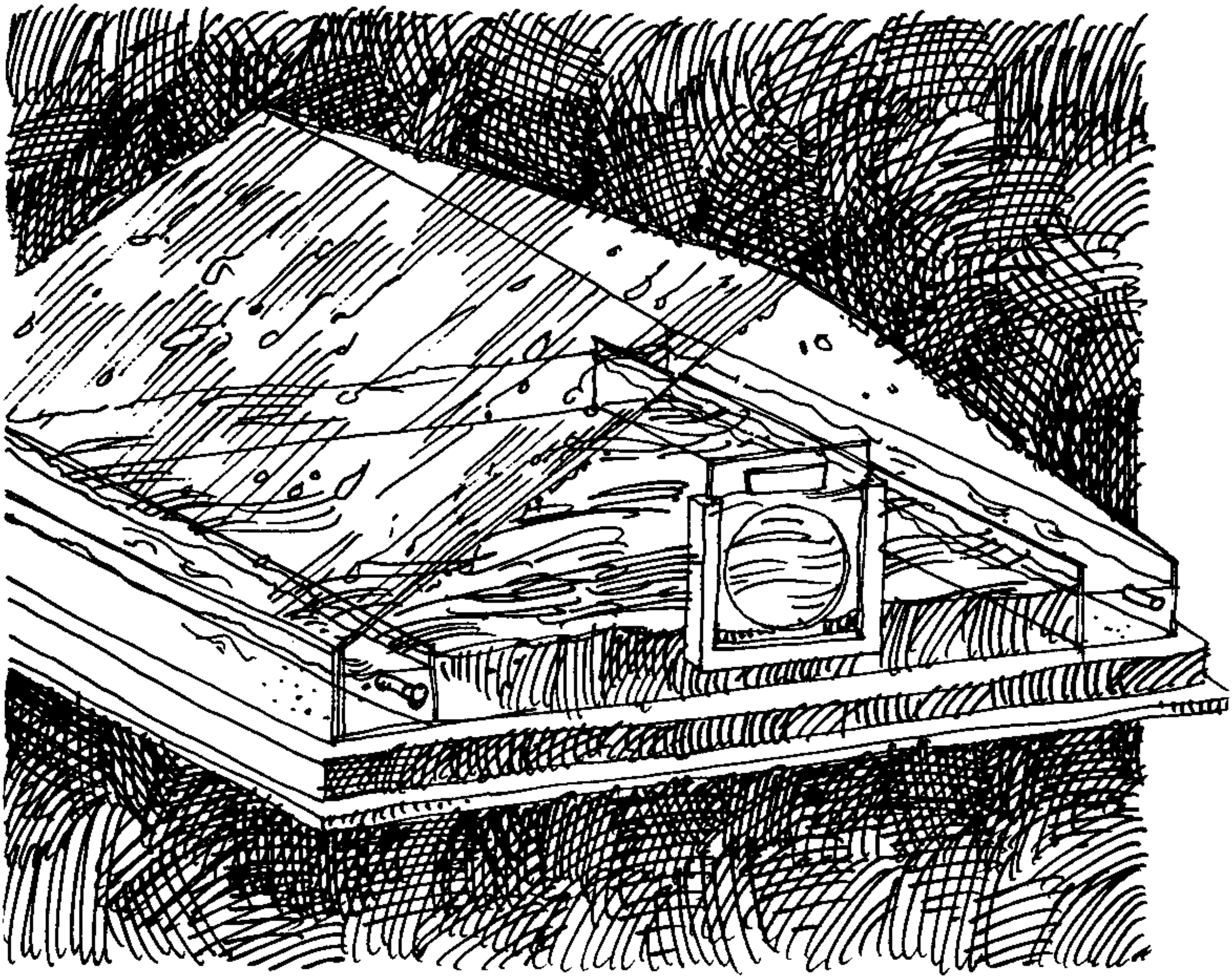
To optimise the process a multi-variable control system continuously monitors several conditions: airflow, relative humidity, light and temperature. In response to the monitored conditions the flow rates are adjusted to optimise the growing conditions within the greenhouse and maximise water production.


Radiación solar
Radiación infrarroja
Radiación visible
Filtro semipermeable
Techo de doble capa
Dirección predominante del viento
Evaporación producida por las plantas y el viento
Agua condensada
Depósito de agua dulce
Agua fría procedente del mar

43: Solar Fun Book. USA 1979.



Glass Solar Still



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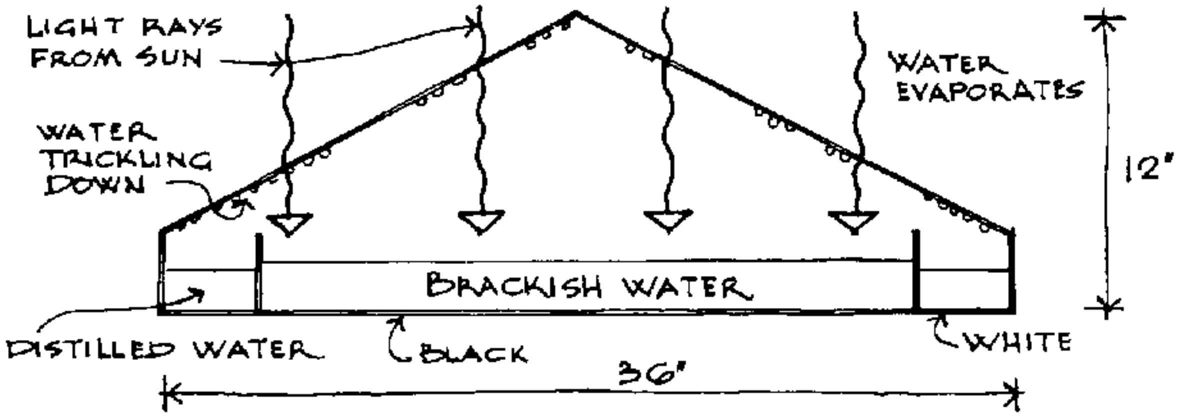
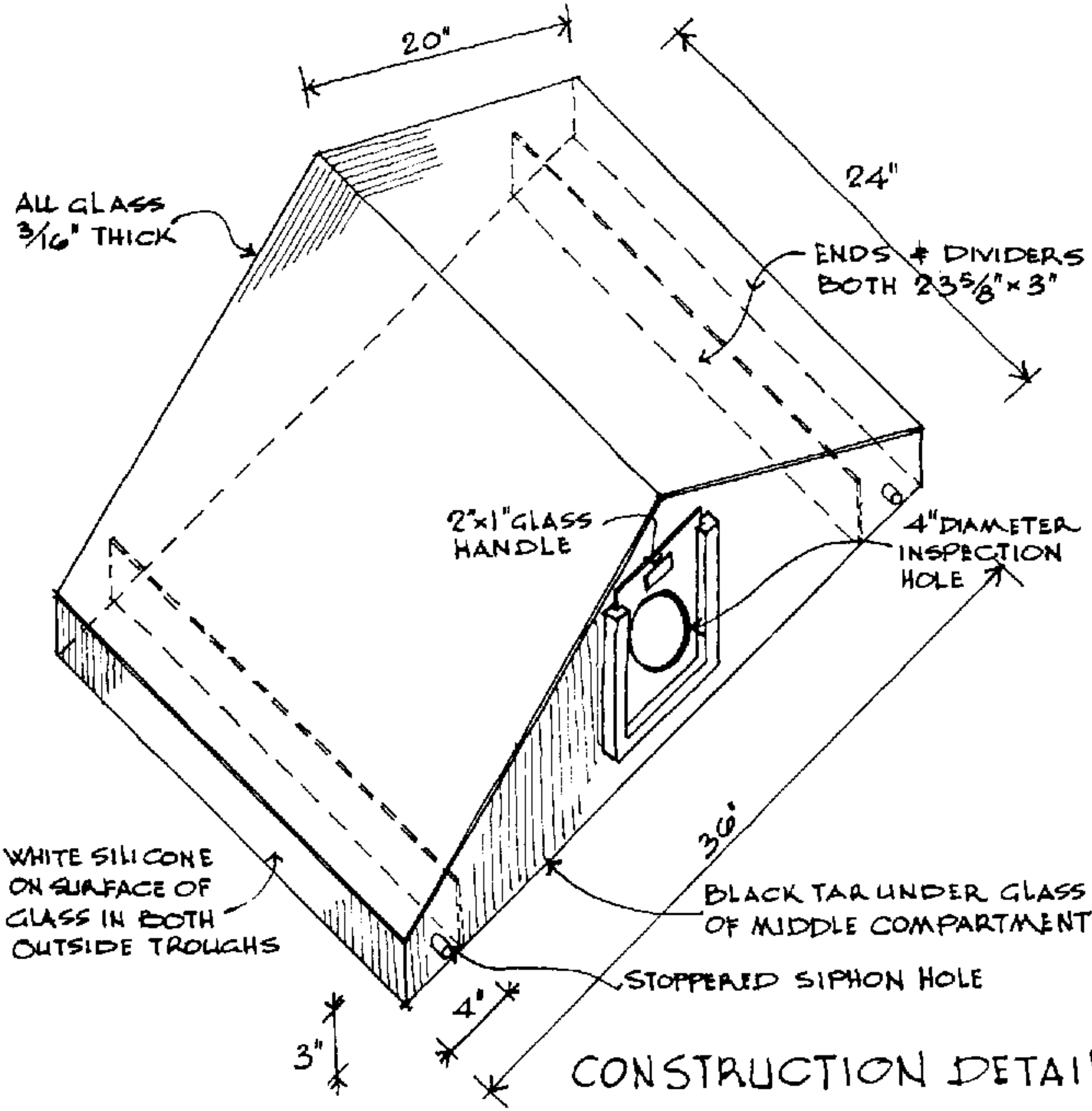
- 4 23⅝-by-3-inch trough dividers and end pieces
- 2 side pieces, 3-foot base, 1 foot high at center, 3 inches high at ends

1 7-by-6-inch inspection hole cover

1 2-by-1-inch (handle)

2 feet of 1-by-1-inch redwood or cedar





CONSTRUCTION DETAIL.

1 caulking cartridge of clear silicone sealant

2 ½-inch-diameter stoppers

1 roll of masking tape

Unless you are quite skilled at glass-cutting, I would suggest that you get that part of the job done by a glass shop. Trying to save money in this case can prove to be an expensive experiment. Used 3/16-inch glass is quite satisfactory and is probably the least expensive glass that has sufficient strength for the project.

Cutting the Glass Components

Using 3/16-inch glass, the quantity of glass required is as follows: a base piece 2 by 3 feet; two top pieces 24 by 20 inches; two endpieces and two trough dividers 23⅝ by 3 inches; and two sidepieces, the base length of which should be 3 feet, height 12 inches at the center (see illustration) and ends 3 inches high. One of the sidepieces should have a hole at least 4 inches in diameter cut in it, the center of the hole being 5 inches from the base. Two smaller holes, ½ inch in diameter, should be drilled 2 inches from the ends and 2½ inches from the base of this same sidepiece.

Assembling and Sealing with Silicone

A bead of clear silicone is then run around the top side of the perimeter of the base. The two endpieces are placed on top of the end beads of silicone. Beads of silicone are then run over the inside edges of the endpieces. (Many hands make light work here, too few make a lot of broken glass!) The sidepieces are pushed down onto the base and then moved firmly against the edges of the endpieces. Masking tape can be used to temporarily hold everything firmly together.

Next silicone the two trough dividers into place by applying the silicone to the edges of the glass that will contact the glass already in place. Each divider should be 4 inches from either end of the still. Leave the silicone to set for twenty-four hours.

White silicone is then smeared over the inner bottoms of the two distilled water collection troughs. Use clear silicone to apply a bead to all interior joints to ensure watertightness. Leave to dry for twenty-four hours. Put water in the still to check for leaks; repair if necessary.

Using a razor blade, remove all excess silicone from the surface of the glass. Fine steel wool gently applied may help to remove any remaining traces of silicone.

Silicone should then be placed all along the upper edge of all the glass in place (apart from the trough dividers). Carefully lower the two top pieces into place and tape securely into position. Remove tape when the silicone is dry and clean up excess.

Inspection Hole Cover

The final job is to fabricate the inspection hole cover. Use 1-by-1-inch cedar and cut three pieces: two pieces 6 inches long and one 7½ inches long. Cut a ⅜-by-⅜-inch slot away from one edge of each of the two pieces. Glue with silicone symmetrically on either side of the opening in the glass and butt against the 6-inch-strip. It is the ⅜-inch edge of the two vertical pieces that should be glued onto the glass.

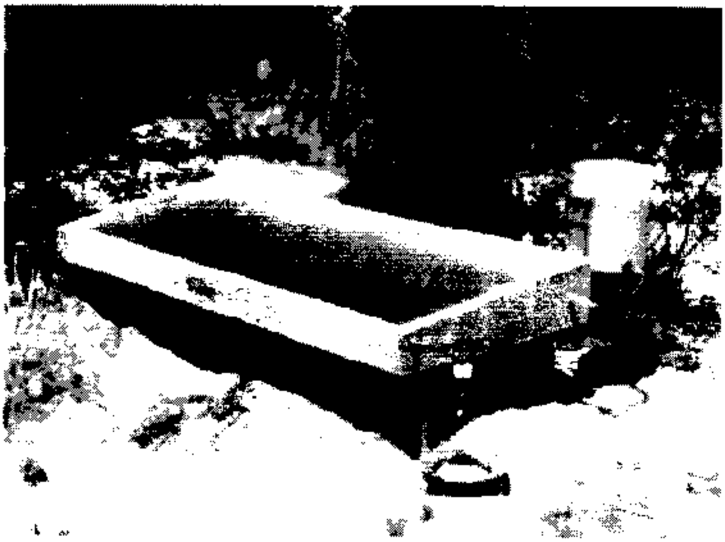
When the silicone is dry, apply thin weatherstripping to the interior edge of each slot to hold the glass cover plate tight against the side of the still. Cut a 7-by-6-inch piece of glass to fit in the slot. Silicone a 2-by-1-by-3/16-inch glass handle close to the top edge of the inspection hole cover.

Plugs for Water Outlets

Rubber stoppers may be used as plugs in the holes from which the distilled water is drawn.

Your still is ready for action!

Solar Water Distiller



The Solar Still

Solar Stills operate on the same principles that produce rainfall. The sun is allowed into and trapped in the Still. The high temperatures produced destroy all pathogens. The water evaporates, and in this process, only pure water vapor rises in the Still, only to condense on the glass. The glass is sloped to the south, and the condensed water runs down the glass and is collected in a trough. The water is allowed out of the collector through silicone tubing, and is collected in 5 gallon glass jugs. There are no moving parts in the solar still, and only the sun's energy is required for operation.

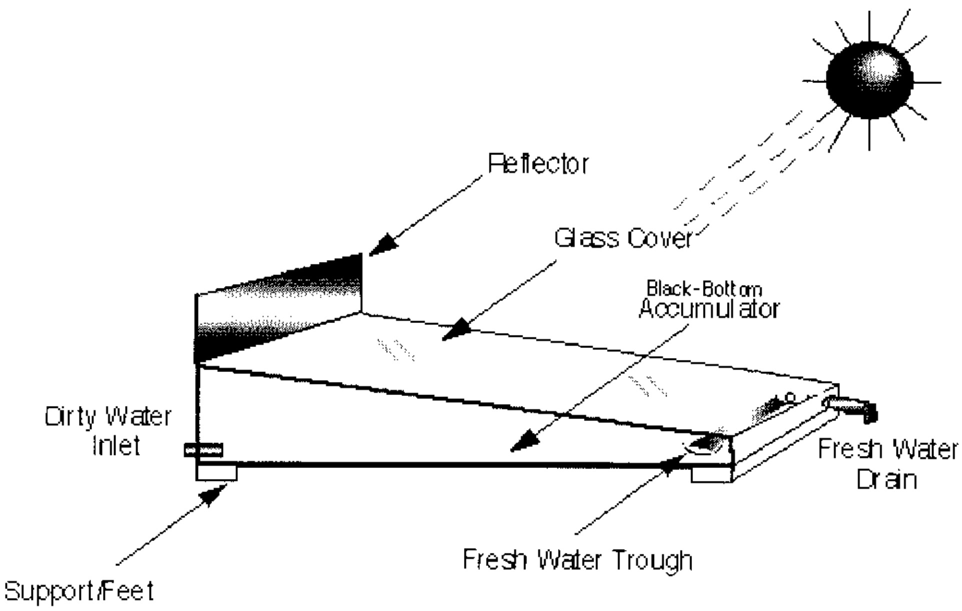
The design of the our Solar Still began with many hours spent researching previous designs, successes and failures. Our goal for the Still project was to design and develop plans for a Still which could be replicated using "off the shelf" materials.

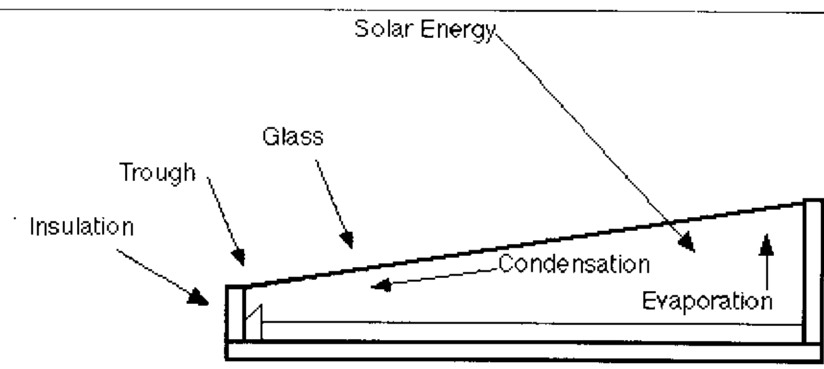
We designed a still which is easy to replicate, using standard building materials, of which 95% are available "off the shelf". The exterior materials were chosen for their ability to withstand our desert climate with minimal maintenance. The still produces an average of 3 gallons per

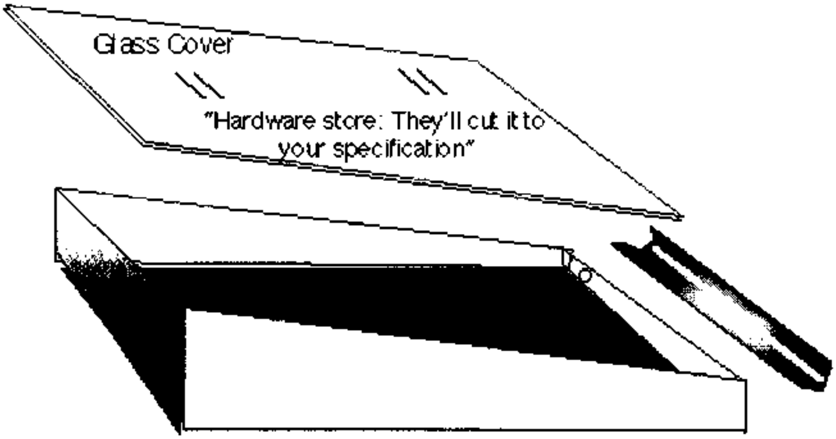
day in the summer months. Winter production is expected to be 1/2 that amount. The Solar Still can utilize a standard size patio glass replacement, 34"X76". The material costs per still are approximately $150.

Brackish water is carefully placed inside Solar Still via an inlet near the base of the Still. As sunlight warms the black silicone bottom and heat is transferred to the water, the top of the water evaporates on to the inside of the glass cover, which is tilted toward the fresh water drain. approximately 8 square feet (of glass cover) will distill around 1 gallon of water per day, over five hours of full sunlight.

The most important elements of the design are the sealing of the base with black, high temperature silicone rubber; (spread it on with a Bondo squeegee) and creating a good seal between the glass cover and the bottom of the box.





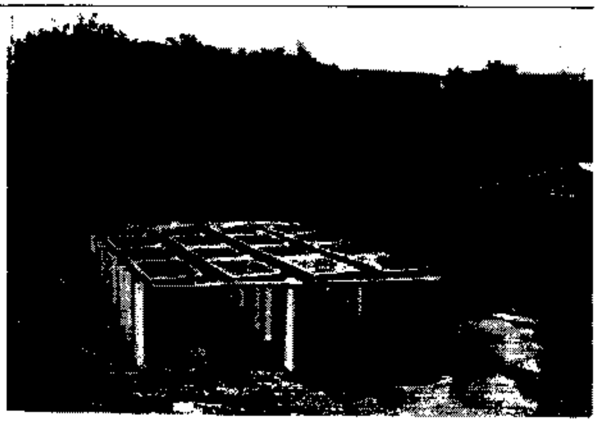


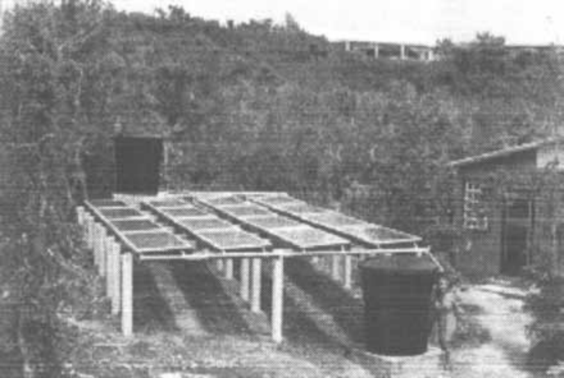
Use Black GE High-Temp Silicone to completely coat the inside bottom of the distillation module
GE Silicone is a Hardware store item. Find it with Caulking in Tubes. You'll also need a caulking gun.

The Solar Basin Still

The Still is filled each morning or evening, and the day's production is collected at that time. The Still will continue to produce after sundown as the water is still very hot. The Still is over filled each day to flush out sediment. The over flow water can be used for irrigation. The only maintenance is to clean the glass occasionally.

A Large Solar Distiller Array!





Fresh Water from the Sea

using solar distillation & PVs for pumping

Horace McCracken

Practically any seacoast and many desert areas can be made inhabitable by using sunshine to pump and purify water. A 10 gallon/day solar still now purifies sea water for drinking, cooking and other household needs for a residence near George Town, Exuma, in the Bahamas. Solar energy does the pumping, purification, and controls seawater feed to the stills.

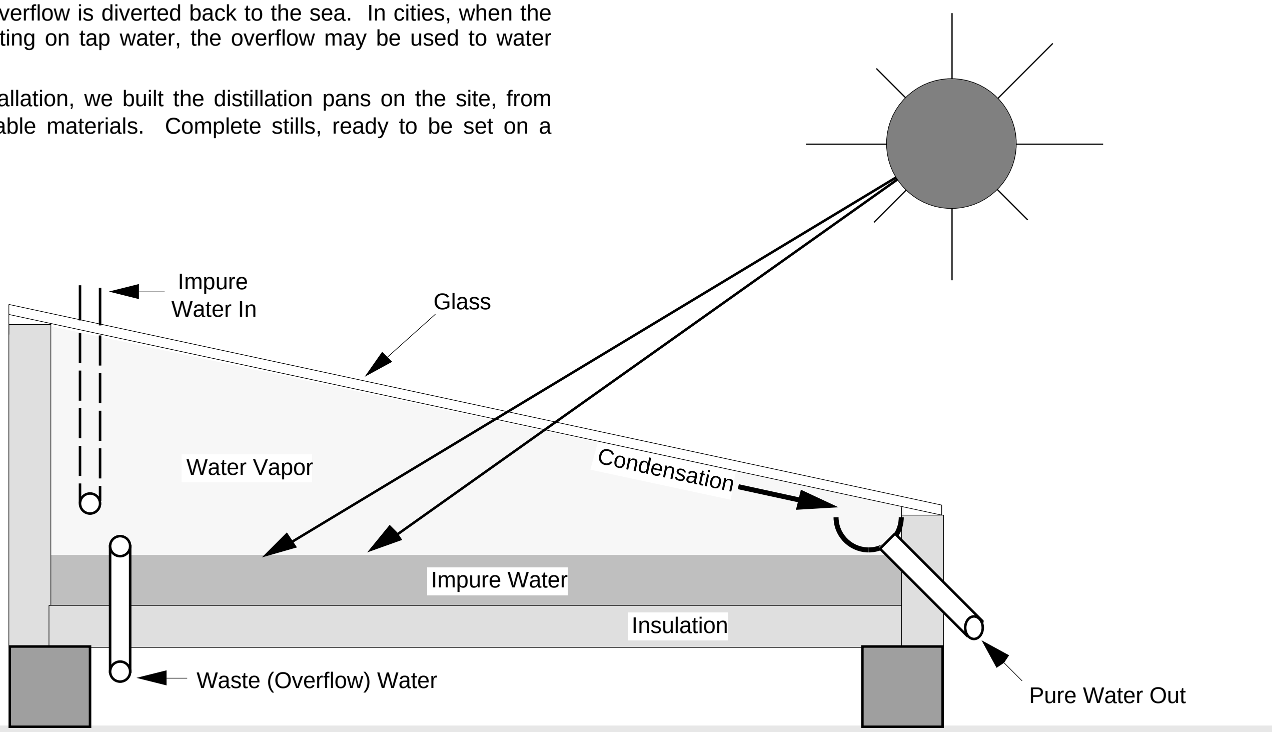
Solar Distillation

This system uses three solar distiller pans 33" wide by 10'3" long. They are insulated, lined with a special corrosion-resistant membrane. The pans contain salt water, about 3/4 of an inch deep. Tempered glass covers are cemented over the pans. Sunlight shines through the glass cover, warming the salt water in the pan. Pure water evaporates, leaving the salts, minerals, fertilizers, etc. in the pan, still dissolved in the brine. In the solar still, the glass cover traps the water vapor which then condenses on the underside of the glass (which is cooled by the outside air). The cover is tilted, so that the condensed water runs into a trough, where it flows into a storage tank. The process is exactly Mother Nature's method of getting fresh water into the clouds from oceans, lakes, swamps, etc. All the water you have ever consumed has already been solar distilled a few thousand times around the hydrologic cycle.

The still is filled once daily, at night or in the morning, with at least twice the amount of water that was distilled the preceding day. There is an overflow fitting at the opposite end, so that the extra water runs out, keeping the salts from building up in the still. In this installation, the overflow from one still feeds the next one and the total amount of feed was set at 40 gallons per night. On this tiny island, the overflow is diverted back to the sea. In cities, when the still is operating on tap water, the overflow may be used to water plants.

For this installation, we built the distillation pans on the site, from locally available materials. Complete stills, ready to be set on a level support, are also available. A photovoltaic panel powers the pump filling the salt water reservoir. The water comes from a well about 10 feet deep in limestone rock. The well's bottom is about a foot below sea level. Some rain water mixes in, but it is mostly sea water, well filtered by the 50' or so of sand between the sea and the well. Good filtration is imperative to keep the pump running dependably. Dropping a hose into the sea with a screen over it is not adequate.

The sea water is pumped up hill via 300 feet of pipe, to a reservoir about 25 feet above sea level. Feeding sea water into the still when the sun is shining would substantially reduce production because the heated water would be flushed from the still, So the PV pumped sea water is held in reserve in a shallow reservoir. A special solar actuated valve (invented and manufactured by McCracken Solar), stays closed all day and then it lets water flow into the stills about an hour after the sun goes down. This slow response time prevents emptying the still when a passing cloud goes by. The reservoir was built with a black impervious membrane liner and a glass cover, so that the stored sea water is also solar



heated during the day, about 60° warmer than the outside air. This pre-heated water also helps evaporation within the still, increasing the day's yield by ≈10%.

All parts of this system, except the working parts of the pump, are designed to last for 20 years. The pump has been chosen for simple, inexpensive, and infrequent maintenance. In this installation, the pump runs for only about an hour a day, so its parts may last for years before replacement.

Solar Still Performance

Operation of the still is totally automatic. It requires no routine maintenance and has no routine operating costs.

The rated production of the still is an estimated annual average and is not exact, as the amount of sunshine can vary widely. These stills produce more in hot climates than in cold ones, more at low latitudes than high, and more in summer than in winter. At the 23° North latitude of the central Bahamas, the estimated average production of this installation in June will be 15 gallons per day, down to about 5 in mid-winter. In higher latitudes, addition of a mirror to the rear of each still increases winter production.

The still also functions in freezing climates. The still itself is entirely unharmed by freezing, any number of times, but exposed water lines must be insulated. The still's production is greatly diminished or ceases in very cold weather, i.e., below freezing during the day. Use a larger distilled water reservoir to store up excess production from summer and fall for winter use.

In addition to leaving salts, minerals, and other dissolved substances behind, the evaporated water also leaves bacteria in the pan. The evaporated water is sterile and does not contain dead bacteria. Fertilizers, pesticides, & other organic materials are largely left behind by this evaporation process. The distilled water produced is of very high quality, normally better than that sold in bottles as distilled water. It routinely tests lower than one part per million total dissolved solids. It is also aerated, as it condenses in the presence of air inside the still, & it tastes delicious.

Solar Still Cost

The cost of a solar distillation system will vary widely, due to size and site-specific circumstances. A residential system, like the one described here, will cost several thousand dollars.

This project was designed and constructed by Horace McCracken, long a pioneer in solar distillation. McCracken Solar Company can be reached at 329 West Carlos, Alturas, CA 96101 or call 916-233-3175.

Clean Water from the Sun

Laurie Stone

Many of us turn on the tap and take the stream of pure water for granted. Or we go down to the corner store and buy distilled water for our car or renewable energy system's battery. Many people throughout the world do not have these options. Of the 2.4 billion people in developing countries, less than 500 million have access to safe drinking water, let alone distilled water. In this country, many people who live in remote areas don't have running water, and are far from any store selling distilled water. A solar still is the answer to all these problems.

A solar still is a simple device that can convert saline, brackish, or polluted water into distilled water. The principles of solar distillation have been around for centuries. In the fourth century B.C., Aristotle suggested a method of evaporating sea water to produce potable water. However, the first solar still recorded was not until 1874, when J. Harding and C. Wilson built a still in Chile to provide fresh water to a nitrate mining community. This 4700 m^2 still produced 6000 gallons of water per day. Currently there are large still installations in Australia, Greece, Spain and Tunisia, and on Petit St. Vincent Island in the Caribbean. Smaller stills are commonly used in other countries.

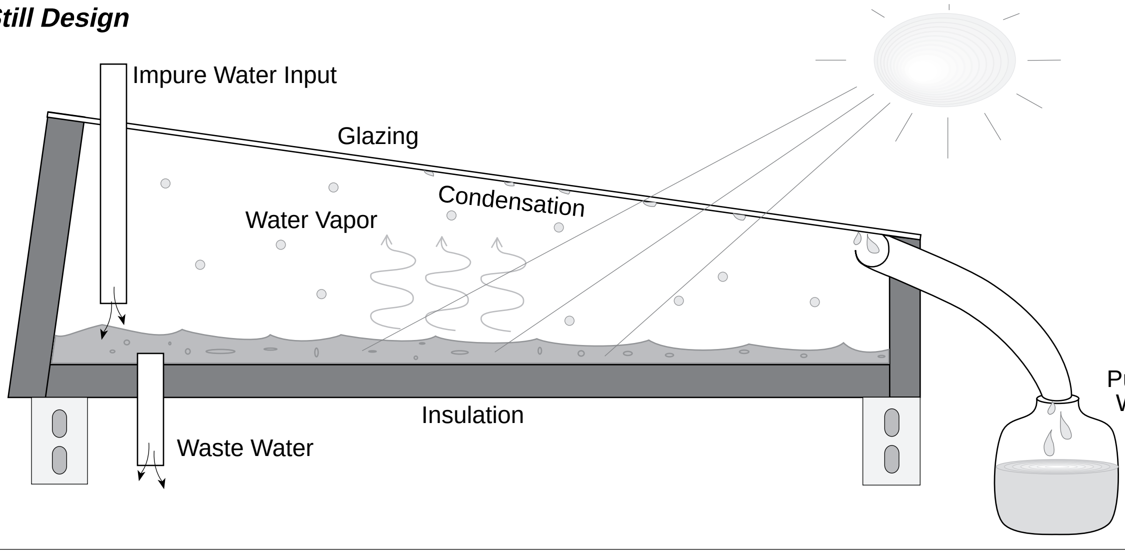
Solar Still Basics

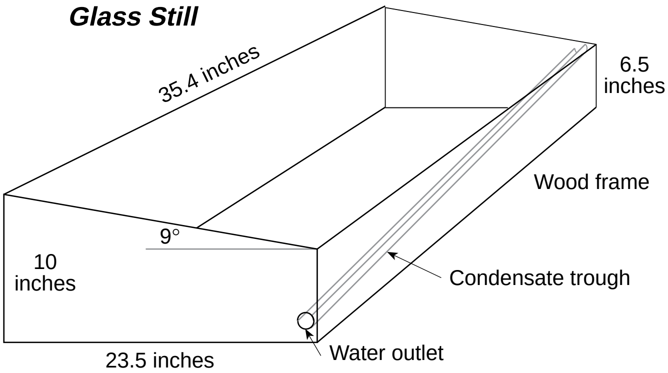
The most common still in use is the single basin solar still. The still consists of an air tight basin that holds the polluted water, covered by a sloped sheet of glass or plastic. The bottom of the basin is black to help absorb the solar radiation. The cover allows the radiation to enter the still and evaporate the water. The water then condenses on the under side of the cover, and runs down the sloped cover into a trough or tube. The tube is also inclined so that the collected water flows out of the still. When the water evaporates, the salt, dirt, and bacteria are left in the still. Thus you have perfectly clean water.

Still Construction

While I was working at the solar department of the Engineering University of Nicaragua, we decided to experiment with distilling water by the sun. Although some commercial stills are available, we decided to construct our own. We built two different types of solar stills. The first one had a glass cover sloped to one side, and the second one had a plastic cover which was sloped on both sides. Both stills were made of wood. We lined the bottom and sides of the interior with black plastic. There is an inlet hole near the top for the dirty water to enter, and another hole at the end of a condensate trough for the clean water to leave. We used some sawed off plastic tubing for the condensate trough.

Solar Still Design



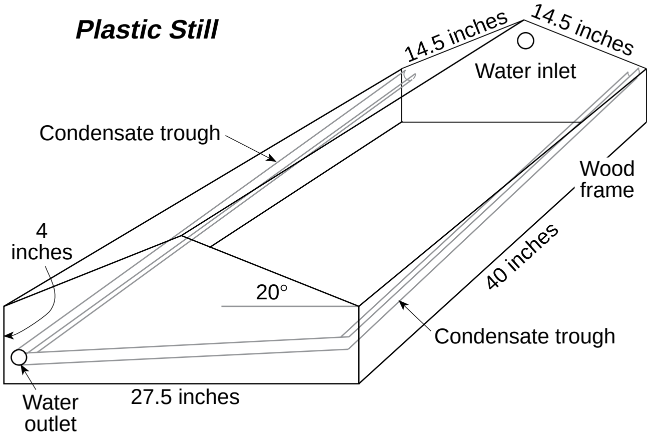


For the glass still we used ¼ inch thick glass. The thinner the glass the better, because thin glass stays cool on the inner surface which helps the water condense faster. The plastic we used for the second still is a 0.5 millimeter thick clear mylar. Both glazings seemed to work well although the water could more easily run down the glass.

The glass still has approximately 0.5 square meters of glazing and produced about 0.7 liters of water per day, or 1.36 liters per square meter of still. The plastic still has about 0.75 square meters of glazing and only produced 0.5 liters of water a day on the average. This corresponds to approximately 0.7 liters per square meter per day. Of course, the output of the stills depended greatly on how much sun there was. On very sunny days we could get over a liter of water out of the glass still.

Greater Efficiency

We did not use insulation in either still. If we had built a box within a box and put insulation between the two, we could have distilled much more water per day. Another way to maximize the output of a still is to use a reflector to increase the amount of insolation hitting the cover of the still, in the same way a reflector is used in a solar oven. However, in places close to the equator, such as Nicaragua, we felt the reflector would not make a large enough difference to be an economically viable option.



One can also run water continuously over the cover of the still. This keeps the cover temperature as low as possible without interfering with the radiation entering the still. The water condenses faster when the glazing is cool. Experiments have also been done putting black dye in the water. The black color helps absorb solar radiation, which speeds up the process and distills more water. When the water evaporates, the dye is left in the still.

Still Costs

The stills were both inexpensive to build. The glass one cost $25 and the plastic one cost $18. If the stills are used for one year, they will produce water at approximately 10 cents per liter.

Water Quality

The water may taste a little strange at first because distilled water does not have any of the minerals which most people are accustomed to drinking. Although everyone at the University seemed to prefer the tap

water, the still water was perfectly healthy. The University of Heredia in Costa Rica has analyzed water distilled using these same types of stills. The results were:

Water Quality Results

	tap water	*distilled water*
hardness (mg/l of $CaCO_3$)	36	4
pH	7.15	5
lead	ND	ND
chlorine (mg/l)	180	10
sulphate (mg/l)	100	10
copper	ND	ND
electric conductivity	80	13

mg/l = milligrams per liter *ND = not detectable

Tests in other countries have shown that the stills eliminated all bacteria, and that the incidence of pesticides, fertilizers and solvents is reduced 75–99.5%. This is good news for many countries where cholera and other water borne diseases are killing people daily.

Since the stills constructed are small and only produce a small amount of water per day, they will not be used for drinking purposes. There are numerous farming cooperatives in Nicaragua that use photovoltaics (PV) for their lighting needs. The solar stills will eventually be donated to two communities to provide distilled water for the batteries of their PV systems. These stills can also be used as prototypes to build larger stills that can be used for communities which need potable water.

Constructing Your Own

If you are going to build your own still there are a few things to keep in mind:

- The tank can be made of cement, adobe, plastic, tile, or any other water resistant material.
- If plastic is used to line the bottom of the still or for the condensate trough, make sure the tank never remains dry. This could melt the plastic (which we learned the hard way!).
- The container holding the distilled water should be protected from solar radiation to avoid re-evaporation.
- Insulation should be used if possible. Even a small amount will greatly increase the efficiency of the still.

Distilled Water for All

Whether you live in a remote area and have no running water, or you just don't trust your tap water, solar stills can provide safe, healthy drinking water at minimal cost and effort. As long as you have a sufficient amount of sun, you can produce distilled water for you, your family, or your batteries.

Above: The solar crew (Laurie is second from right) in Nicaragua with their solar stills.

Access

Author: Laurie Stone, Solar Energy International, POB 715, Carbondale, CO 81623 • 303-963-8855 • FAX 303-963-8866

For more information:

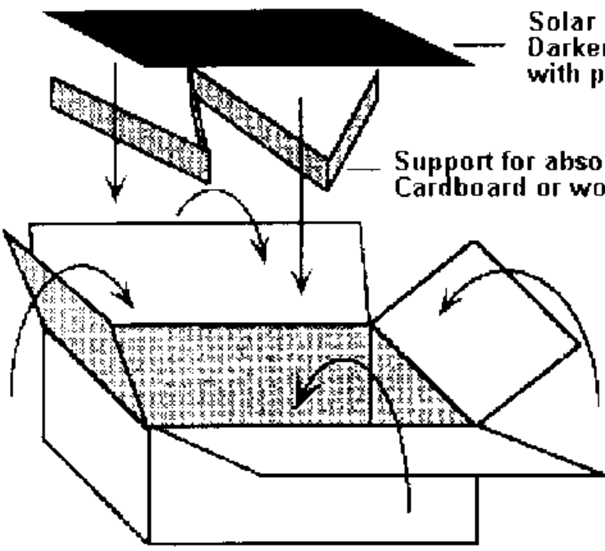
McCracken Solar Stills, 329 W. Carlos, Alturas, CA, 96101

Dr. Shyam S. Nandwani, Universidad Nacional Heredia, Costa Rica.

Brace Research Institute, MacDonald College of McGill University, Ste. Anne de Bellevue, Quebec, Canada, H9X 1C0: For plans and blueprints on how to make solar stills.

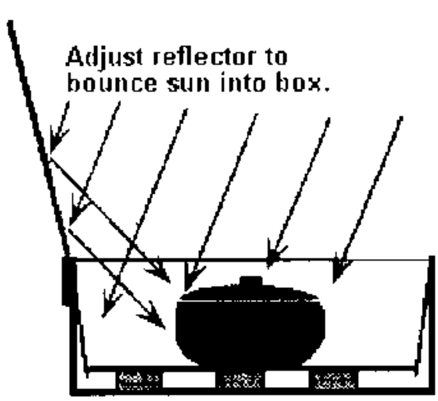
A Simple Solar Water Pasteurizer

Drinking water can be easily pasteurized using solar energy and a few simple materials. When water or milk is pasteurized the common disease-causing organisms are killed.



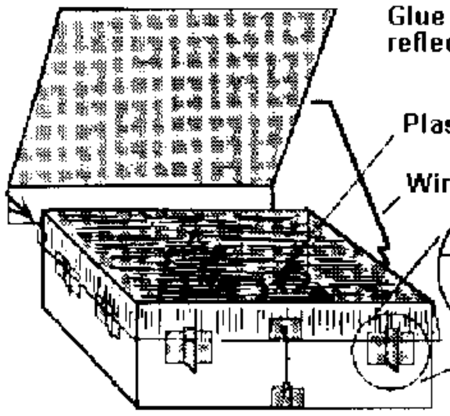
What you will need

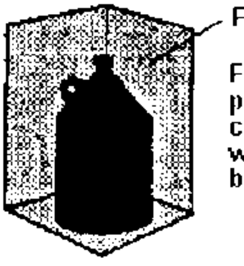
- A cardboard box or other container such as a basket or wooden box. Container materials must have basic heat retaining qualities. Bricks and metal containers do not work well unless they are insulated.
- Aluminum foil to like the inside of the box and the flaps. While it is possible to pasteurize a small amount of water without aluminum foil, its use appreciably improves performance.
- A dark colored solar absorber plate made of sheet metal, cardboard, or wood. Metal works best to conduct the heat to the water containers.



The absorber plate must be supported above the box bottom to prevent heat loss.

- A solar "window"made of glass or plastic film over the top of the box.





- A reflector to bounce in additional sunlight.
- Dark or clear containers to hold water or food (since you can cook in this oven as well).

To pasteurize water, heat it in the solar box to at least 65 degrees C (150 F) and keep the water at that temperature or above for at least 30 minutes. If no thermometer is available, heat until bubbles are rising from the bottom steadily. Natural waxes, such as beeswax, can be used to indicate pasteurization temperature.

Solar conditions, weather conditions, latitude and box efficiency are all variables that affect the ability of solar boxes to pasteurize water. As a general guideline, 4 liters (~1 gallon) of water can be pasturized in about 3 hours on a day with strong sunlight and the sun high in the sky. The plastic- or glass-covered opening should be at least 45 x 60 cm (18" x 24") and have a depth just taller than the water containers inside. Larger boxes can pasteurize more water, smaller less.

Pasteurization kills germs and disease-carrying organisms in drinking water including bacteria, rotaviruses, enteroviruses, and cysts commonly transmitted in contaminated water. Pasteurized water is not sterilized, however, and therefore should not be used for medical procedures. Pasteurization does not remove chemical contamination such as pesticides or industrial wastes.

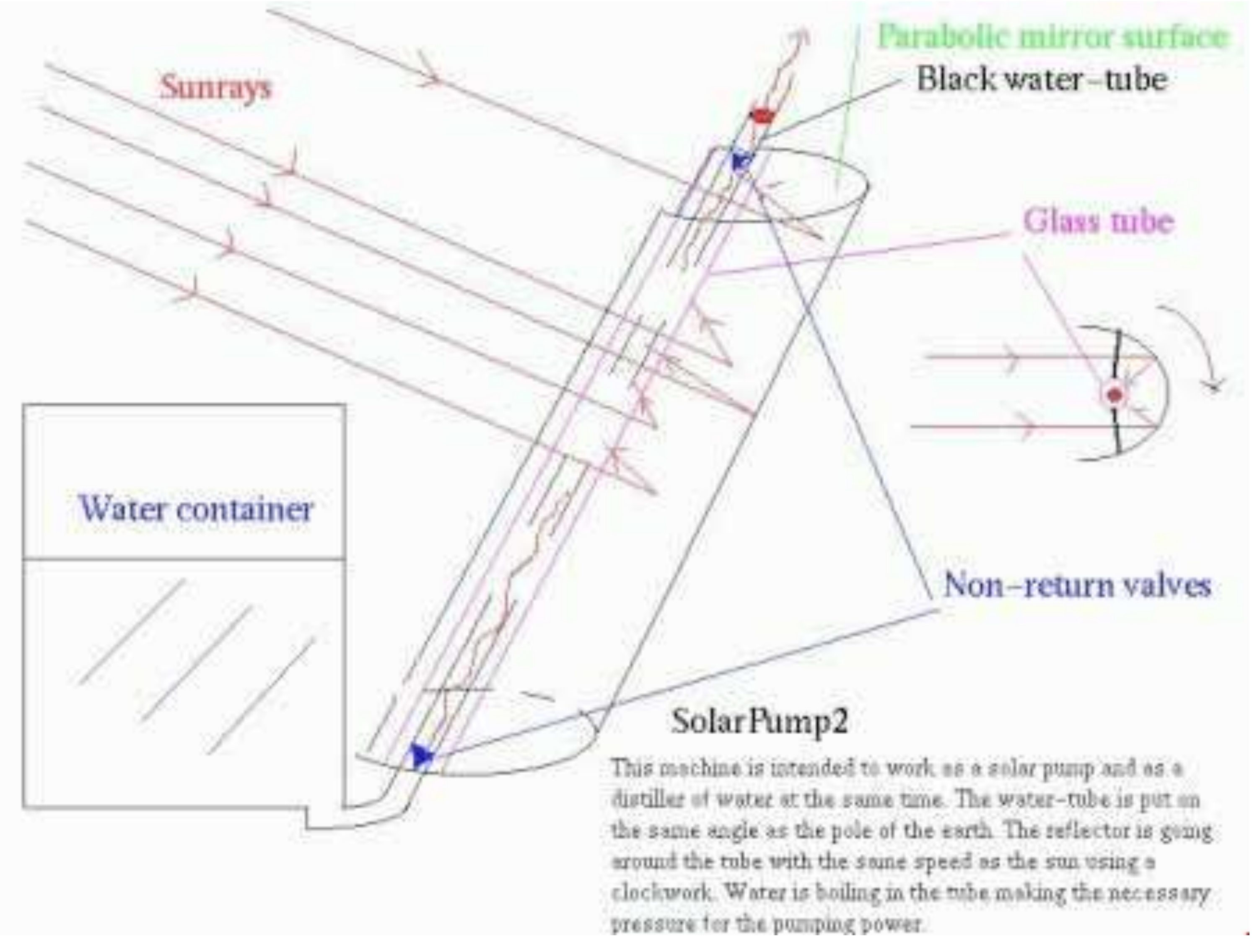
For further information on solar pasteurization see the following documents:

- Recent Advances in Solar Water Pasteurization (*Solar Box Journal* #18)
- The Solar Puddle Water Pasteurizer
- Improved Devices to Pasteurize Drinking Water (*Solar Box Journal* #16)
- Pasteurization of Naturally Contaminated Water with Solar Energy (*Applied and Environmental Microbology* v. 47 no 2, 1984)

Solar box cookers, in use throught the world, are also very effective for cooking food. For further information, contact

Solar Box Cookers Northwest
7036 18th Ave. NE
Seattle, WA 98115 USA

or email: sbcn@accessone.com


Parabolic mirror surface
Black water-tube
Sunrays
Glass tube
Water container
Non-return valves
SolarPump2
This machine is intended to work as a solar pump and as a distiller of water at the same time. The water-tube is put on the same angle as the pole of the earth. The reflector is going around the tube with the same speed as the sun using a clockwork. Water is boiling in the tube making the necessary pressure for the pumping power.

INSTRUCTIONS FOR HOUSEWIVES SOLAR DISINFECTION OF DRINKING WATER

45: Solar Disinfection of Drinking Water. Acra, Raffoul, Karahagopian. Dept. of Environmental Health American Univ. of Beirut. Lebanon/UNICEF.

GENERAL INFORMATION

The following instructions are intended primarily for the benefit of housewives in rural areas in developing countries where safe community water supplies are not available. It is assumed that in these areas water-borne diseases are endemic or sporadic.

These instructions concern the procedure to be adopted on a routine basis for the proper disinfection of drinking water for household use. The procedure involves exposure to sunlight of water from the usual community source for a minimum period of time in available transparent containers such as colourless or blue-tinted glass or plastic bottles.

In order to save time and effort, it is highly desirable for a housewife to make her own arrangements to carry out the routine disinfection operation regularly once a day, or once every other day. For this reason, a housewife should ensure enough containers that would hold the desired quantity of drinking water estimated by her to meet the needs of the family for one or two days.

At the end of the sunlight exposure period, a housewife could then transfer indoors the whole set of containers for use. To avoid recontamination, the already disinfected water should preferably be kept in the same containers used in the solar exposure operation. However, if there is a shortage of small containers, then the disinfected water could be transferred from each exposed container to a clean large container reserved for bulk storage of processed water.

Once a set of emptied containers becomes available after usage, the refilling and exposure procedures are repeated. If the containers are maintained in a good state of cleanliness, then there would be no reason for having to clean them repeatedly each time they are to be re-used.

PROCEDURE

1. *Containers:*

- From among those found at home, or purchased from the local market, select a number of containers made of colourless or blue-tinted glass or transparent plastic estimated to hold an amount of drinking water sufficient for household consumption for one or two days. The selected containers could include ordinary bottles, jars, or any other types of vessels provided they are transparent to light. Coloured containers other than blue, or greenish-blue should not be used as they are not as satisfactory.
- Remove any detachable paper labels from bottles, and wash all the containers with water (and soap, if necessary) to remove dirt and any residue from the previous contents.

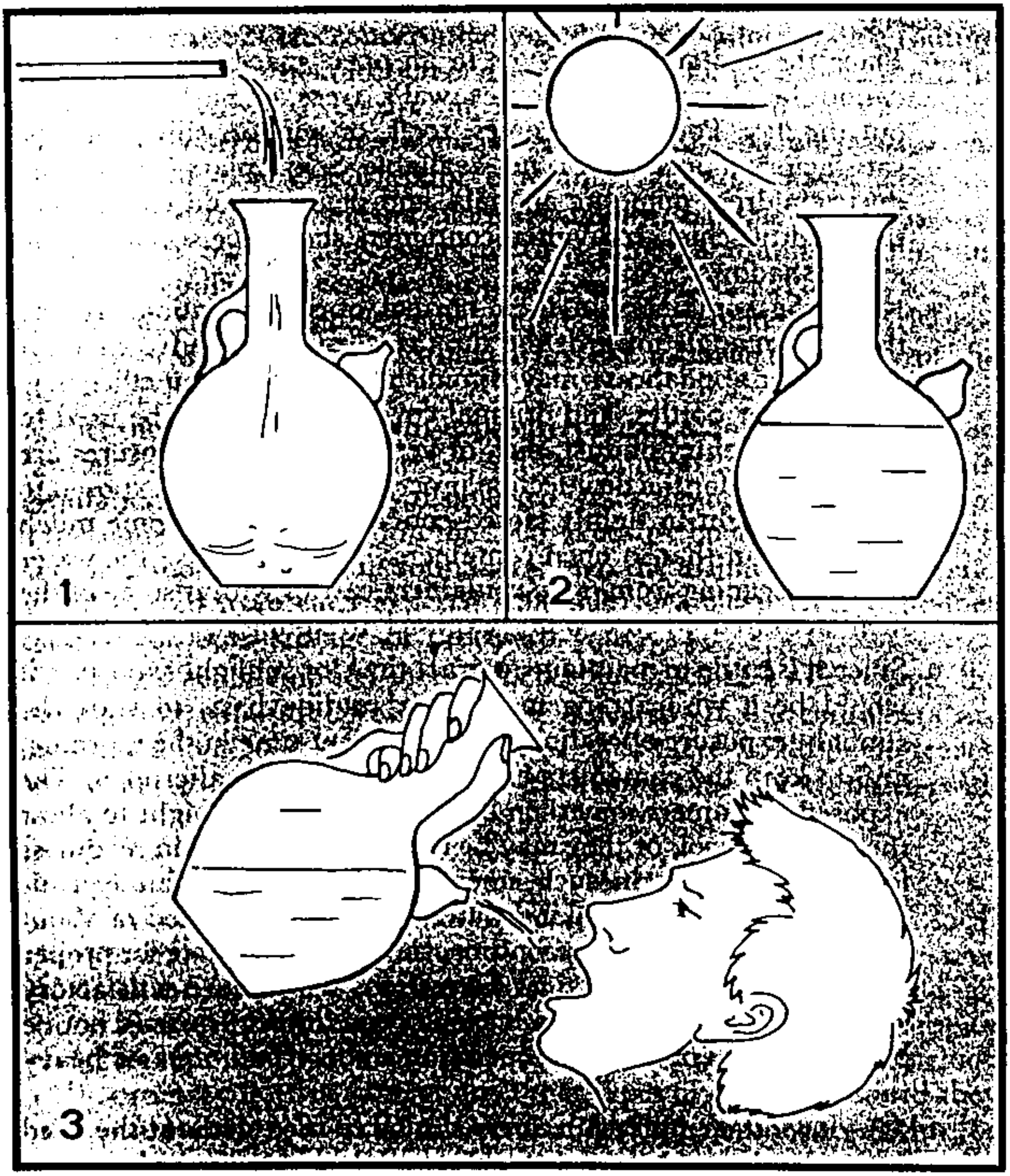
2. *Water:*

- Fetch water in the usual manner from the common village supply (stream, well, pond, reservoir, etc.). If the water is highly turbid, then clarify the water by allowing the suspended particles to settle. Decant the clear water into other vessels.
- Carefully fill each of the containers hereafter reserved for the solar disinfection operation with the clarified water.

3. *Exposure:*

- Place the containers outdoors in an open space where sunlight cannot be obstructed by houses, walls, trees, or bushes throughout the day. Porches, balconies, roofs, or window sills would be satisfactory if open land is not available. Select places away from dust, children, domestic animals, and pets to avoid contamination and mischief. Individual containers should be spread out to avoid shadows.
- Keep the containers in their normal upright position. Tilting them at an angle towards the sun (as is commonly advocated for other solar appliances) may diminish the disinfection efficiency. Stoppers for bottles, and original covers for jars may be used to prevent the entry of dust, dirt, or vermin. But, such closures are not essential for the disinfection process. In fact, water exposed to bright sunlight in tightly closed containers could become much warmer than that in open containers. This is because the water vapour escaping from open containers carries with it some of the heat acquired by the water exposed to sunlight.
- Since it is futile to maintain an exact time for sunlight exposure, it would be a wise arrangement on a routine basis to start the sunlight exposure operation at a convenient time in the morning, and to keep the containers exposed until the late afternoon. The exposed containers may then be kept in place overnight to allow the water to cool, or they may be transferred indoors in readiness for use. However, in such emergencies as when a family runs short of disinfected drinking water, an exposure period of about two hours, especially at noontime, should be adequate for proper disinfection. These practical suggestions will ensure satisfactory results even under moderately cloudy conditions. It would not be practical to carry out the operation under conditions of heavy rainfall.
- After use, the empty containers can be re-used without the need for rewashing unless they accidentally become dirty. The cycle can now be repeated from the stage of refilling with water through the stage of sunlight exposure. With time and experience, the whole operation becomes a matter of routine.

It should be noted that these instructions need to be modified or simplified further by health educators and primary health care promoters to suit local conditions, provided the essential requirements are not altered in any way.



A SUMMARY OF WATER PASTEURIZATION TECHNIQUES

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Much of this document is taken from: RECENT ADVANCES IN DEVICES FOR THE HEAT PASTEURIZATION OF DRINKING WATER IN THE DEVELOPING WORLD by Dale Andreatta, Derek T. Yegian, Lloyd Connelly, and Robert H. Metcalf, from the proceedings of the 29th Intersociety Energy Conversion Engineering Conference, American Institute of Aeronautics and Astronautics, Inc., 1994.

Introduction

Water quality and human health have been closely linked throughout history. However, it was not until the last quarter of the 19th century that pioneering work by Robert Koch and Louis Pasteur established the germ theory of infectious disease. With the understanding that fecal-borne bacteria, viruses, and protozoans were responsible for most water-borne diseases, it was possible to develop sanitation and water treatment practices which provided people with a safe water supply. In industrial countries safe water is now taken for granted.

In developing countries however, the burden of disease caused by contaminated water and a lack of sanitation continues to be staggering, particularly among young children. Diarrhea is caused by microbes entering the mouth, most often from contaminated water. According to the United Nations Children's Fund (UNICEF) diarrhea is the most common childhood disease in developing countries. Dehydration resulting from diarrhea is the leading cause of death in children under the age of five, annually killing an estimated five million children. Diarrhea is also the most common cause of child malnutrition, which can lead to death or permanently impaired mental and physical development.[1]

UNICEF estimates that 60% of rural families and 23% of urban families in developing countries are without safe water. In some areas all water supplies may be contaminated.[2] If a water source is suspected of being unsafe, the most common recommendation is to boil the water.[1] This recommendation is seldom followed for several understandable reasons, the most important being the time and the amount of scarce fuel it would require.

Contrary to what many people believe, it is not necessary to boil water to make it safe to drink. Also contrary to what many people believe, it is usually not necessary to distill water to make it safe to drink. Heating water to 65° C (149° F) for 6 minutes, or to a higher temperature for a shorter time, will kill all germs, viruses, and parasites.[3] This process is called pasteurization and its use for milk is well known though milk requires slightly different time temperature combinations. One obvious problem that arises with pasteurization is the question of how to tell when and if the water has reached the right temperature. Solutions to this problem will be covered in the next section. Pasteurization will not help if water is brackish or chemically contaminated.

In this document we describe several pasteurization techniques applicable to developing countries. Pasteurization is not the only technique that can be used to make water safe to drink. Chlorination, ultra-violet disinfection, and the use of a properly constructed, properly maintained well are other ways of providing clean water that may be more appropriate, particularly if a large amount of water is needed. Conversely, if a relatively small amount of water is needed, pasteurization systems have the advantage of being able to be scaled down with a corresponding decrease in cost. As always, the selection of the right system should be based on local conditions.

This document describes techniques used to pasteurize water, but it is also necessary to educate people about the need for clean water and how to keep their water clean. Among many people in the developing world clean water is not perceived as being important. Also, since many people do not understand how germs are transmitted, many cased have been reported where people unthinkingly recontaminate their clean water by putting it into a contaminated container.

Basic Methods of Solar Water Pasteurization-Solar Cookers

A simple method of pasteurizing water is to simply put blackened containers of water in a solar box cooker, an insulated box made of wood, cardboard, plastic, or woven straw.[3] A solar box cooker is sketched in Fig. 1. One popular type of solar box cooker is made of aluminized cardboard and has a solar collection area of about 58 cm by 48 cm (23 inches by 19 inches). It has a reflective lid that increases the sunlight collected. With this device a yield of 4 to 12 liters (1 to 3 gallons) per day is achieved in the field. Each person requires about 4 liters (1 gallon) of water per day, about half of which is for drinking and the other half is for dish washing and brushing one's teeth. The cost for this device is on the order of $20, US, depending on how easily available the basic materials are.

Figure 1: A solar box cooker being used to pasteurize water.

Other types of solar cookers can be used. A recent development in solar cookers is the solar panel cooker, which consists of reflective panels that concentrate sunlight on the food. The food is in an oven roasting bag to reduce heat loss. Replacing the food with a darkened container of water makes a solar water pasteurizer. While the cost of these panel cookers is low, not more than 2 liters of water can be pasteurized at a time, though in the right climate several batches per day can be pasteurized.

Regardless of the type of solar cooker used, a way of knowing that the water reached the pasteurization temperature is needed. An inexpensive device that does this was developed, and is shown in the Fig. 2. It is a plastic tube with both ends heated, pinched, and sealed, and with a particular type of soybean fat in one end that melts at 154° F. The tube itself is buoyant, but is weighted with a washer so it sinks to the bottom (coolest) part of the water, with the fat in the high end of the tube. If the fat is found in the low end of the tube at any time after, the water reached the proper temperature, even though the water may have since cooled down. A nylon string makes it easy to take the tube out without recontaminating the water. The tube is reused by flipping it over and sliding the string through the other way. This device works in any size water container, costs about $3, and is available from Solar Cookers International, 1724 11th Street, Sacramento, California, 95814, (916) 444-6616. This device also works with fuel-heated water. Since heating the water to the pasteurization temperature rather than the boiling point reduces the energy required by at least 50%, the fuel savings offered by this simple device alone is considerable.

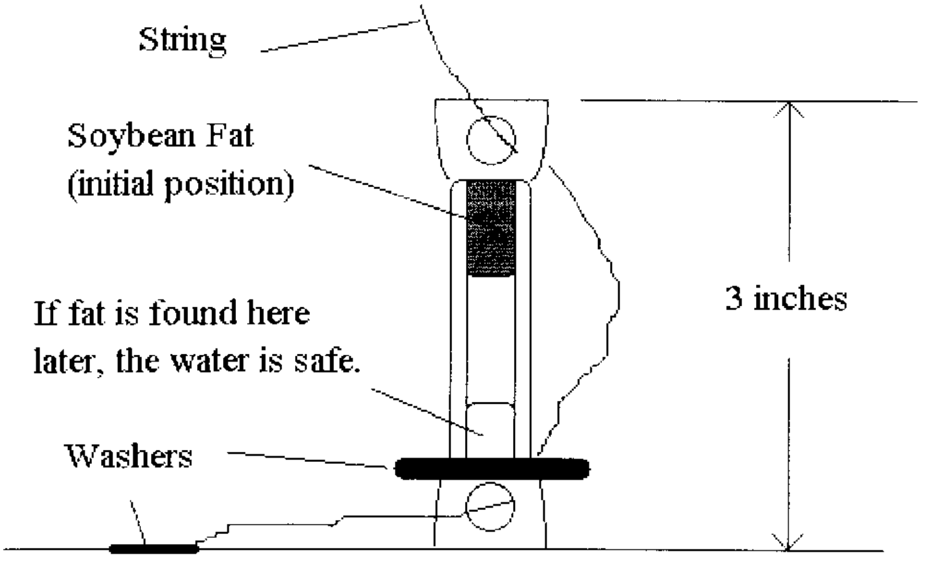
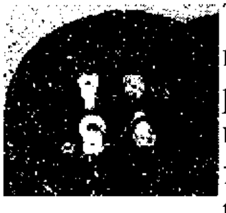


Figure 2: A Water Pasteurization Indicator. The indicator would sit at an angle in the bottom of a water container.



This device works anytime when water is pasteurized in batches regardless of the source of the heat. If one were burning fuel to pasteurize pots of water the pasteurization indicator would still be usable, as long as one didn't get the nylon string too close to the fire. Since heating the water to the pasteurization temperature rather than the boiling point reduces the amount of energy required by at least 50%, the fuel savings offered by this simple device is considerable.

Flow-Through Pasteurization Devices

In order to produce more water PAX World Service produced a flow-through unit which consists of 15 meters (50 feet) of black-painted tubing coiled within a standard solar box cooker. One end of this tubing is connected to a thermostatic valve and the other to a storage tank for the untreated water supply. This storage tank also contains a sand/gravel/charcoal filter that does the preliminary filtering. The small amount of water (about 1.5 liters) within the tubing allows rapid heating of the water to the valve's opening temperature of 83.5° C (182° F). This is well above the required temperature, but the valve is derived from a mass-produced automotive radiator thermostat valve, so there is a limited selection of opening temperatures. The thermostatic valve opens allowing the pasteurized water to drain out of the tubing and into a second storage vessel for treated water. As the treated water drains from the solar box cooker, contaminated water from the storage tank automatically refills the tubing. Once this cool water reaches the valve the valve shuts and the pasteurization process begins anew.

This flow-through device addresses several of the problems inherent in the batch processes. First, potable water becomes available throughout the day as new increments of treated water are added to the clean storage vessel. Second, this type of unit can adapt to variable solar conditions which takes the guesswork out of filling the jugs in a batch process. If the insolation increases the time required to pasteurize and release the water in the tubing decreases, thus supplying increments of treated water at a faster rate. If insolation decreases the residence time in the solar box cooker will increase, but it will still be pasteurized which may not be the case in a batch unit where the user overestimated the amount of water which could be treated for that day. This is also a totally automatic process, freeing time for other chores and decreasing the likelihood of an accident occurring when transferring water in and out of a batch unit. Field trials by PAX World Service and the Pakistan Council of Appropriate Technology have regularly shown yields of 16 to 24 liters per day (4 to 6 gallons per day). The cost of this device is on the order of $50, US.

Although this is a respectable increase, much more dramatic improvements can still be achieved by recycling the heat in the outgoing pasteurized water. Once the water has been pasteurized and released from the solar box cooker the energy in this water can be used to preheat the incoming water. This process is shown in Fig 3. Since the temperature of the water entering the solar box cooker is higher, it takes less time to finish the pasteurization process, allowing more water to be treated. Also, the flow resistance of the heat exchanger smoothes the flowrate of the water.

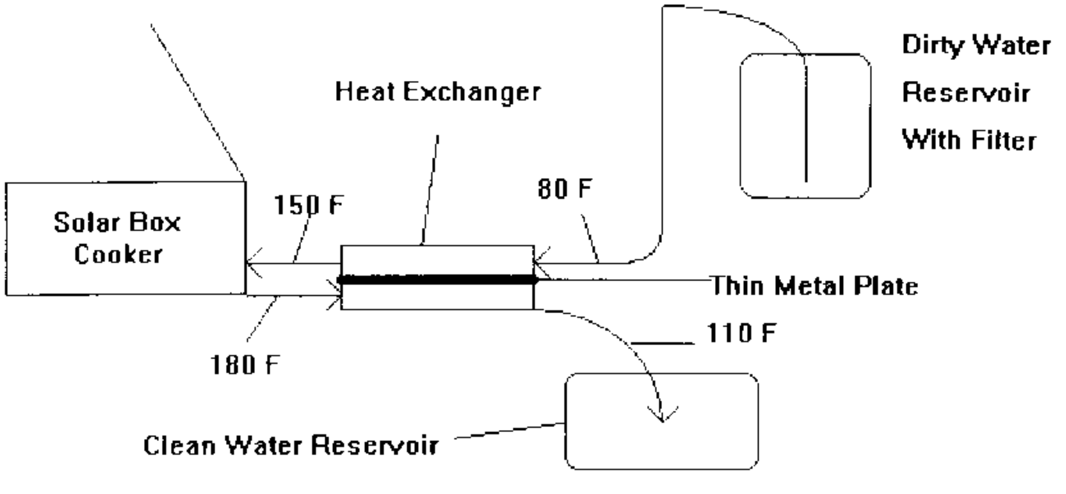


Figure 3: PAX -style water pasteurizer with heat exchanger. Typical temperatures are shown in degrees Fahrenheit.

A simple device which accomplishes this preheating is a counter-current heat exchanger. The hot water flows on one side of a metal plate, while on the other side of the plate cooler fluid flows in the opposite direction. The energy from the hot water is transferred to the cold water, thus preheating the incoming contaminated water by lowering the temperature of the outgoing pasteurized water.

There are many ways of building a counter-current heat exchanger. Both a tubular version and a flat version have been tested using various configurations and materials, with experimental results favoring the less expensive flat version, though the tubular version is easier to construct from purchased parts. The flat plate unit allows between 75% and 80% of the energy to be reused in preheating the incoming water, and roughly four to five times more water will be pasteurized over a flow-through unit without a heat exchanger. This corresponds to about 80 to 96 liters (20 to 24 gallons) of treated water per day, which is a ten to twelve-fold improvement over the original solar box cooker batch method. An additional benefit is that the chance of burns is greatly reduced because the outflowing water is much cooler reducing the burn hazard. The cost of the heat exchanger itself is on the order of $15 US, making the cost of the complete PAX system about $65. Thus for an increase in cost of about 15% the heat exchanger provides about a 400% increase in water output.

Other Sources of Heat

A heat exchanger can produce benefits with any source of heat, including the exhaust heat from an engine, a fire (that may be used to cook food at the same time,) and heat from other types of solar collectors. We have done some engineering analysis and generated an equation to determine the water output of a particular system of this type. 4 This analysis can also be used to determine the relative benefits of a better heat exchanger, vs. a bigger solar collector vs. a better insulated collector.

If one went with a flame-heated system one would require a short piece of metal tubing, a thermostatic valve with housing, and a heat exchanger. The total cost of this type of system would be about $30. At present we have not done any experiments in this area.

The Solar Puddle-A Low Cost Large Area Device

While many factors determine the usefulness of a water pasteurizer, an important figure of merit is the water delivered per unit cost. A device which is made only of low cost materials is being called a "solar puddle" and it is essentially a puddle in a greenhouse. One form of the solar puddle is sketched in Fig. 4, though many variations are possible.

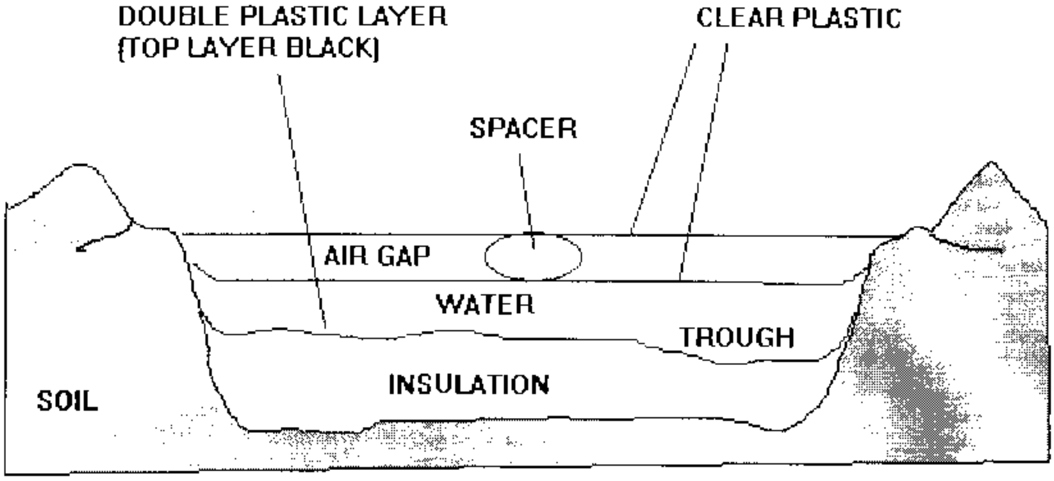


Figure 4: A basic solar puddle. Horizontal dimensions are shown compressed for clarity. A puddle can alse be built with wooden sides on top of a table or roof.

One begins by digging a shallow pit about 10 cm (4 inches deep). The test device was a "family-size" unit, about 1 meter by 1 meter (3 1/2 feet by 3 1/2 feet) but the puddle could be made larger or smaller. If the puddle is made larger there is more water to pasteurize, but there is also proportionately more sunshine collected. The pit is filled with at least 5 cm (2 inches) of solid insulation. We used wadded paper, but straw, grass, leaves, or twigs could be used. This layer of insulation should be made flat, except for a low spot in one corner of the puddle, which is marked "trough" in Fig 4. A layer of clear plastic and then a layer of black plastic goes over the insulation with the edges of the plastic extending up and out of the pit. Two layers are used in case one develops a small leak. We used inexpensive polyethylene from a hardware store, though special UV stabilized plastic would last longer. One would then put in some water and flatten out the insulation so that the water depth is even to within about 1 cm (1/2 inch) throughout the puddle, except in the trough which should be about 3 cm (1 inch) deeper than the rest. More water would be added so that the average depth is 2 to 7 cm (1 to 3 inches) depending on how much sunshine is expected. A pasteurization indicator should go in the trough since this is where the coolest water will collect. At this point the drain siphon should be installed. It should be at the lowest part of the trough so that the most water will be siphoned out before the siphon starts to draw air. The end of the siphon should be held solidly in place by a weight or by several rocks. A layer of clear plastic goes over the water, again with the edges extending beyond the edges of the pit. An insulating air gap is formed by putting one or more spacers on top of the third layer of plastic (large wads of paper will do) and putting down a fourth layer of plastic, which must also be clear. The thickness of the air gap should be 5 cm (2 inches) or more. Finally, dirt or rocks are piled on the edges of the plastic sheets to hold them down. If the bottom of the puddle is flat, well over 90% of the water can be siphoned out.

Once the puddle is built it would be used by adding water each day, either by folding back the top 2 layers of plastic in one corner and adding water by bucket, or by using a fill siphon. The fill siphon should NOT be the same siphon that is used to drain the puddle, as the fill siphon is recontaminated each day, while the drain siphon MUST REMAIN CLEAN. Once in place the drain siphon should be left in place for the life of the puddle.

The only expensive materials used to make the puddle are a pasteurization indicator ($2-$3), a siphon tube (about $1), and 4 sheets of plastic (about $2 for the size tested). Many tests were done in the spring and summer of 1994 in Berkeley, California. On days with good sunshine the required temperature was achieved even with 68 liters (17 gallons) of water corresponding to a depth of 62 mm (2 1/2 inches). With thinner water layers higher temperatures can be reached. With 24 liters (6 gallons) corresponding to a depth of 21 mm (1 inch) 80° C (176° F) was achieved on one day.

The solar puddle works even under conditions that are not ideal. Condensation in the top layer of plastic doesn't seem to be a problem, though if one gets a lot of condensation the top layer should be pulled back to let the condensation evaporate. Small holes in the top layers don't make much difference. The device works in wind, or if the bottom insulation is damp. The water temperature is uniform throughout the puddle to within 1° C (2° F).

After some months the top plastic layers weaken under the combined effects of sun and heat and have to be replaced, but this can be minimized by avoiding hot spots such as places that are exposed to the sun but not cooled by the water. Another option would be to use a grade of plastic that is more resistant to sunlight. The two bottom layers of plastic tend to form tiny tears unless one of very careful in handling them. This is why there are two layers on the bottom. A tiny hole may let a little water through and dampen the solid insulation, but this is not a big problem.

There are many variations of the solar puddle. The least expensive form of a solar puddle is built into the ground as in Fig. 4, but a puddle could be built with wooden sides on top of the ground, on a tabletop, or on a roof. We've been able to put the top layer of plastic into a tent-like arrangement that sheds rain. This would be good in a place that gets frequent brief showers. Adding a second insulating layer of air makes the device work even better, though this adds the cost of an extra layer of plastic. As mentioned the device can cover a larger or smaller area if more or less water is desired. A larger puddle would have a higher initial cost, but a lower unit cost for the water, since the same drain line and water pasteurization indicator could be used. One could make a water heater by roughly tripling the amount of water so that the maximum temperature was only 50° C (120° F) or so, and this water would stay warm well into the evening hours. This water wouldn't be pasteurized though. One could help solve the problem of dirty water vessels by putting drinking cups into the solar puddle and pasteurizing them along with the water. The solar puddle could possibly cook foods like rice on an emergency basis, perhaps in a refugee camp.

Cost Summary

The table below shows an approximate cost summary of the basic methods of water pasteurization described in this document. The initial cost is the amount of money that needs to be spent to get the system running. The water produced per dollar of long term cost is based on a 5-year lifetime, and includes expected maintainance costs and replacement parts. In some cases, a), b), and c) in particular, the maintainance costs are small. For the solar puddle, cases e) and f), the replacement costs for the plastic layers that degrade in the sunlight make up the majority of the long-term cost.

The assumption used in these calculations are:

1. The fuel cost is $0.02 per liter of boiled water (cases a) and b)). This number comes from a recent issue of the Solar Cookers International newsletter, and is the amount of money that some people in the developing world are willing to pay for the fuel to boil drinking water.
2. Pasteurization indicators must be replaced twice in 5 years (cases b), c), e) and f)).
3. Thermostatic valves must be replaced once in 5 years (case d)).
4. For the solar puddle the top 2 layers of plastic are replaced every 3 months, while the bottom 2 layers are replaced every 6 months (cases e) and f)).

System Name	Initial Cost (US dollars)	Liters of Water per Dollar (long term)
a) Flame-heated water pot (heated to boiling with no pasteurization indicator)	small	50
b) Flame-heated water pot with pasteurization indicator	3	96
c) Solar Box Cooker with pasteurization indicator	23	375
d) PAX unit with recuperator	65	580
e) Solar Puddle ("family size")	6	1800
f) Solar Puddle (community size, 10 ft. by 25 ft.)	25	3500

It can be seen that the systems using fuel have low initial cost but high long term cost. The pasteurization indicator is an inexpensive way of nearly doubling the water produced per unit of fuel, though the long term costs of such systems are still high due to the cost of the fuel. The solar puddle has low initial cost and low long term costs, but involves the work of replacing the plastic layers frequently.

Conclusion

In this document water pasteurization has been presented as a way of providing clean drinking water in developing countries. Several techniques for pasteurizing water have been presented here. Some of these methods are less expensive, some produce more water per day, and some are in the form of a compact device that is easy to ship and set up in the field. Pasteurization is only one way of providing clean water. The purpose of this document is not to say that pasteurization is the best way of providing drinking water or to say that one pasteurization technique is necessarily better than other. As always, the selection of a method for providing clean water should be based on local conditions, and the selection process should include a variety of social factors as well as the technical and cost factors explored here. Field experience shows that education is also necessary to achieve successful results with any water system.

References:

1. UNICEF, The State of the World's Children, 1988, Oxford University Press, pg. 3, 1988.

2. UNICEF, The State of the World's Children, 1989, Oxford University Press, pg. 48, 1989.

3. Ciochetti, D. A., and Metcalf, R. H., Pasteurization of Naturally Contaminated Water with Solar Energy, Applied and Environmental Microbiology, 47:223-228, 1984.

4. Recent Advances in Devices for the Heat Pasteurization of Drinking Water in the Developing World, Dale Andreatta, P. E., Derek T. Yegian, Lloyd Connelly, and Robert H. Metcalf, Proceedings of the 29th Intersociety Energy Conversion Engineering Conference, 1994.

See also Solar Water Pasteurizers Make Safe Drinking Water in Tanzania

http://www.accessone.com/~sbcn/solarwat.htm

http://www.fc.net/~tdeagan/water/past.txt

49: Passive Solar Water Heaters. Reif. Brick House Publishing. Massachusetts USA 1983 0-931790-42-5

SITE ANALYSIS

Your site is one of the most important factors determining both the best placement of your solar collector and the amount of heat your system will produce. There are two criteria for determining the solar potential of the collector location: *the orientation of the collector toward solar south*, and *the amount of shading on the collector throughout the year*. The information you collect from studying your potential collector site should be added to the Analysis Section of the System Selection Worksheet on page 64.

ORIENTATION

At midday, go outside and stand at the south side of your house. To find *solar south* you must first find out at what times the sun rises and sets on that day. Newspapers often list these times. Exactly halfway between sunrise and sunset, the sun's east to west position is directly *solar south*. Solar south is also called *true south*. The shadow of a vertical stick at midday points directly away from solar south.

If you live near a time change zone line, actual sunrise and sunset in your area may vary as much as one half hour from that stated for your time zone. To check the direction of solar south, the shadow of a vertical stick is shortest when the sun is directly solar south.

You can also find solar south by using a compass, but you must compensate for the fact that the direction of solar south can vary from magnetic south. Use the Magnetic Variation Map (Figure 4—1) to find the variation between maguetic and solar south for your area.

Note: Always take compass readings from several locations because if there are any large metal objects or heavy electrical lines above or below the ground near where you are standing, these objects can significantly affect your compass reading. Even a metal belt buckle close to the compass can affect the reading; and you don't want to build the collector facing in the wrong direction!

First, find your location on the Magnetic Variation Map. Next, note the direction and number of degrees of variation between magnetic and solar south. If

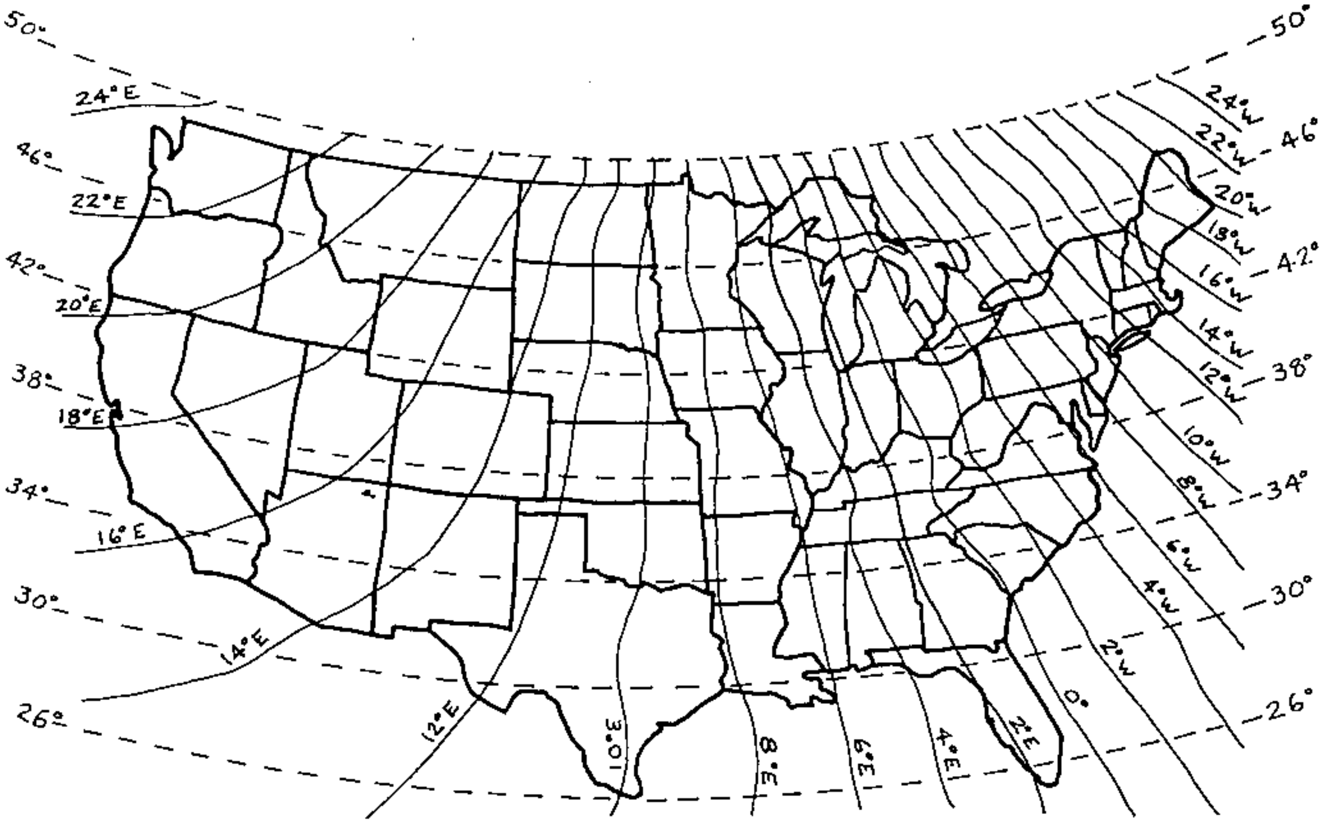


Figure 4–1. *Magnetic Variation Map.* This map of the United States indicates magnetic variation away from solar south. (Source: Isogonic Chart of the Unites States, U.S. Department of Commerce, Coast and Geodetic Survey, 1965.)

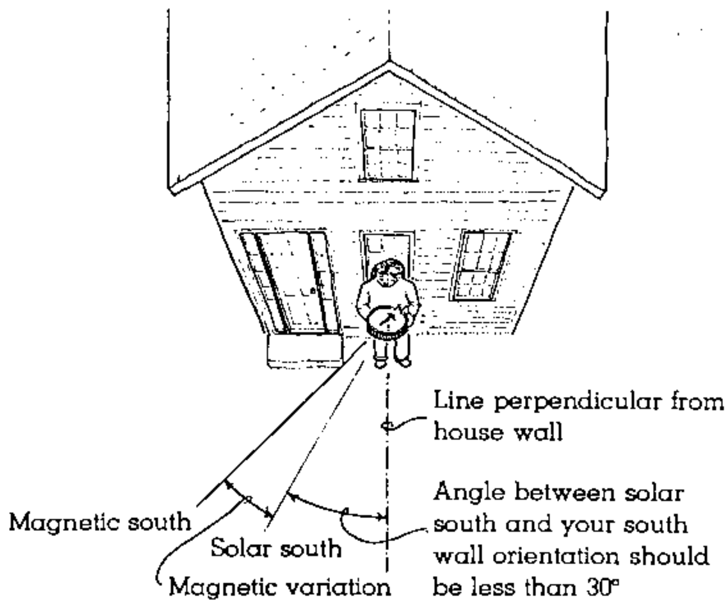


Figure 4–2. Finding the orientation of the south wall or roof.

you live near the line of zero variation, running from Lake Michigan to Georgia, magnetic south and solar south are in the same direction. If you live *east* of this line, magnetic south is to the *left* (east) of solar south; and if you live to the *west* of this line, magnetic south is to the *right* (west) of solar south.

Once you have located solar south, stand with your back in line with the proposed collector. For a south-wall-mounted collector, stand against the south wall. Point one arm straight ahead and the other arm toward solar south. Both arms should be at the same height. The size of the angle between your arms is the number of degrees your south wall is oriented away from solar south.

The orientation of the collector toward solar south must be combined with the slope of the collector to determine the percentage of maximum sunshine the collector will receive in a given location. (See the sample tables for Boston, Miami, Los Angeles, and Seattle.)

Percent of annual maximum performance for Boston (Blue Hill), Massachusetts (42° North Latitude)

	Collector Orientation			
Collector Slope	*0°*	*30°*	*60°*	*90°*
Latitude-15	99	97	91	83
Latitude	100	98	91	80
Latitude+15	95	93	87	74
Vertical	61	60	55	46

Percent of annual maximum performance for Miami, Florida (26° North Latitude)

	Collector Orientation						
Collector Slope	*0°*	*30°*	*60°*	*90°*	*120°*	*150°*	*180°*
Latitude-15	98	98	96	94	92	90	89
Latitude	100	99	97	93	86	80	78
Latitude+15	97	96	94	88	79	68	62
Vertical	53	53	51	45	29	—	—

Percent of annual maximum performance for Los Angeles, California (34° North Latitude)

	Collector Orientation			
Collector Slope	*0°*	*30°*	*60°*	*90°*
Latitude-15	97	96	92	87
Latitude	100	99	94	87
Latitude+15	97	96	92	83
Vertical	58	58	55	47

Percent of annual maximum performance for Seattle, Washington (48° North Latitude)

	Collector Orientation			
Collector Slope	*0°*	*30°*	*60°*	*90°*
Latitude-15	100	98	93	86
Latitude	100	98	92	83
Latitude+15	93	92	86	76
Vertical	60	61	59	52

Source: Fuller, W. "Collector Location: No Taboos on East or West," *Solar Age*, December 1980. Reprinted with permission.

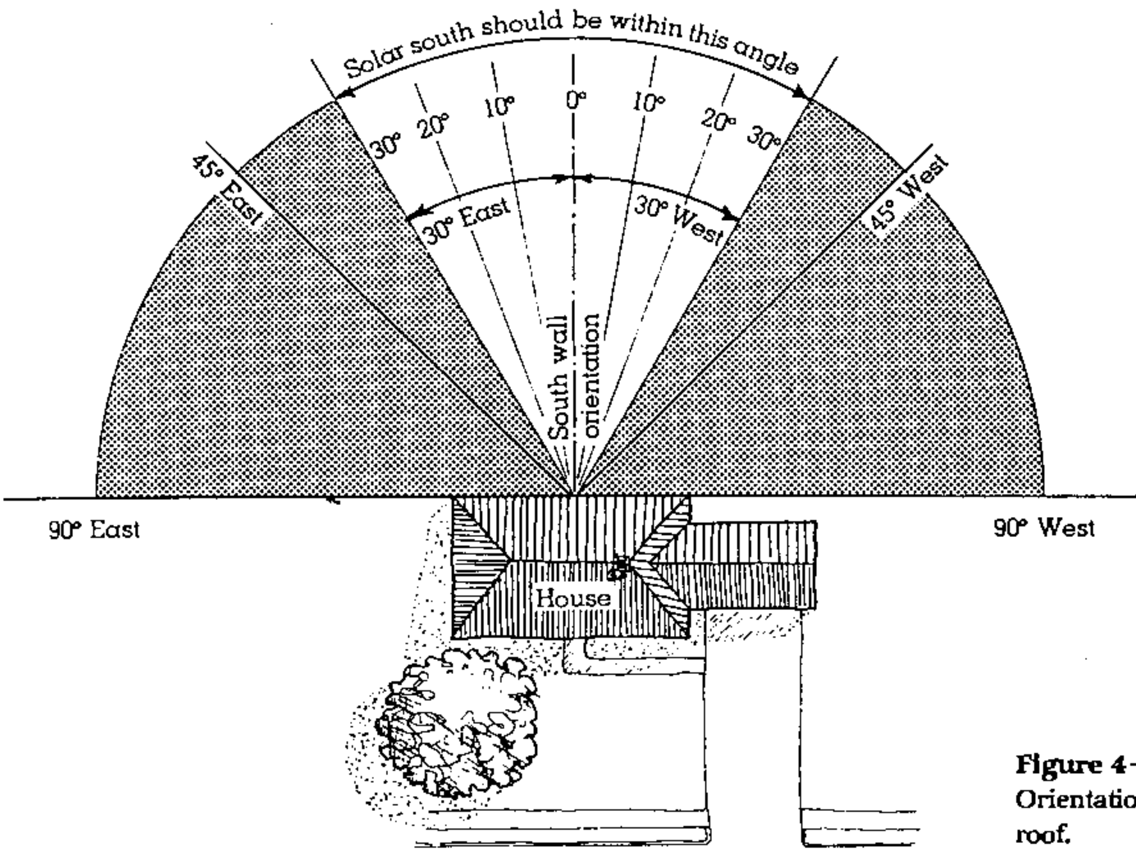


Figure 4–3.
Orientation of the south wall or roof.

For maximum year-round performance, the collector should be oriented toward solar south and be sloped at an angle equal to your latitude. Fortunately, if the collector is oriented within 30° east or west of solar south, collector slopes at angles plus or minus 15° from your latitude angle still receive over 90% of the maximum amount of solar energy.
Therefore, most houses have a wall or roof that is suitable for solar collection. With freestanding solar heating systems, just aim the collector toward solar south. And, if the reflector is separate from the collector, then the reflector should be oriented toward solar south with the collector directly in front of it.

Collectors that are sloped at angles *less* than the latitude angle (more horizontally) receive more sunlight in summer and less in winter. Collectors sloped at angles *greater* than the latitude angle (more vertically) receive more sunlight in winter and less in summer. In general, collectors that are oriented away from solar south benefit from being sloped more horizontally rather than more vertically than the latitude angle.

Since reflectors can significantly add to the amount of solar energy striking the collector, reflectors are an excellent way to achieve good performance with less than optimum orientation and slope. This allows the flexibility to construct a collector that is more easily built and still performs well. In the freestanding vertical passive water heater design (Chapter 6), reflectors can more than offset the loss of efficiency due to the vertical slope of the collector by increasing the amount of solar energy striking the collector by a factor of two or more times.

Slightly easterly or westerly collector orientations can have unique advantages or disadvantages, depending on your exact site. An easterly orientation usually has the advantage of supplying warm water earlier in the morning, while a westerly exposure gives you a little extra heat just before the cold night arrives. Of course, local weather conditions such as frequent morning fogs or afternoon clouds can negate these advantages.

Shading of either the morning or afternoon sun is another consideration in determining a collector's optimum orientation. When the morning sun is shaded, a slightly western orientation is preferable, while shading of the afternoon sun makes a slightly eastern exposure ideal. When building a new house or an addition, orient it to within 30° of solar south so that you not only achieve maximum solar water heating performance, but are also correctly oriented for solar heating and cooling of your house, and for photovoltaics—solar electricity!

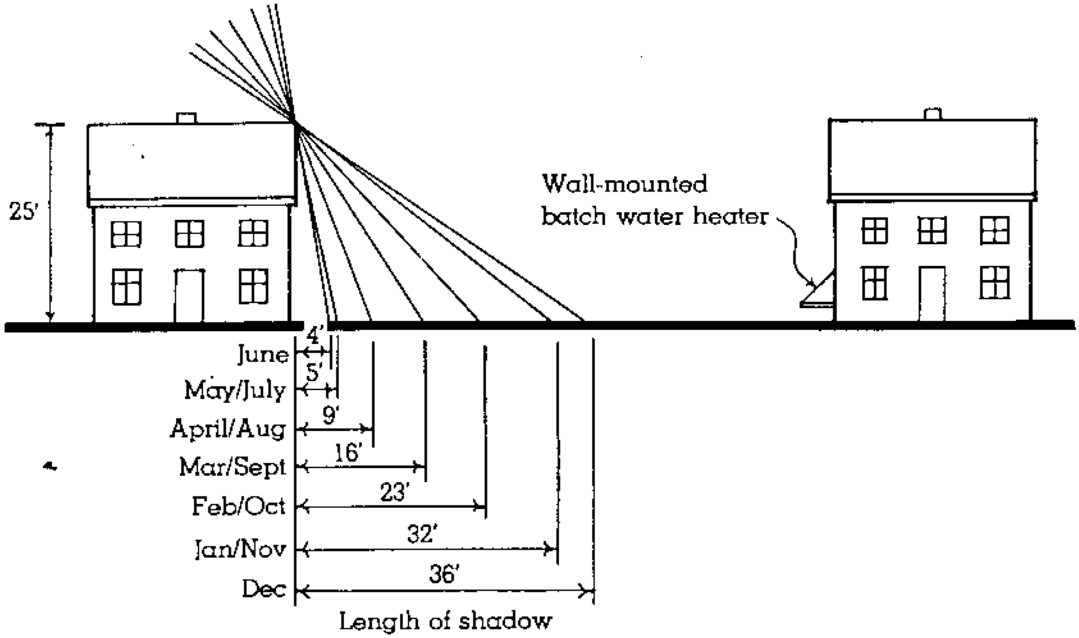
SHADING

Many an otherwise fine site has been avoided because it is shaded. Shading of the sun's rays can be a monumental problem for both solar retrofits and new construction. You need to determine which areas of the south wall, roof, or ground are *not shaded from the midday sun throughout the year*.

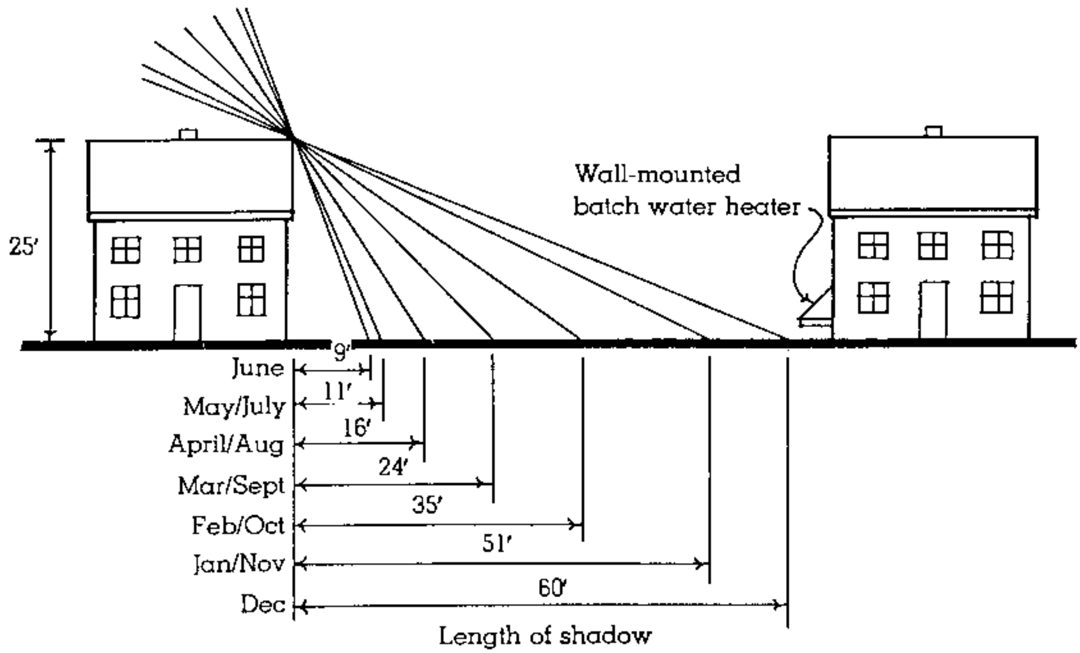
While standing where the collector would be, imagine the path of the sun as it rises in the east, reaches its highest position at midday, and sets in the west. Actually in winter the sun rises in the southeast and sets in the southwest; and in summer the sun rises in the northeast and sets in the northwest. Ouly on March 21 and September 21 does the sun rise, then set, exactly east and west. Of course, the sun only appears to rise and set; it is the earth that is rotating toward (rise), and away (set) from the sun.

Shading of the morning or late afternoon sun is not as crucial as shading of the strong midday sun. Winter shading from decidous trees is less than winter shading from evergreens or from solid obstructions, such as the house next door. If you are evaluating your site in summer, spring, or fall, remember that shadows cast by the low winter sun will be *much longer* than those cast during the other seasons. If your potential site has shading of no more than 20% of the sun between 9:00 AM and 3:00 PM and your collector orientation is within 30° of solar south, you have a good solar site!

Since the low winter sun casts the longest shadows, it is most likely to be blocked from reaching your collector. If the shadow is cast by a deciduous tree, then at least some sunlight (about 25% to 50%) will penetrate through the bare tree. Shading of the winter sun is usually not critical for good year-round performance from your solar water heater. (Shading of the winter sun's rays is crucial, however,



32° North Latitude



44° North Latitude

Figure 4–4. Length of the shadow cast at solar noon for the twenty-first day of each month by an obstruction 25′ high, for latitudes 32° north and 44° north. A 50′ high obstruction casts a shadow twice as long.

Figure 4–5.
The Solar Card is an easy-to-use, low-cost solar evaluation tool. It can also be used to determine how much sun strikes a potential garden spot or where to plant to let summer shade and winter sun fall on the house.

for solar heating your house.) This is because the amount of sunshine during winter is only a small portion of the year-round potential sunshine.

If you are uncertain about the amount of shading on your collector or want a more exact sighting of the sun's path, you can construct a *solar siting mask*. This device lets you see the winter, fall, and spring sun paths. Because the summer sun is so high in the sky, almost overhead, this siting mask cannot project the sun's path in summer. You will have to approximate the summer sun's path in order to determine any summer shading. Instructions for constructing a solar siting mask are given at the end of this section.

Commercially constructed siting devices are available from:

Solar Card, Design Works, Inc., P.O. Box 489, North Amherst, MA. 01059 ($12.95 postpaid);

Solar Site Selector, 105 Rockwood Drive, Grass Valley, CA 95945 ($89.50 + $4 shipping);

Solar Pathways, Inc., 3710 Highway 82, Glenwood Springs, CO 81601 ($144.00).

The amount of shading varies as you move around your site. Shading from nearby obstructions such as bushes, a chimney, a roof overhang, or a protruding part of your house changes considerably if you move several feet sideways, or up or down.

In new construction, shading from your neighbor's house or trees can cause you to position your building to the north side of your site. When there is no space left to go north, raising the collector a few feet is sometimes as good as moving the building north by twice the distance.

In retrofitting, where you usually have a lot less flexibility, pruning and tree cutting have often been solutions. But, please do not cut down a 100-year-old tree to decrease your shading by a few percentage points.

There is always some frustration after you have decided to go solar— and are faced with the sometimes unwilling site. When building on a compromised solar site, you can sometimes overcome obstacles by using reflectors, or you may simply have to rely on other renewable energy sources and strong water conservation measures.

Sites without any shading on the collector area and optimum orientation are rare. Since there are few perfect solar sites, you must work to integrate the collector with the best qualities of your site.

SOLAR SITING MASK

A solar siting mask is an excellent tool for performing a thorough shading analysis and is especially helpful for evaluating questionable solar sites. The mask can be constructed in several hours with material costs of about $5. When you are finished with your site analysis, the mask is a great gift for a friend.

Construction

Materials

1. 14 1/2'' long, 1'' x 8'' (actual measurement 3/4'' x 7 1/4'') pine board
2. 12'' long, 1/2'' diameter wood dowel
3. 23'' x 16'', .005-mm (or thicker) clear acetate or 1/16'' plexiglass sheet
4. twelve 1/2'' pan head wood screws with 1/2'' washers
5. 23'' x 2'' piece of cardboard

Tools

1. drill and 1/16'', 1/4'', and 1/2'' drill bits
2. sabre saw or keyhole saw
3. black marking pen
4. screwdriver
5. ruler
6. string (for drawing 14 1/2'' diameter circle)
7. glue
8. Six 8 1/2'' x 11'' sheets of 1/8'' graph paper
9. Sun Path Chart (page 77) and Magnetic Variation Map (page 68)

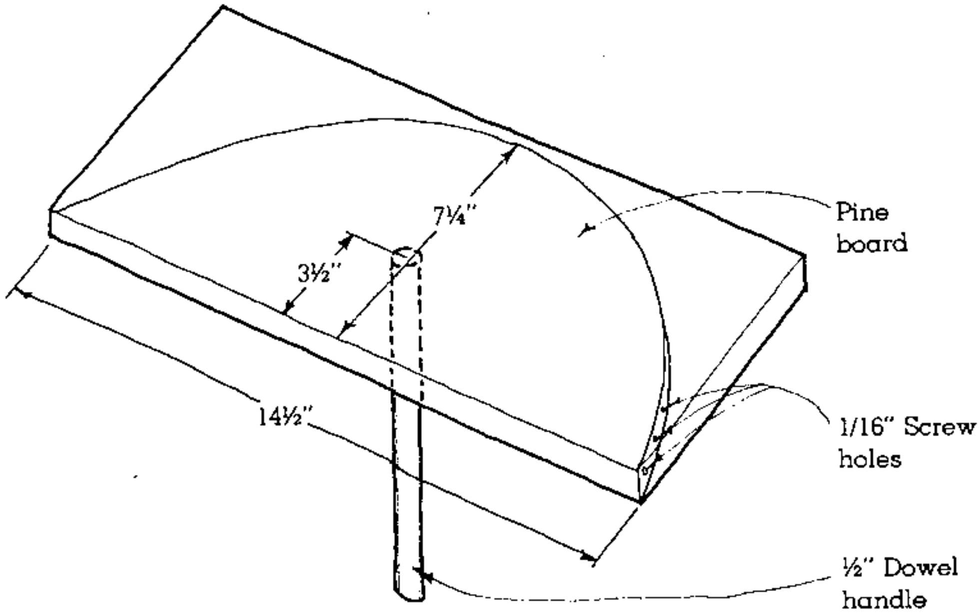


Figure 4–6.
Solar siting mask base and handle.

Constructing the Base and Handle

1. Using a pencil tied to a string, draw a 14 1/2″ diameter semicircle on the 1″ x 8″ x 14 1/2″ board.
2. Mark the point 3 1/2″ from the edge and equidistant from the sides.
3. Cut the board to form a semicircle.
4. Drill a 1/2″ hole at the center point of the board, and glue the end of the 1/2″ dowel into this hole to make the handle.
5. Drill 1/16″ holes every 2″ along the curved edge of the semicircle as shown.

Drawing the Sun Paths

1. Join six 8 1/2″ x 11″ sheets of graph paper to make one 22″ x 24″ sheet. The 24″ side should be held horizontally.
2. Find the Sun Path Chart for the latitude nearest yours. You can determine your latitude from the Magnetic Variation Map.
3. Using a ruler, draw the Solar Altitude/Solar Azimuth Graph according to the dimensions in figure 4–7. Solar altitude is the height of the sun above the horizon. Solar azimuth is the east-to-west position of the sun. Note that the solar altitude spacing varies for each 10° interval. This is because when the sun's circular and overhead paths are projected and drawn onto a flat surface, such as the shading mask, the paths are distorted.
4. Draw the Sun Path Chart for your latitude onto the 22″ x 24″ graph paper. The easiest way to do this is to mark a dot on the graph paper on each solar azimuth

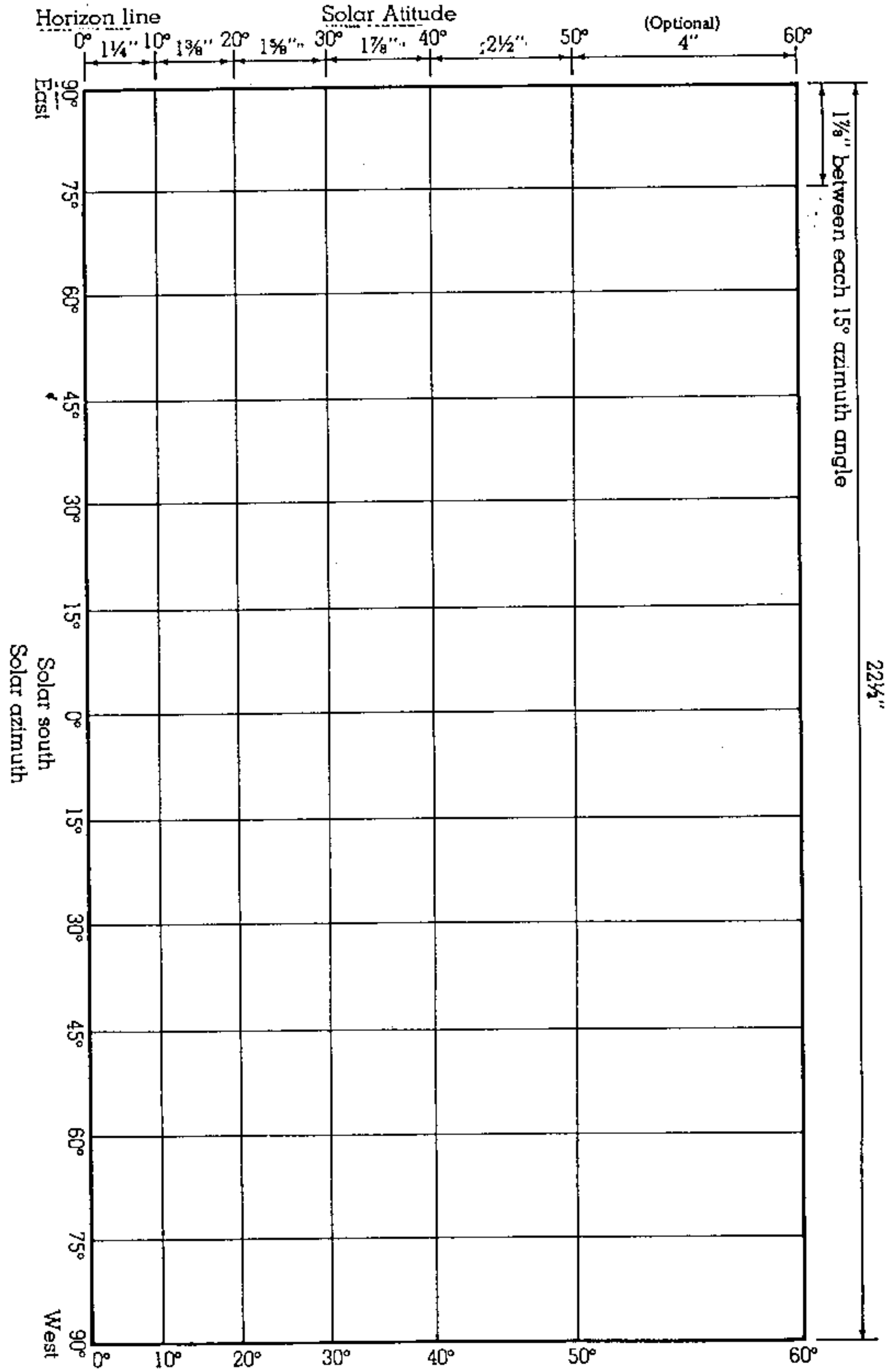
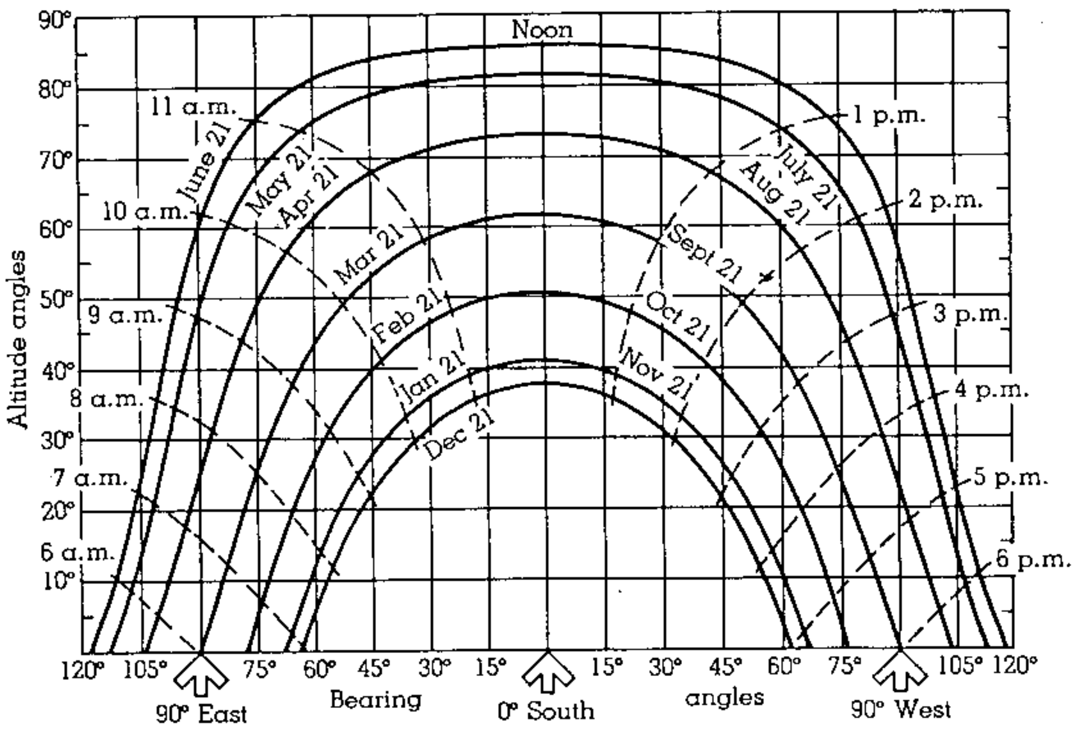


Figure 4–7.
Solar Altitude/Solar Azimuth Graph

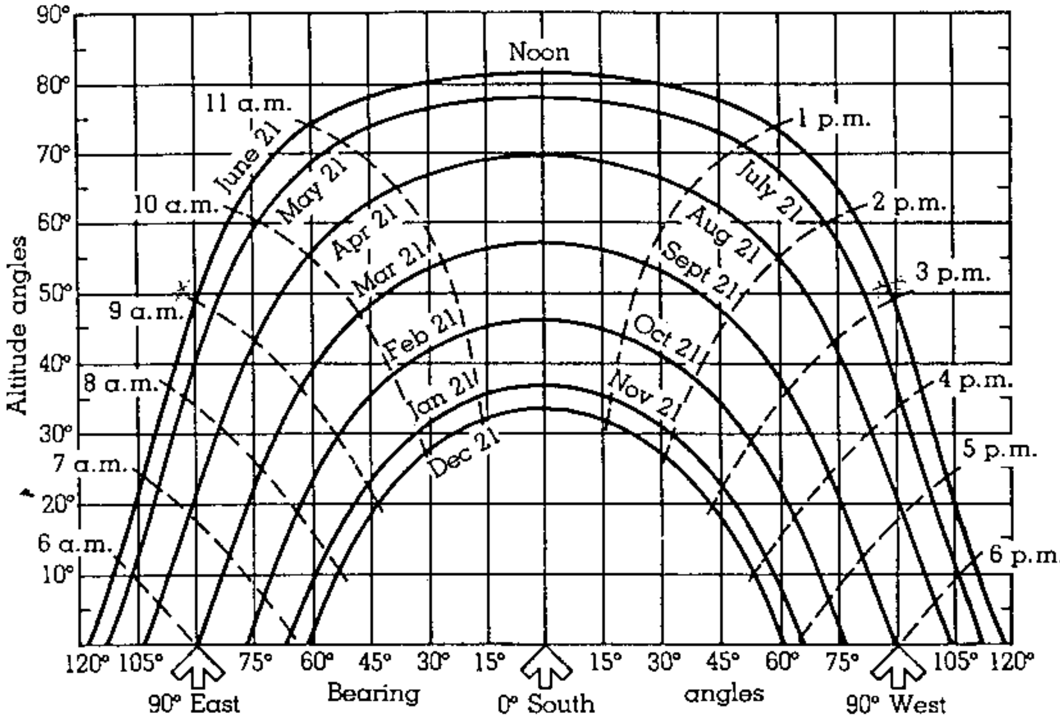
line where the curve of the sun paths cross that azimuth. Then, simply connect the dots to form the correct curves. Next, add the time of day lines. Only the portions of the sun's paths between 90° east and 90° west, and up to 60° solar altitude, can be drawn on this shading mask. The sections of the sun's paths not on the mask, mostly those in summer, can easily be imagined to determine if shading is a problem.

5. Find your location on the magnetic Variation Map. Read the number of degrees variation and the direction—east or west. Remember that if you are east of the zero variation line, your magnetic south line is *left* of the solar south line; if you are west of the zero variation line, your magnetic south line is *right* of the solar south line. Draw a dotted vertical line crossing the horizon line representing magnetic south for your location.
6. Trace the sun's paths, solar and magnetic south lines, time of day lines, and horizon line on to the acetate from the prepared graph paper. Leave 2 1/4″ between the bottom of the acetate sheet and the horizon line. Label each of the sun's paths by month, solar and magnetic south, time of day line, horizon line, and east and west.

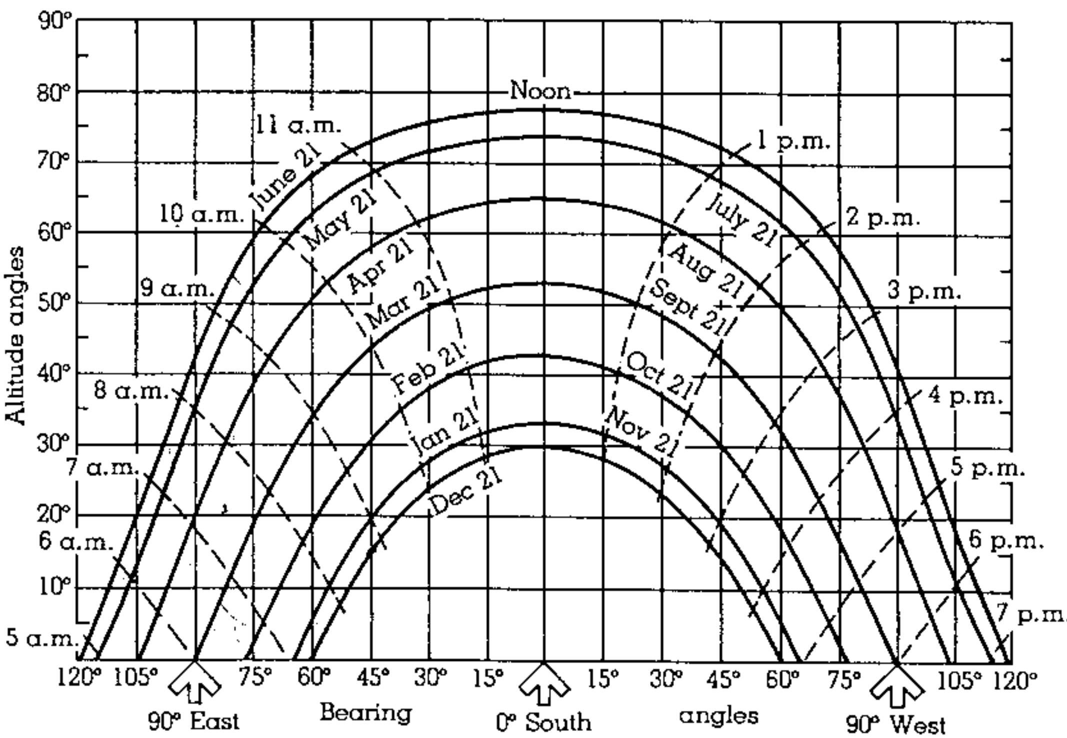
Figures 4–8 (a-g). Sun paths for northern latitudes



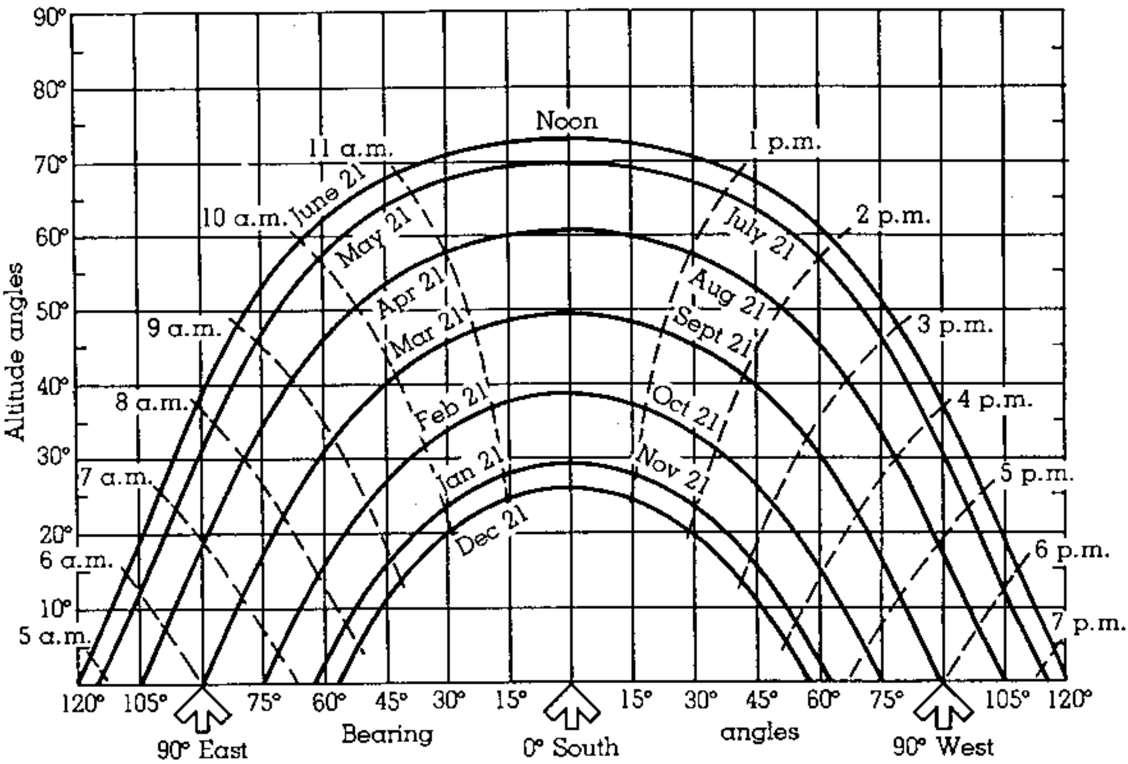
(a) 28° north latitude



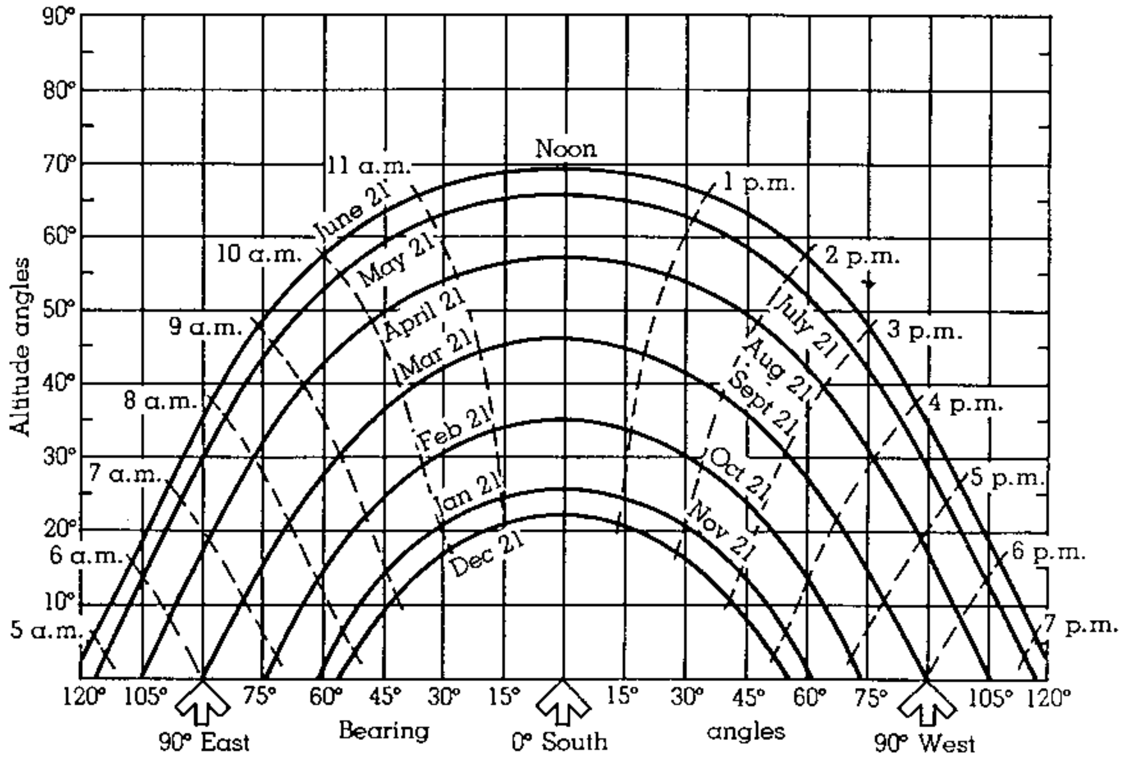
(b) 32° north latitude



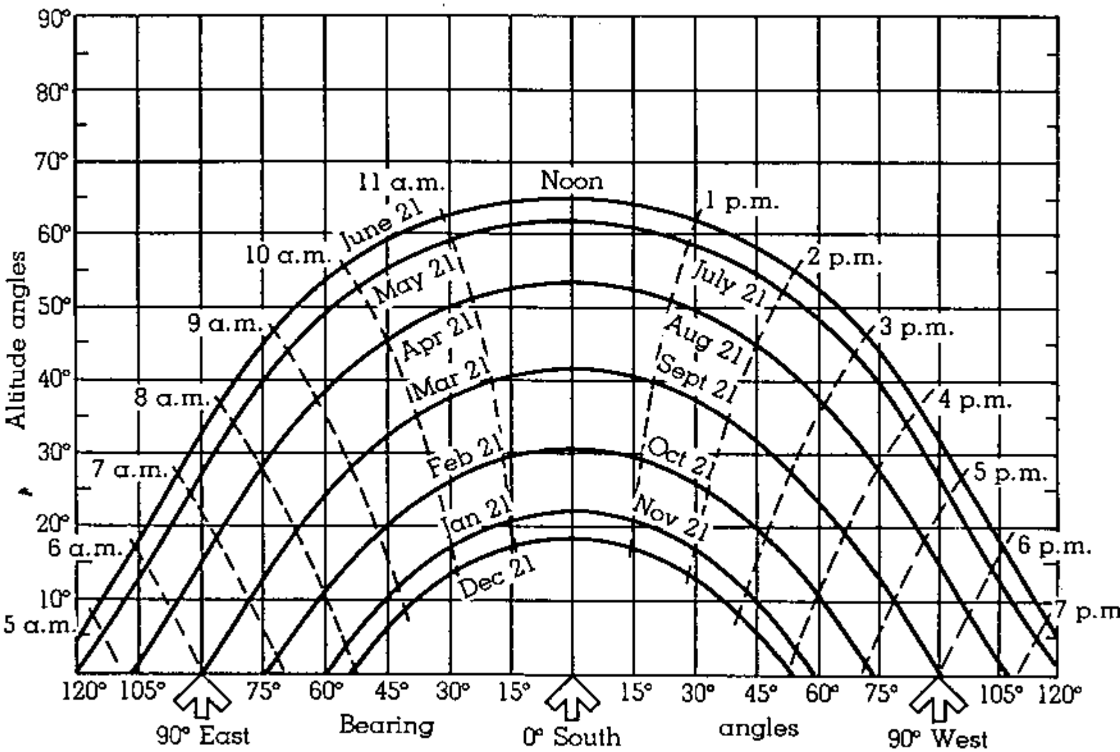
(c) 36° north latitude



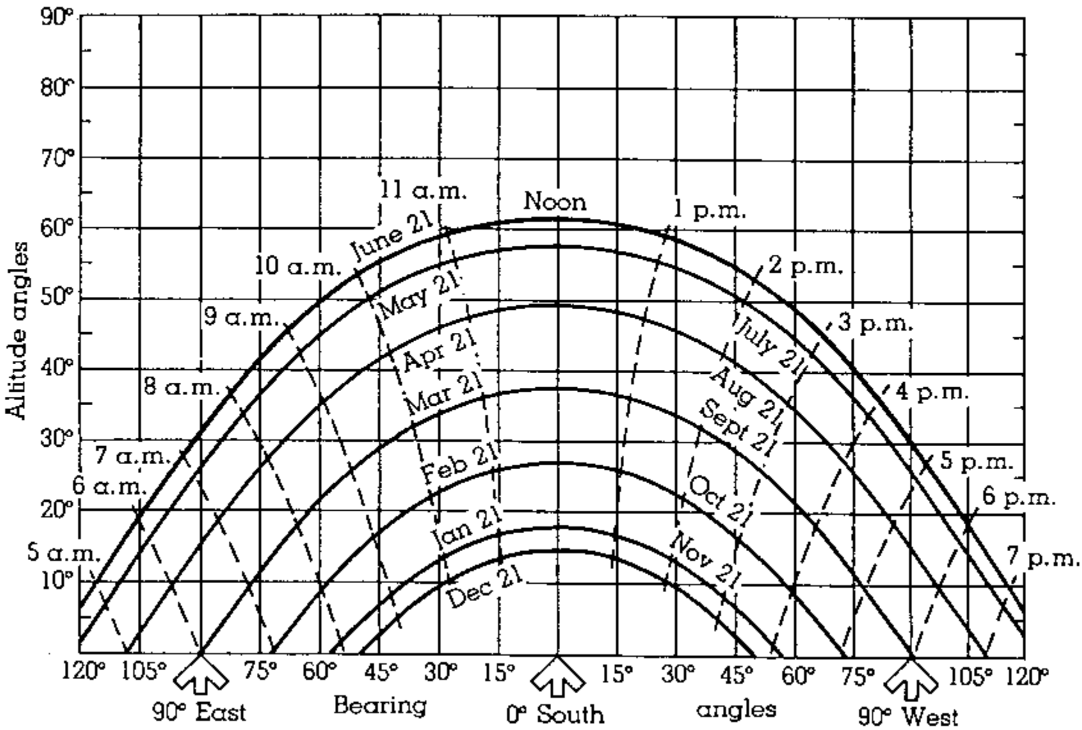
(d) 40° north latitude



(e) 44° north latitude



(f) 48° north latitude



(g) 52° north latitude

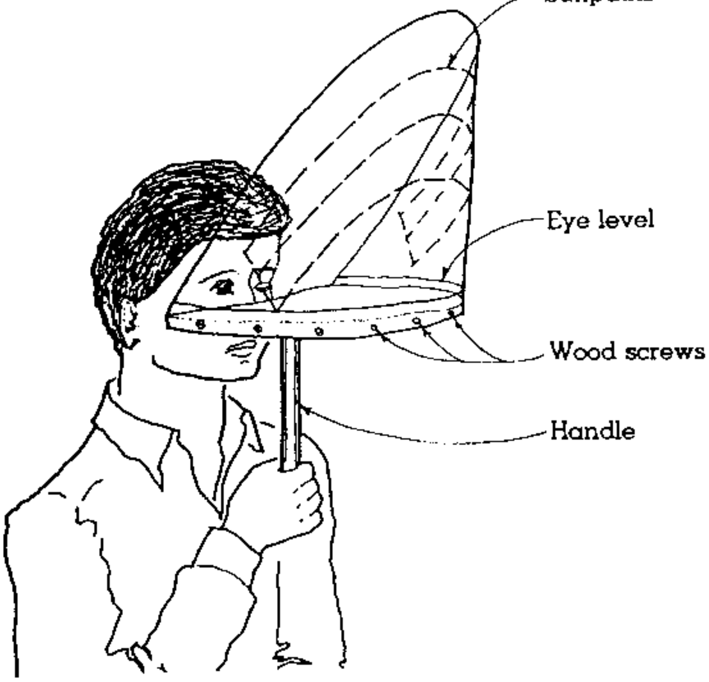


Figure 4–9.
Looking through a solar siting mask.

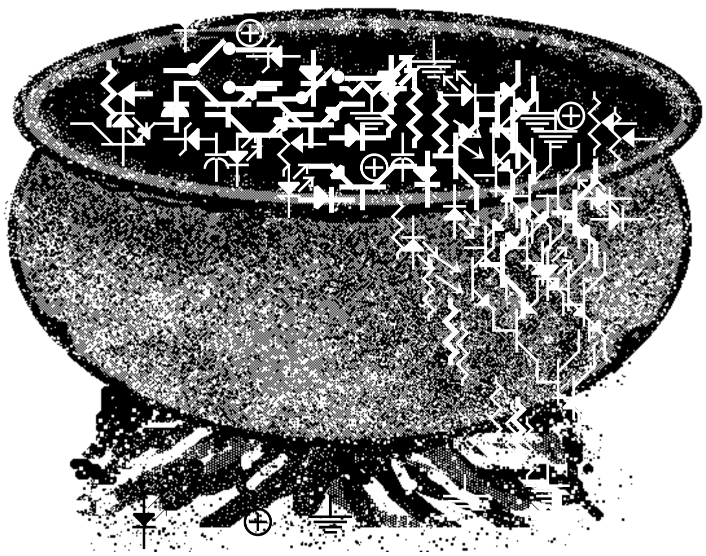
7. Use the screws, washers, and cardboard to attach the finished acetate sheet to the base. Drill 1/4″ holes through the acetate or Plexiglas sheet, so that the screws do not crack it. Place the cardboard under the washers to add rigidity to the acetate. The horizon line should be 1 1/2″ above the top of the base.
8. Cut away excess acetate about 1/2″ above the highest sun path to add stiffness.

Using the Solar Siting Mask

To determine the amount of shading, stand with your back in line with the potential collector installation. Use a compass to locate magnetic south. Hold the siting mask so that your eye is at the center of the semicircle and level with the horizon line on the mask. Close the other eye. Now aim the magnetic south line on the mask toward magnetic south. Make certain you are holding the base of the mask level. Remember that even small amounts of metal near a compass can disturb its reading, so be sure to check the direction of magnetic south from several positions.

View the sun's path for each month and see when the sun will be shaded. Move to several potential collector sites and compare the amount of shading. Remember that shading of up to 20% of the sun between 9:00 A.M. and 3:00 P.M. is common and acceptable. For further study, sketch the view through the mask on your sun path chart and think about it later.

Homebrew



Will The Sun Shine On Your Solar Modules All Winter?

Steve Willey

Most solar module users know that their panels generate electricity only when mounted directly in sunlight. In fact, a shadow on even part of a solar module can stop it from producing power. I have seen solar modules installed by the U. S. Forest Service that were almost completely blocked by trees, because they had considered only the appearance of the building, and neglected practicality.

It seems easy to pick out a good sunny spot for solar modules by just watching shadows outdoors to find a spot that is sunny all day long. But as the seasons change, those shadows become longer or shorter. You don't see the whole picture until you watch for a full season – unless you have a solar siting device.

Winter is the most critical time since the sun is lowest in the sky and shadows are longest. This simple homebrew solar sight shows winter sunshine access at a glance. You stand at the intended PV location and look across the device to see the daily path of the sun in the five winter months, when the sun is lowest in the sky and shadows are longest. Any trees, buildings, or things other than clear sky that are seen to be higher than the edge of the sight will cast a shadow on your spot during those winter months.

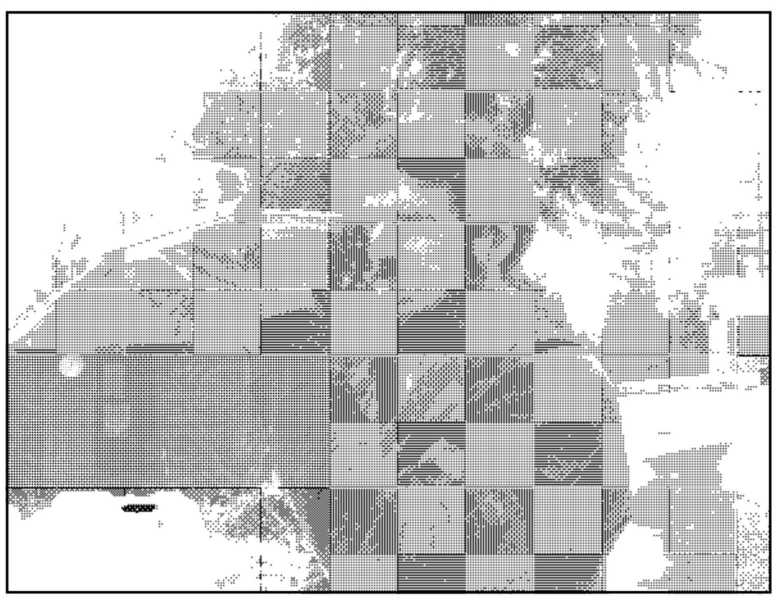
This sight is simple, but accurate enough to do the job. The pattern with this article is shown for one latitude only, but you can build one for other latitudes using Part One dimensions given in the table. The pattern on page 62 is for 46° to 50° latitude (north or south).

Part One Line height for latitudes other than 46°-50°

Angle	45°	30°	15°	0°
Time	8:30 & 3:30	10 & 2	11 & 1	12 Noon
Latitude				
36°	3 1/2"	4 1/4"	4 1/2 "	4 7/8"
40°	2"	3 5/8"	3 3/4"	4"
44°	1 7/8"	2 7/8"	3 1/4"	3 5/8"
56°	5/8"	1"	1 1/2"	2"

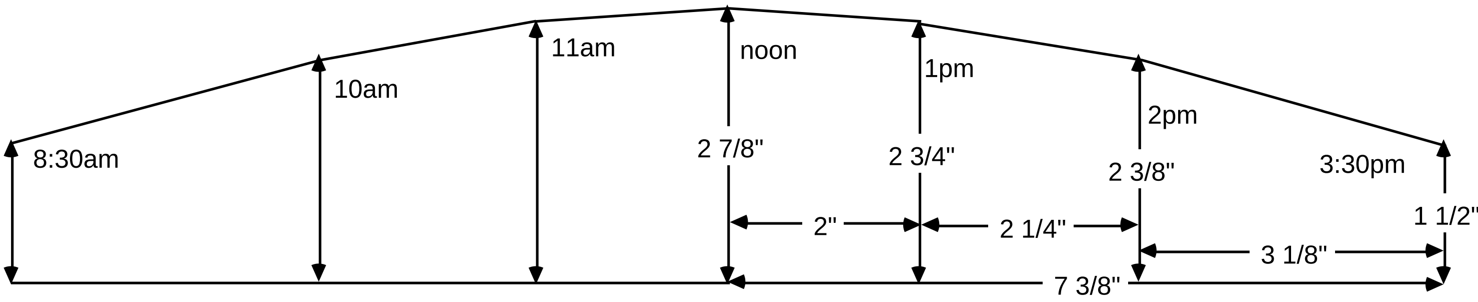
Assembly

The two parts of the solar sight are printed on the next page at half their real size. Cut out pieces of plywood (or cardboard for short term use) to the measurements specified on the pattern (or the table above depending on your latitude). Copy the converging lines onto Part Two and press in a thumbtack where the lines come together to a point for easier visibility. Copy the hours of the day onto Part One. Join Part One at a right angle to Part Two at the dotted line. The joint can be made sturdy by gluing in a piece of quarter-round moulding on the back side (see photo). Elmer's wood glue works great; do not use screws or nails unless they are brass, because they may affect your compass.

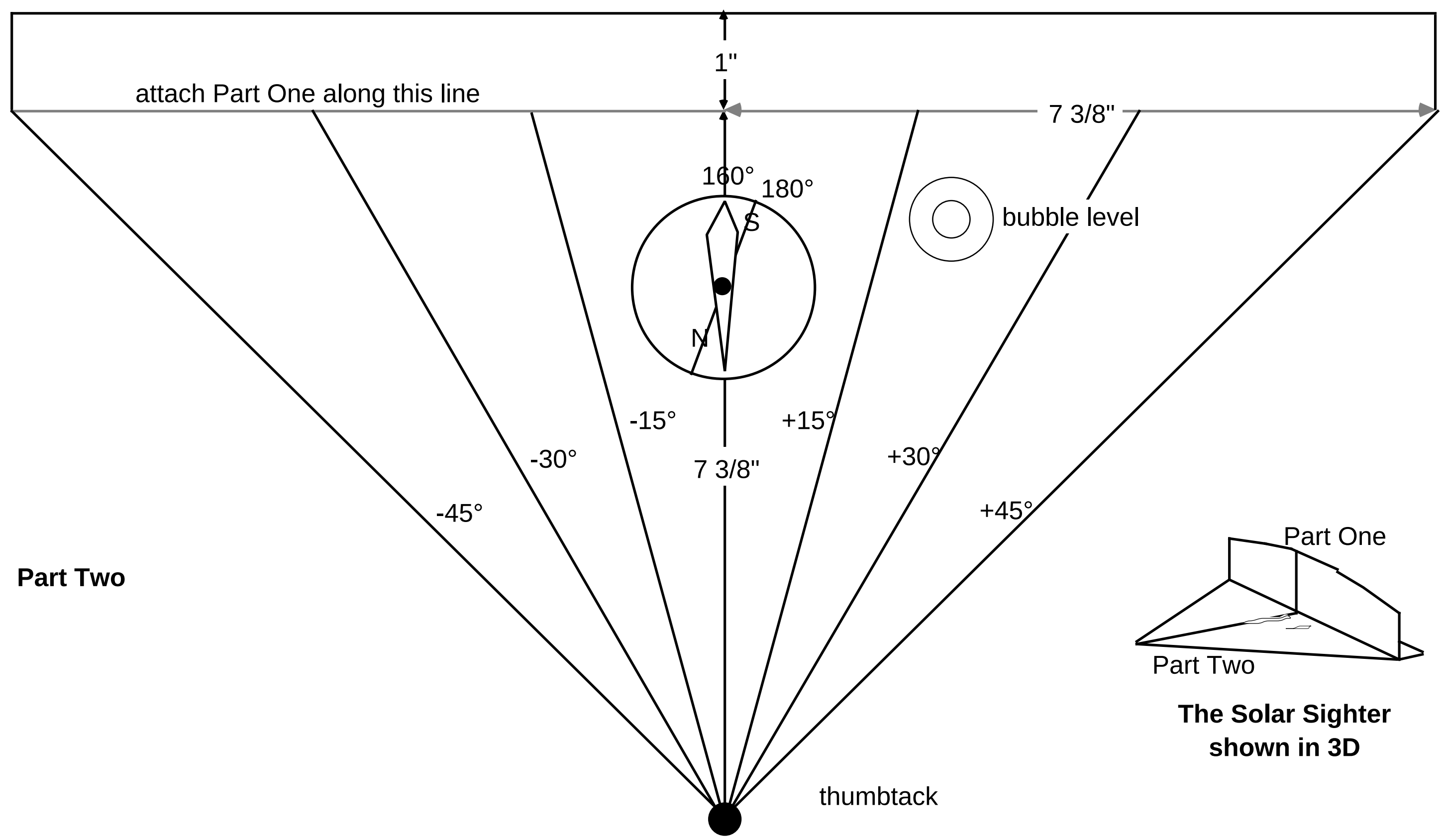


Above: Steve Willey uses his homemade Solar Sight at his home in Sandpoint, Idaho. Photo by Elizabeth Willey

Part One



SOLAR SIGHT PATTERN
shown 50% of real size



Part Two

The Solar Sighter shown in 3D

To align the sight, a compass and a bubble level should be glued on the triangle surface. Round bubble levels are available that mount flat on a horizontal surface and have one bubble that you line up in a central circle for leveling in all directions at once. Look for one in hardware and recreational vehicle stores.

Just about any compass will do, but don't believe the markings on it! True south, or solar south, is the direction of the sun at noon (don't be fooled by Daylight Savings Time). In the northwest U.S. true south is a full 20 degrees left of magnetic south shown on the compass. To point true south, just mount the compass with south mark 20 degrees right of the 0 degree line on the sight as shown on the pattern. Then when you hold the sight so that the needle points to S on the compass, the sight points to the real south. It is just the opposite on the east coast, with true south 20 degrees right from magnetic south. In mid-North America, magnetic south is right on true south. A call to local surveyors will get you the right correction angle for your area.

Using the Solar Site

Hold the sight level, with the 12 noon center line facing true solar south. Put the head of the thumb tack in front of your eye and gaze up across the top edge of the site. Be sure you are looking right along a straight line starting at the thumb tack and rising to the upper edge of the sight, where the time of day is marked, your eye always level with the thumb tack. What you see just over the edge approximately represents the sun's path in November, December and January, at the time of day shown. Mentally add 1-1/4 inch to the height of the sight to see the sun's path in October and February. Any trees or mountains or buildings that you can see above the curved sight edge will cast a shadow on you in those months. Ideally, you want to see only sky.

Access

Author: Steve Willey, Backwoods Solar Electric Systems, 8530 Rapid Lightning Creek Road, Sandpoint, ID 83864 • 208-263-4290.

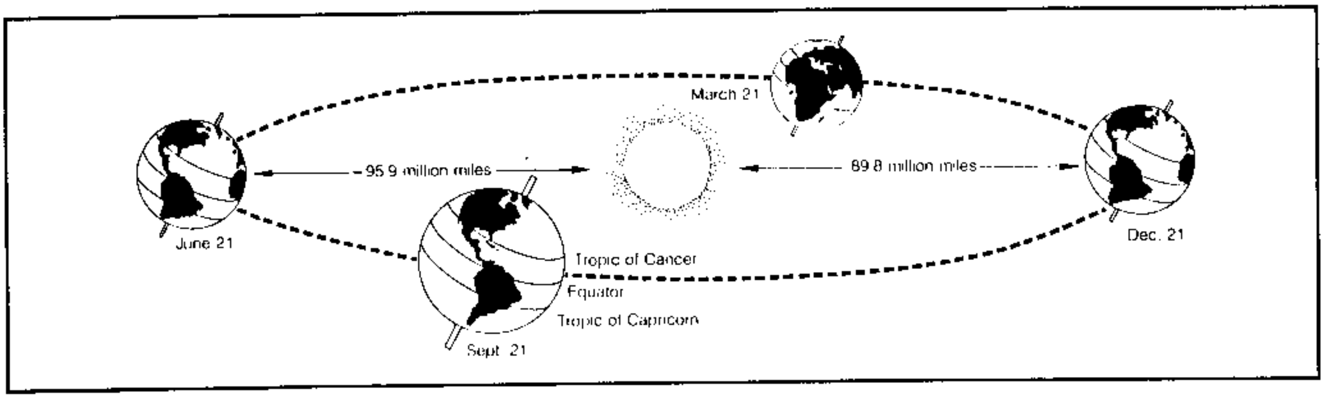


Figure 4.9 The motion of the earth around the sun.

The solar altitude, which is the angle the sun rises above the horizon, is important in two respects. First, a higher solar altitude means that the solar radiation travels a shorter distance to traverse the atmosphere. A low solar altitude forces the radiation to travel through a great deal more air mass; the attenuating effects are proportionally greater. (The stunning visual effects at sunrise or sunset are thus possible—when else can you look directly at the

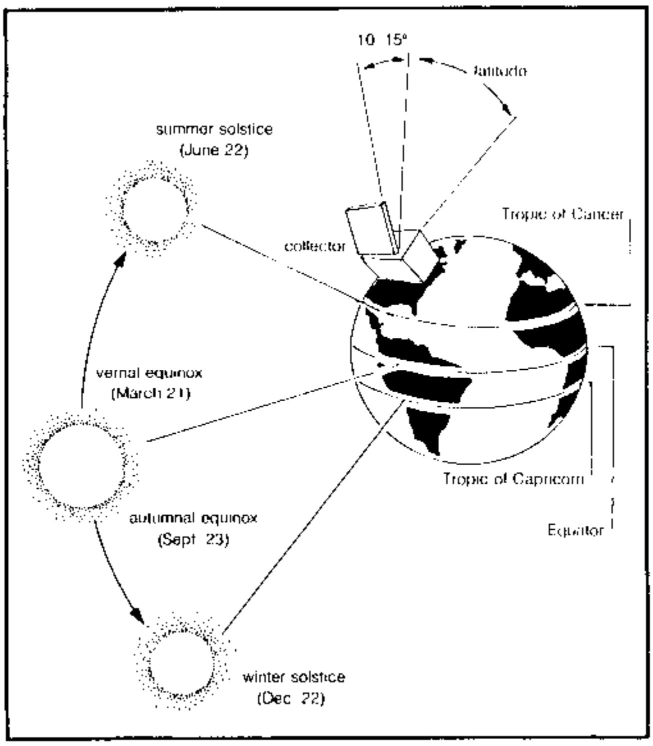


Figure 4.10 Seasonal relations between the sun and earth.

sun and enjoy it so?) Second, higher solar altitudes imply more daylight hours.

The relationship between seasons, solar altitude, and incident solar radiation is shown in Figure 4.11. The solar altitude is shown as a function of the daylight hour (by the clock) for a number of days during the year. An accompanying graph shows the amount of solar energy which would fall on a horizontal surface. These values assume there are no local atmospheric anomalies; no clouds, smog, or mist. Note that the impinging solar energy, or *insolation*, is given in Btu per hour per square foot (Btu/hr-ft²). This is a set of units which can be used to express the rate of energy falling on each square foot of surface area—in this case, horizontal surface area. The curves show us what we've suspected all along—more solar energy is available during the summer solstice than during any other time of the year. The insolation values are higher and the exposure time is longer.

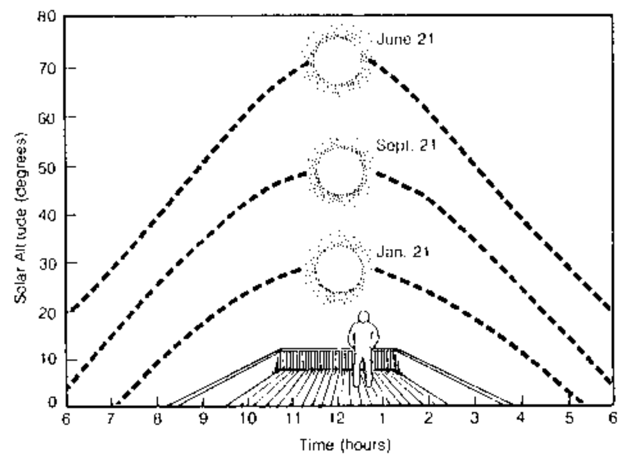


Figure 4.11a Solar altitude at 40°N latitude (June, September, and January).

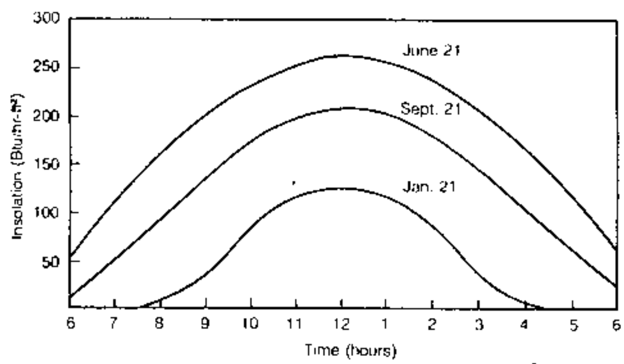


Figure 4.11b Cloudless insolation values for a horizontal surface located at 40°N latitude.

The Sun Charts

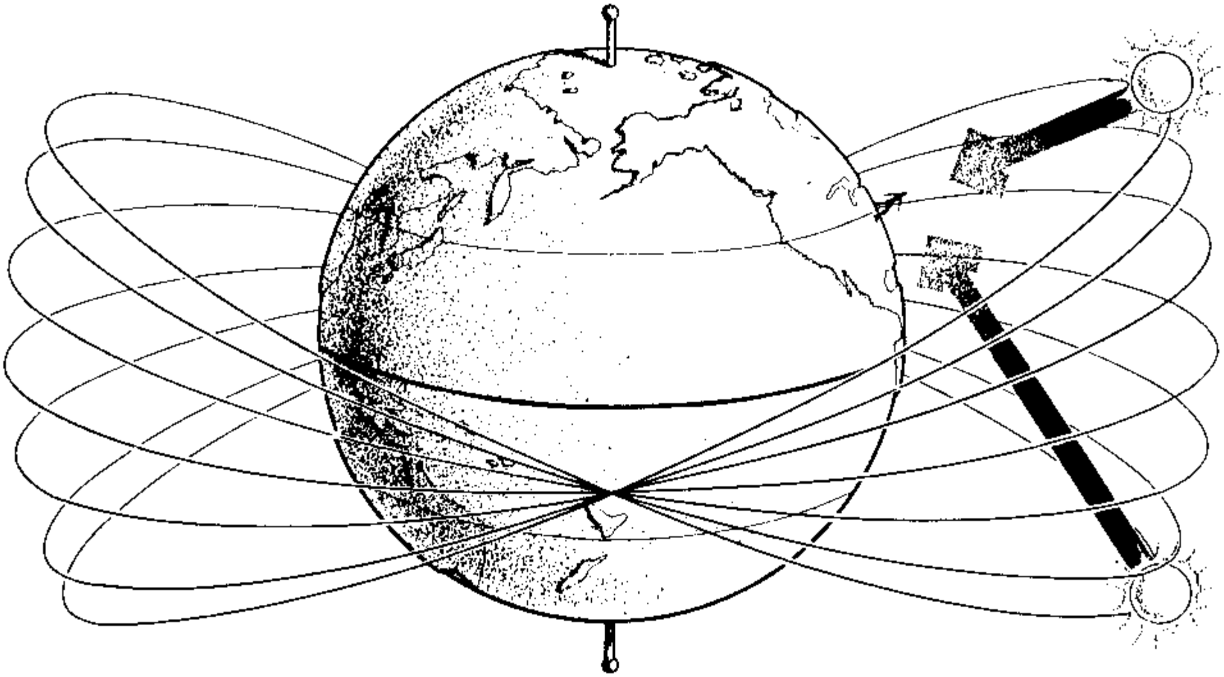
How the Sun Works

For our purposes, it is convenient to assume that the earth is stationary and the sun is in motion around the earth. Figure V-1 lists the angle (declination) of the sun above (+) or below (−) the equator, on the twentieth of each month, as seen from the earth. From the Northern Hemisphere, you can see that the sun lingers at its highest position in the sky for three months during the summer, then moves very quickly through fall towards winter, where it appears low in the sky for another three months.

In order to understand and be responsive to the effects of the sun on the location and design of places, it is necessary to know, at any given moment, the sun's position in the sky. This information is necessary in order to calculate solar heat gain, and to locate buildings, outdoor spaces, interior room arrangements, windows, shading devices, vegetation and solar collectors.

The Cylindrical Sun Chart

The Cylindrical Sun Chart, which is developed here, provides an easy-to-understand and convenient way to predict the sun's movement across the sky as seen from any point in the world between 28° and 56°NL. The chart is a vertical projection of the sun's path as seen from earth. It could be said, then, that the Sun Chart is an earth-based view of the sun's movement across the skydome.



The table below lists approximately how far above or below the equator the sun is on the twentieth day of each month.

20th of	Degrees
Jan.	−20
Feb.	−11
Mar.	0
Apr.	11
May	20
June	23
July	21
Aug.	13
Sept.	1
Oct.	−10
Nov.	−20
Dec.	−23

Fig. V–1: The sun as it appears from earth on the twentieth day of each month.

The following sequence is a description of how a sun chart is developed. It is included here to provide you with a visual understanding of the sun's movement across the skydome.

Two coordinates are needed to locate the position of the sun in the sky. They are called the *altitude* and *azimuth* (also called the bearing angle).

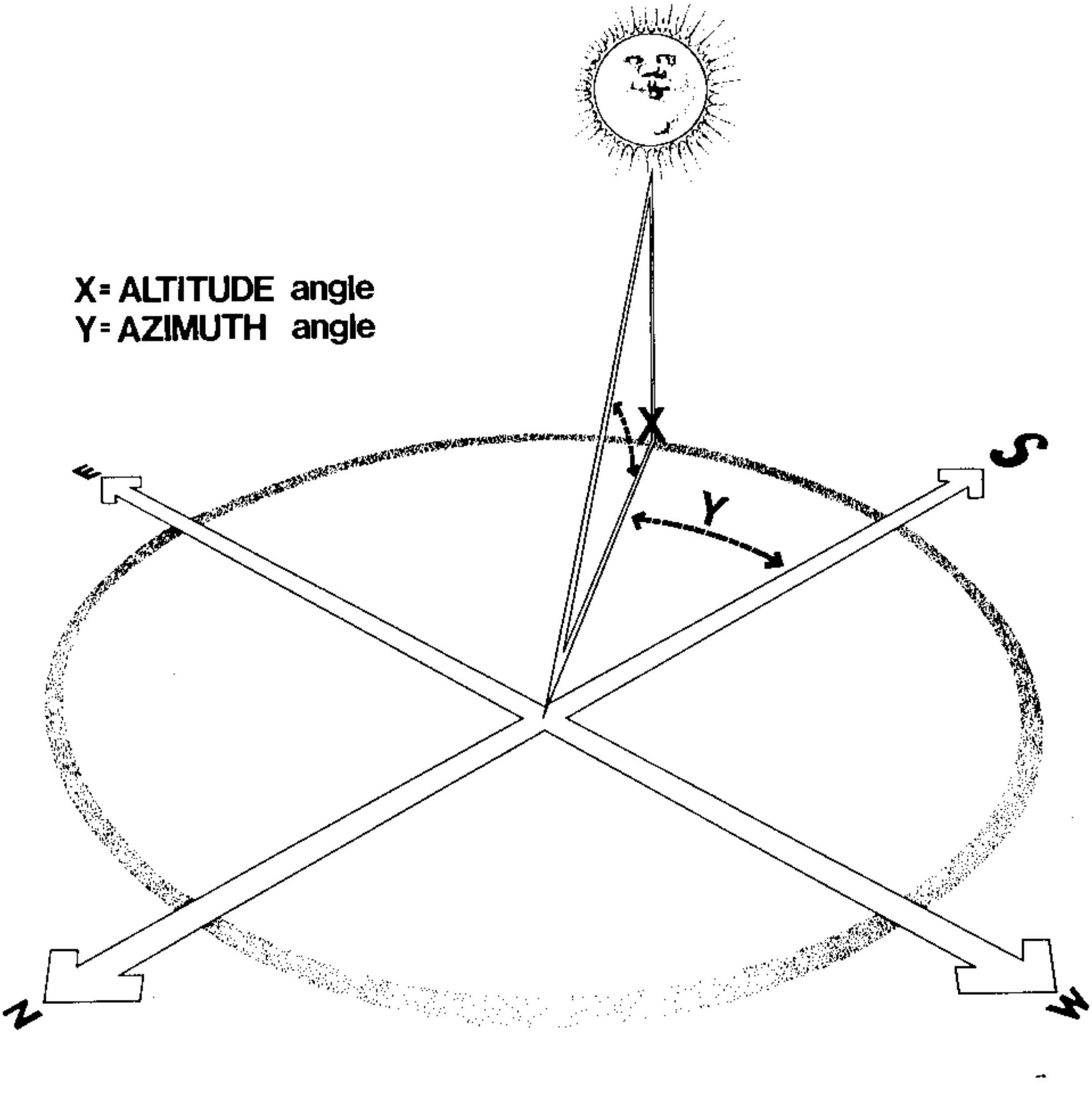


Fig. V–2: Altitude and azimuth angles.

Altitude

Solar altitude is the angle measured between the horizon and the position of the sun above the horizon. The horizontal lines on the chart represent altitude angles in 10° increments above the horizon.

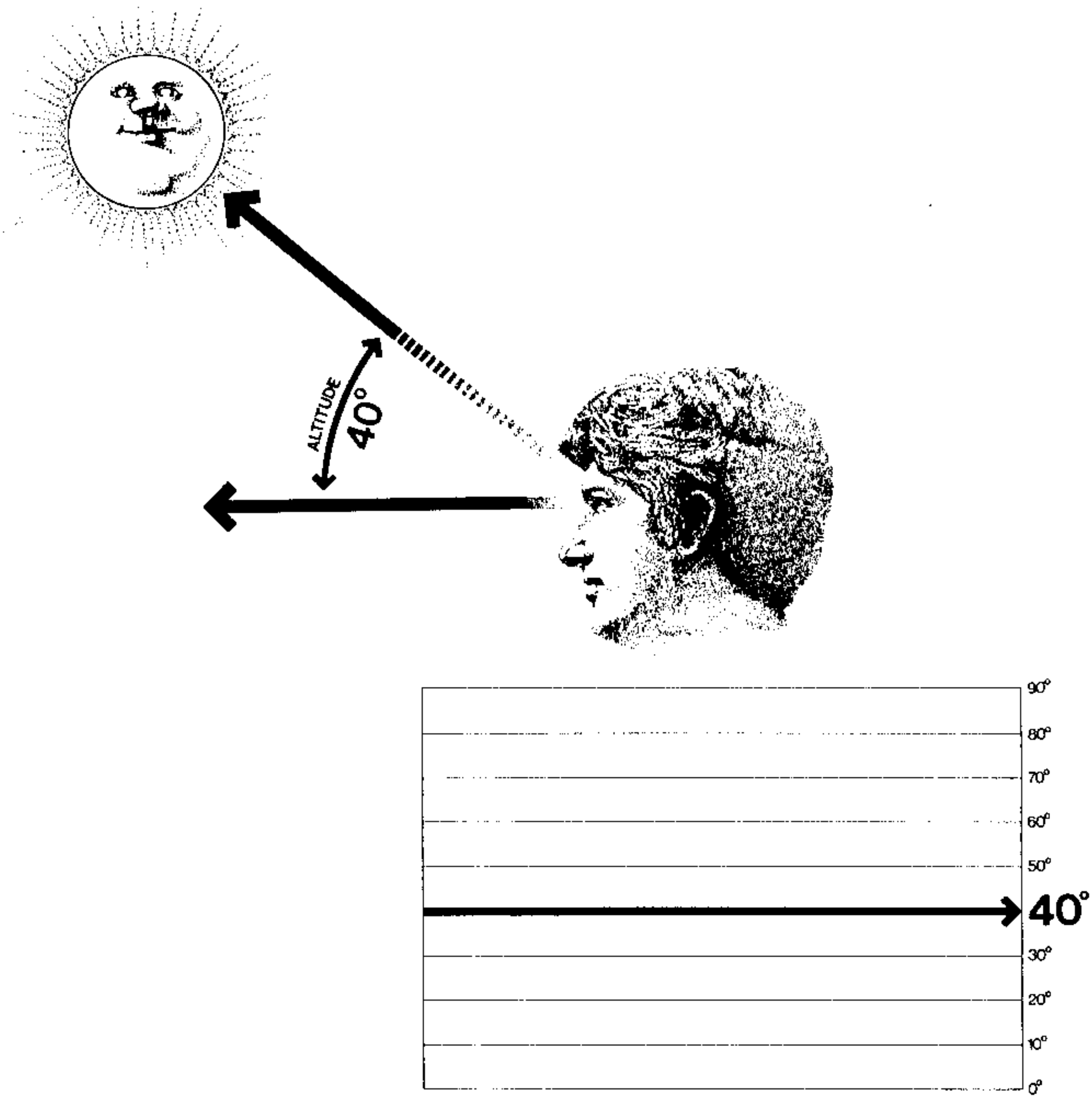


Fig. V–3: Altitude angle.

Azimuth (bearing angle)

Solar azimuth is the angle along the horizon of the position of the sun, measured to the east or west of true south.

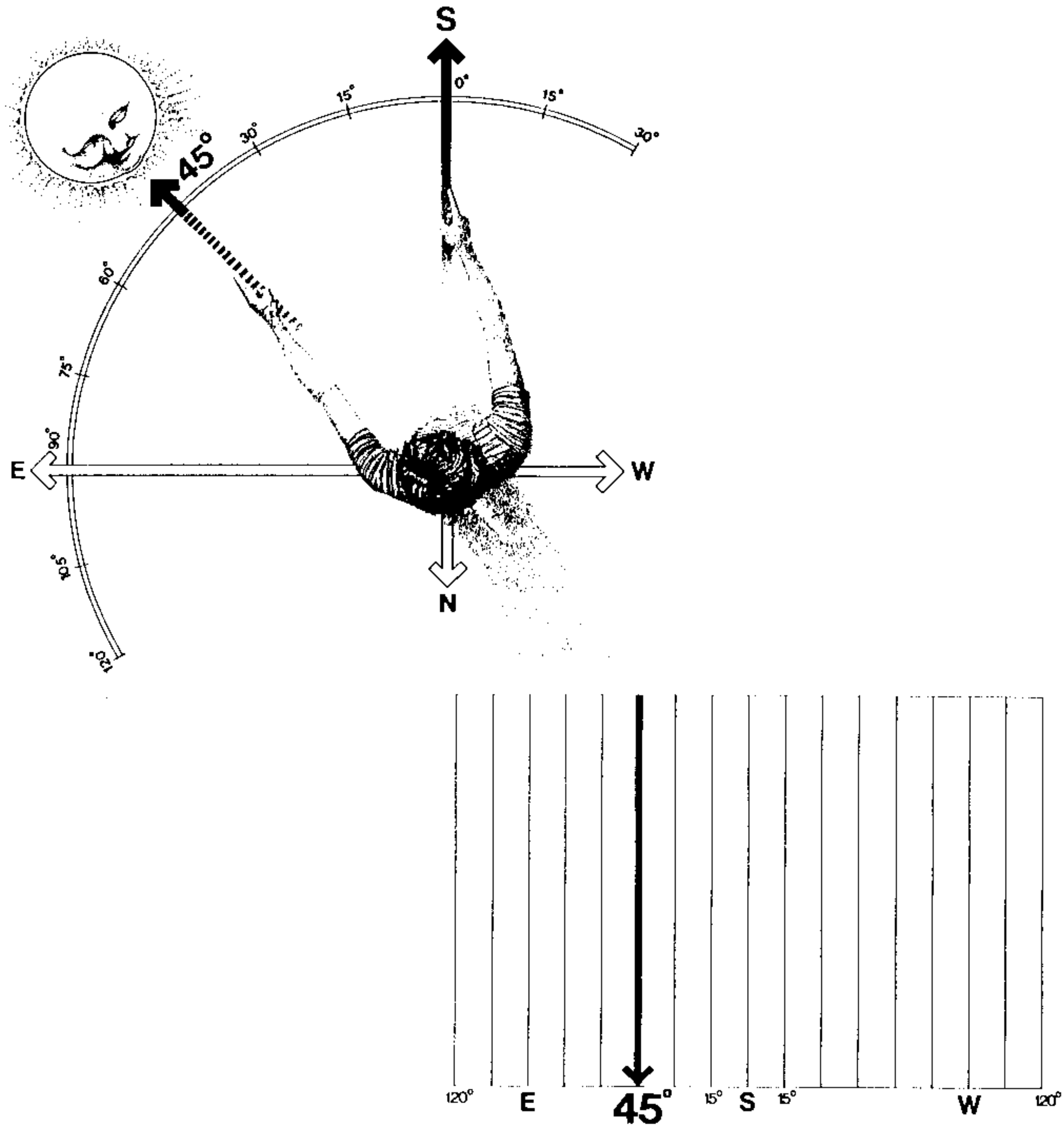


Fig. V–4: Azimuth angle.

Skydome (sky vault)

The skydome is the visible hemisphere of sky, above the horizon, in all directions. The grid on the chart represents the vertical and horizontal angles of the whole skydome. It is *as if* there were a clear dome around the observer, and then the chart were peeled off of this dome,* stretched out and laid flat.

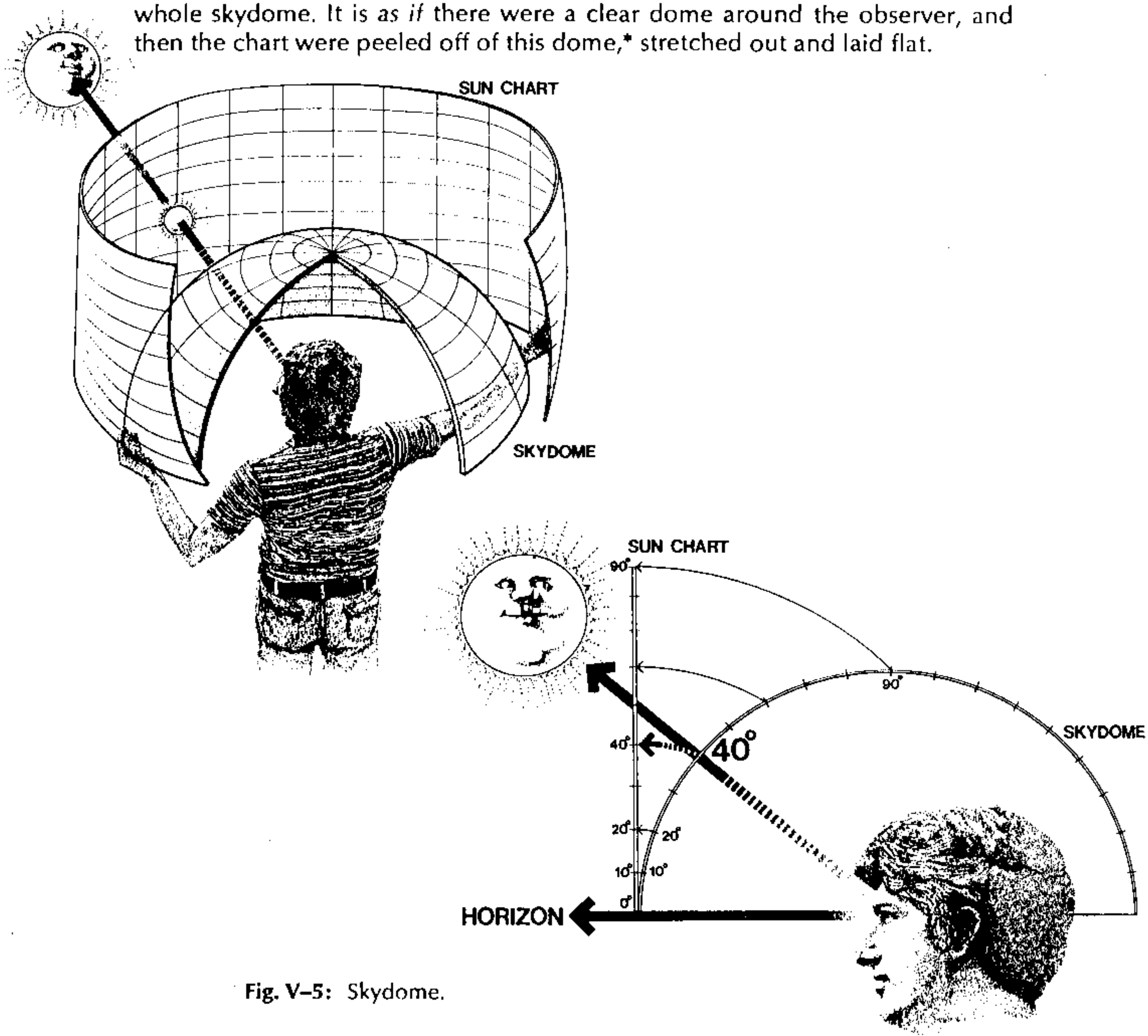
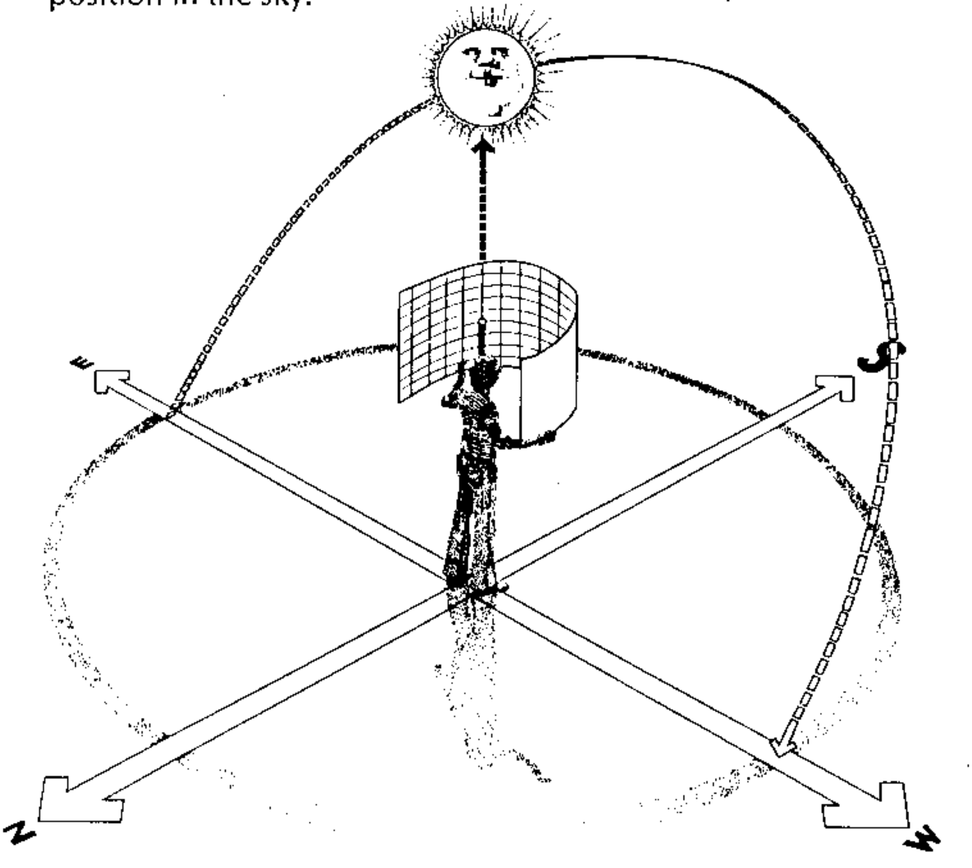


Fig. V–5: Skydome.

*In reality this is not possible. The intention of the illustration is to present you with a visual image of the skydome projected onto a flat sheet.

Sun's Position

Once the altitude and azimuth angles are known, the sun can be located at any position in the sky.



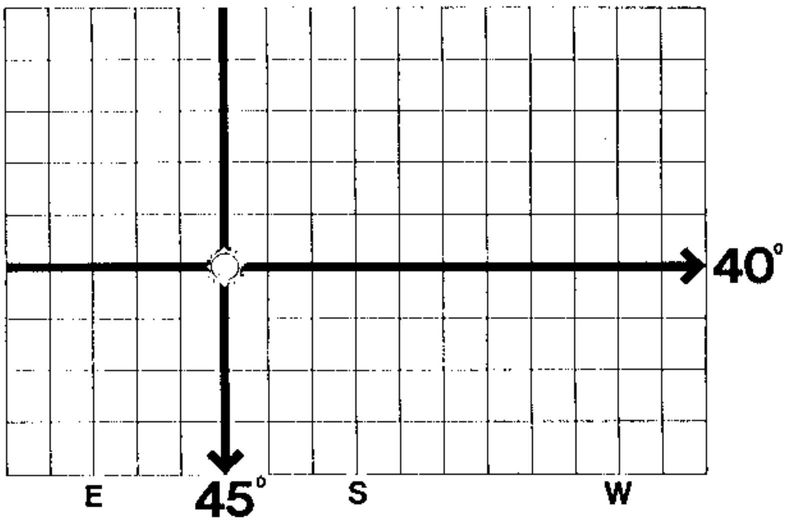


Fig. V–6: Sun's position.

Sun's Path

By connecting the points of the location of the sun, at different times throughout the day, the sun's path for that day can be drawn.

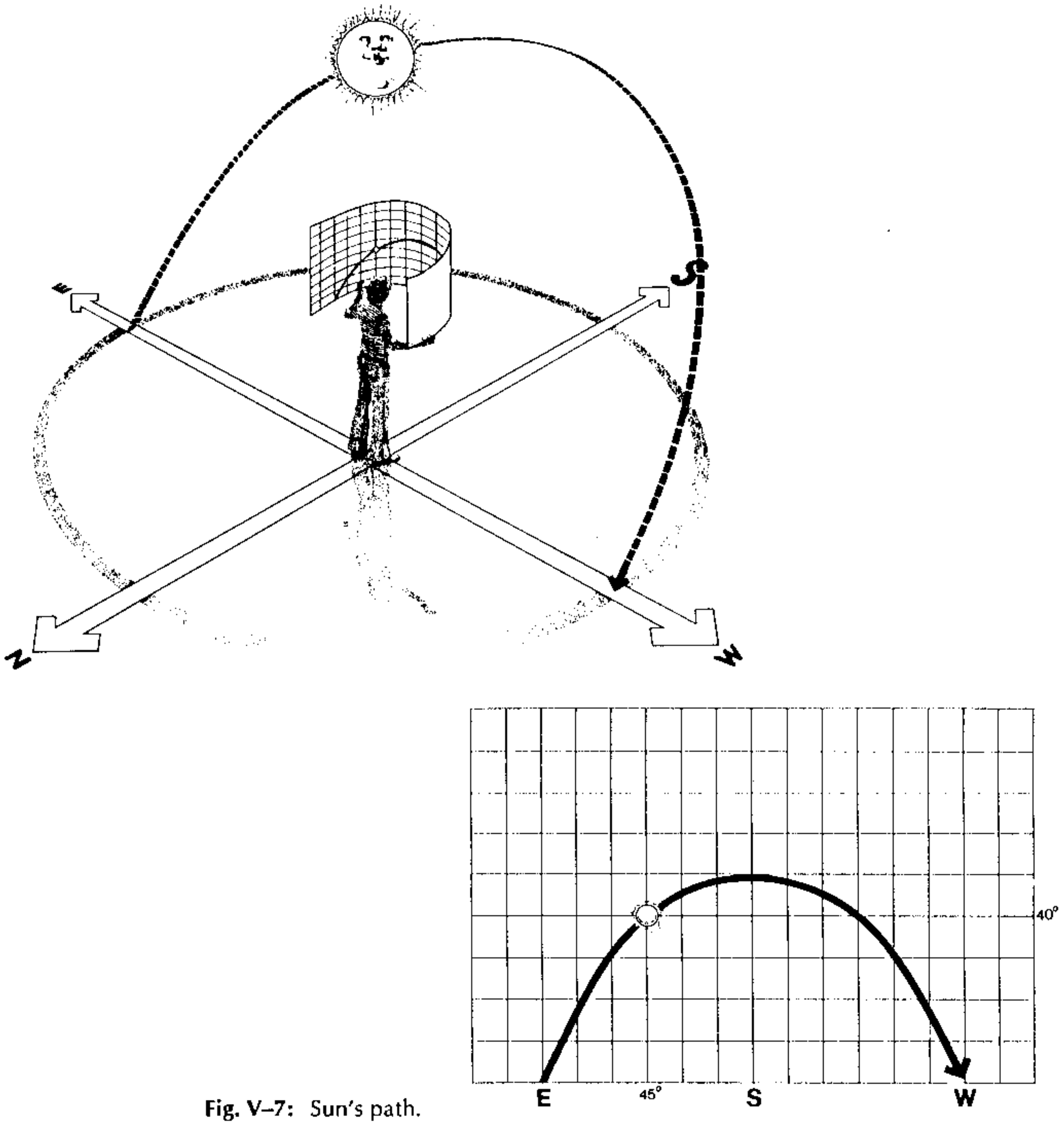
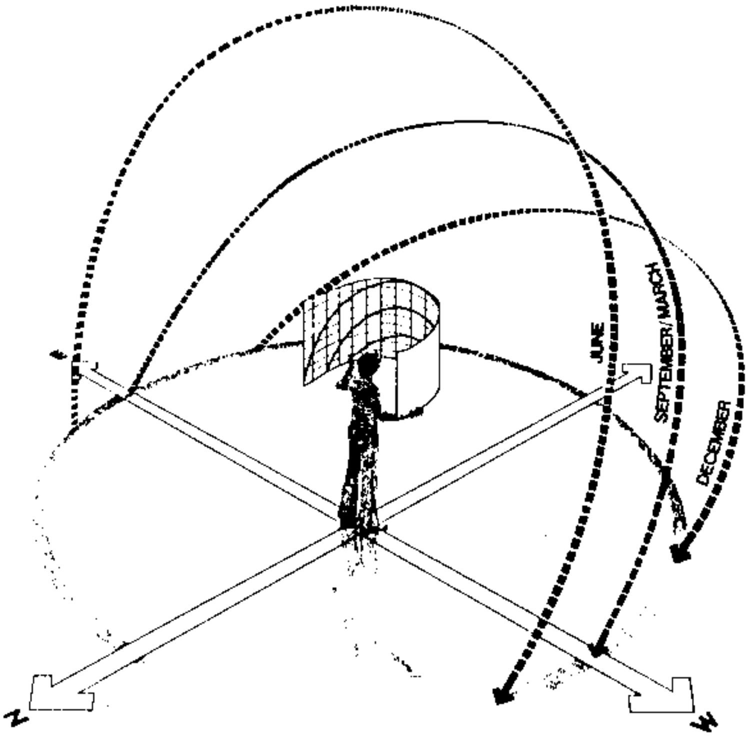


Fig. V–7: Sun's path.

Monthly Paths

Thus, we can plot the sun's path for any day of the year. The lines shown represent the sun's path for the twentieth day of each month. The sun's path is longest during the summer months when it reaches its highest altitude, rising and setting with the widest azimuth angle from true south. During the winter months the sun is much lower in the sky, rising and setting with the narrowest azimuth angles from true south.



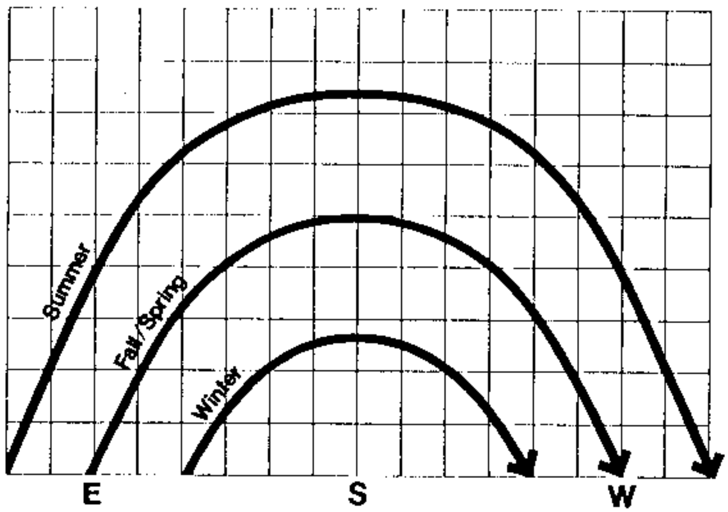
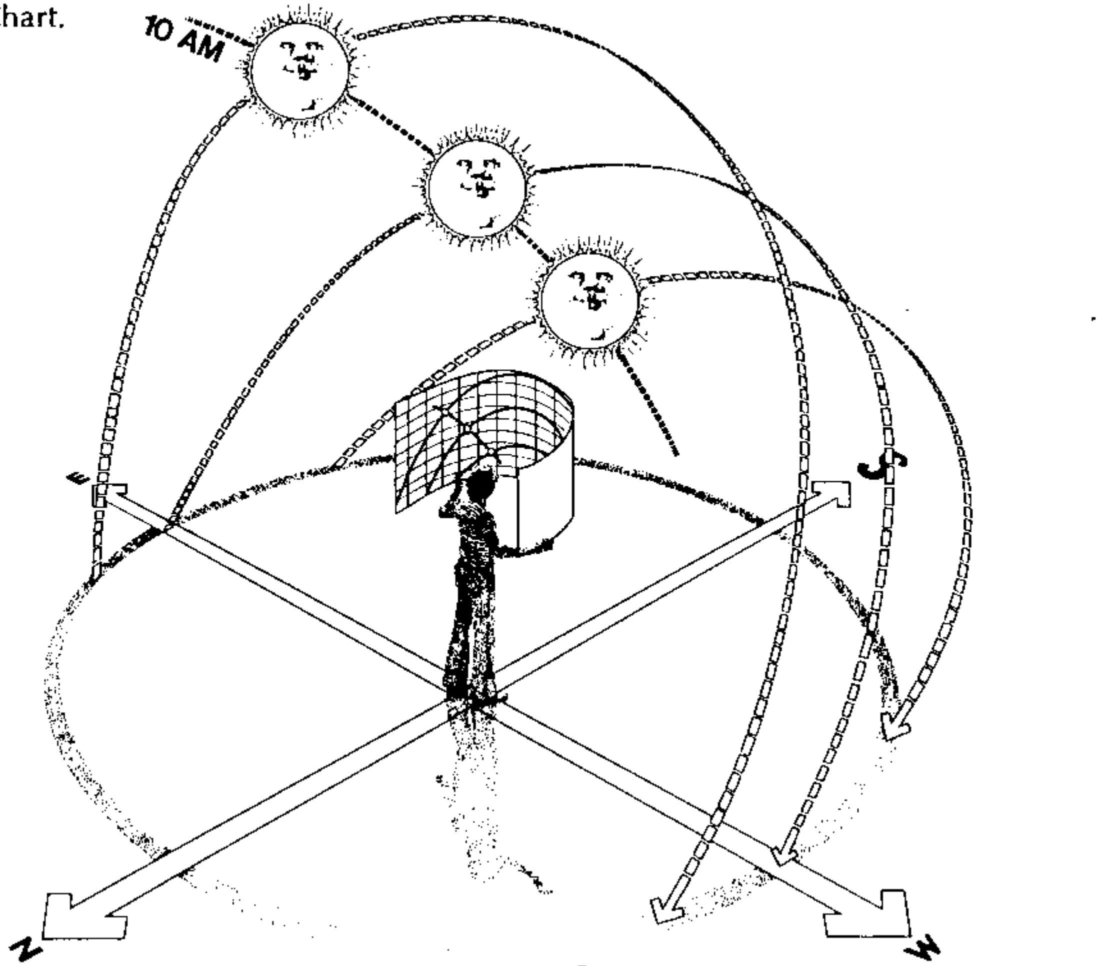


Fig. V–8: Monthly paths.

Times of Day

Finally, if we connect the times of day on each sun path we get a heavy dotted line which represents the hours of the day. This completes the Cylindrical Sun Chart.



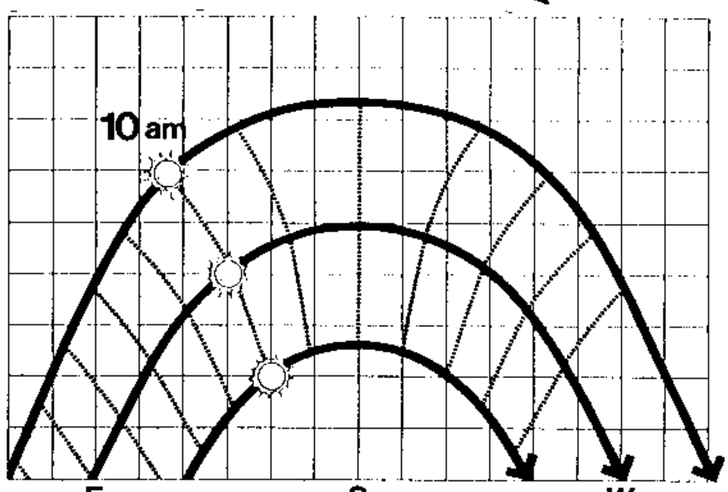


Fig. V–9: Times of day.

Note: The times on the sun chart are for sun time. This may vary from standard time by as much as 75 minutes for different locations and different times of the year. This is fine for most practical uses of the sun chart. It's important to remember to at least use standard time (if daylight savings time is in effect, subtract 1 hour from local time) when using the charts. For very detailed studies, where it is necessary to know the exact relationship between sun time and local time, an explanation of the conversion process is provided later in this chapter.

Latitude and Magnetic Variation

Since the sun's path varies according to the location on earth from which it is being calculated, a different sun chart is required for different latitudes. Sun charts for latitudes in the United States and southern Canada (28° to 56°NL) are provided in this section. The map in figure V-11 will assist you in selecting the sun chart (latitude) closest to your location.

The map also shows magnetic compass variations for your area. Because of the earth's magnetic field, it is necessary to adjust your compass reading by a few degrees east or west to obtain true north (as different from magnetic north). The amount of variation depends upon your location. When true and magnetic north are in the same location, the variation is zero. In the United States a line of zero variation runs from the eastern end of Lake Michigan to the Atlantic coast in northern Georgia. If you are located on the west side of that line, your compass needle will point to the east of true north. This is called an

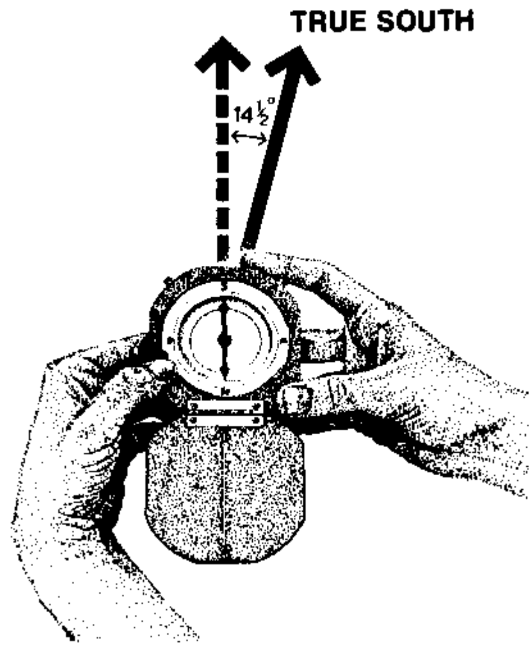


Fig. V–10: A westerly variation.

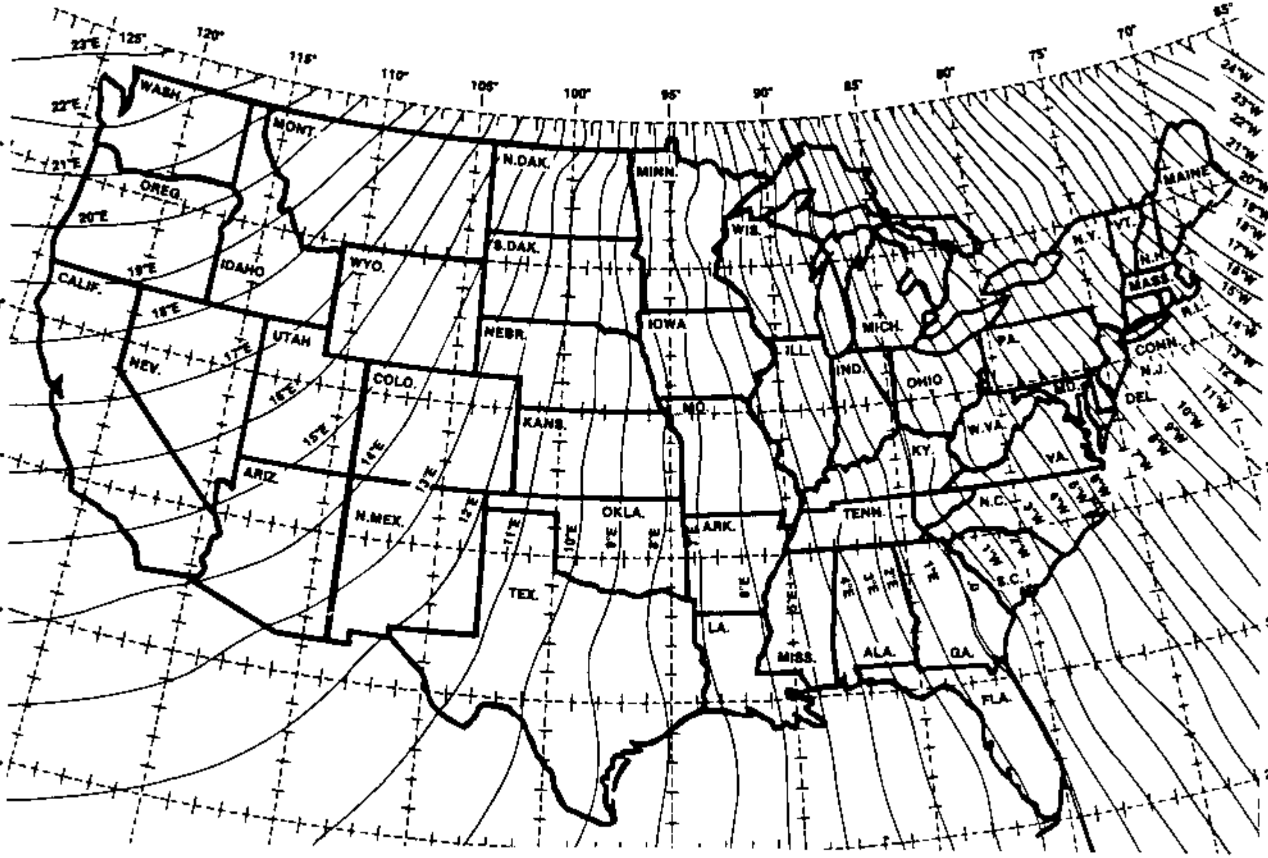


Fig. V–11: Use map to find sun chart (latitude) closest to your location.

Source: Redrawn from the Isogonic Chart of the United States, U.S. Department of Commerce, Coast and Geodetic Survey, 1965.

"easterly variation." Similarly, if you are located to the east of the line, your compass needle will point to the west of true north. This is called a "westerly variation." For example, the map shows a deviation of 14½° west for Boston. This means that the compass is pointing 14½° to the west of true north, or true north is 14½° to the east of compass-indicated north (true south is then 14½° west of compass south). Due to "local attraction," magnetic variation may be slightly different for your locality. The map is accurate for most uses of the sun chart; for more exact information, consult a surveyor.

The sun chart enables you to locate the position of the sun at any time of day, during any month, for any location within the United States (excluding Alaska) and southern Canada.

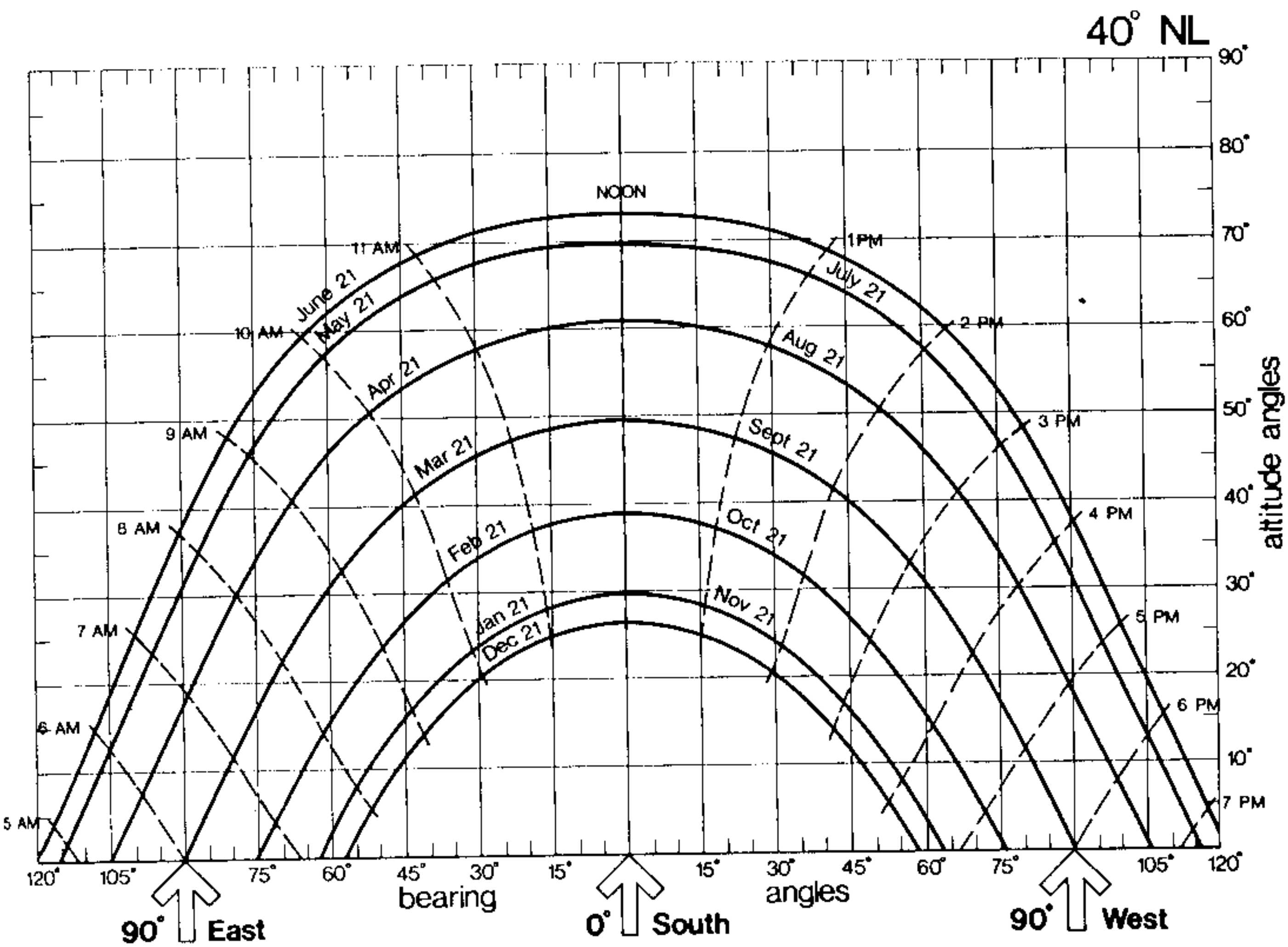
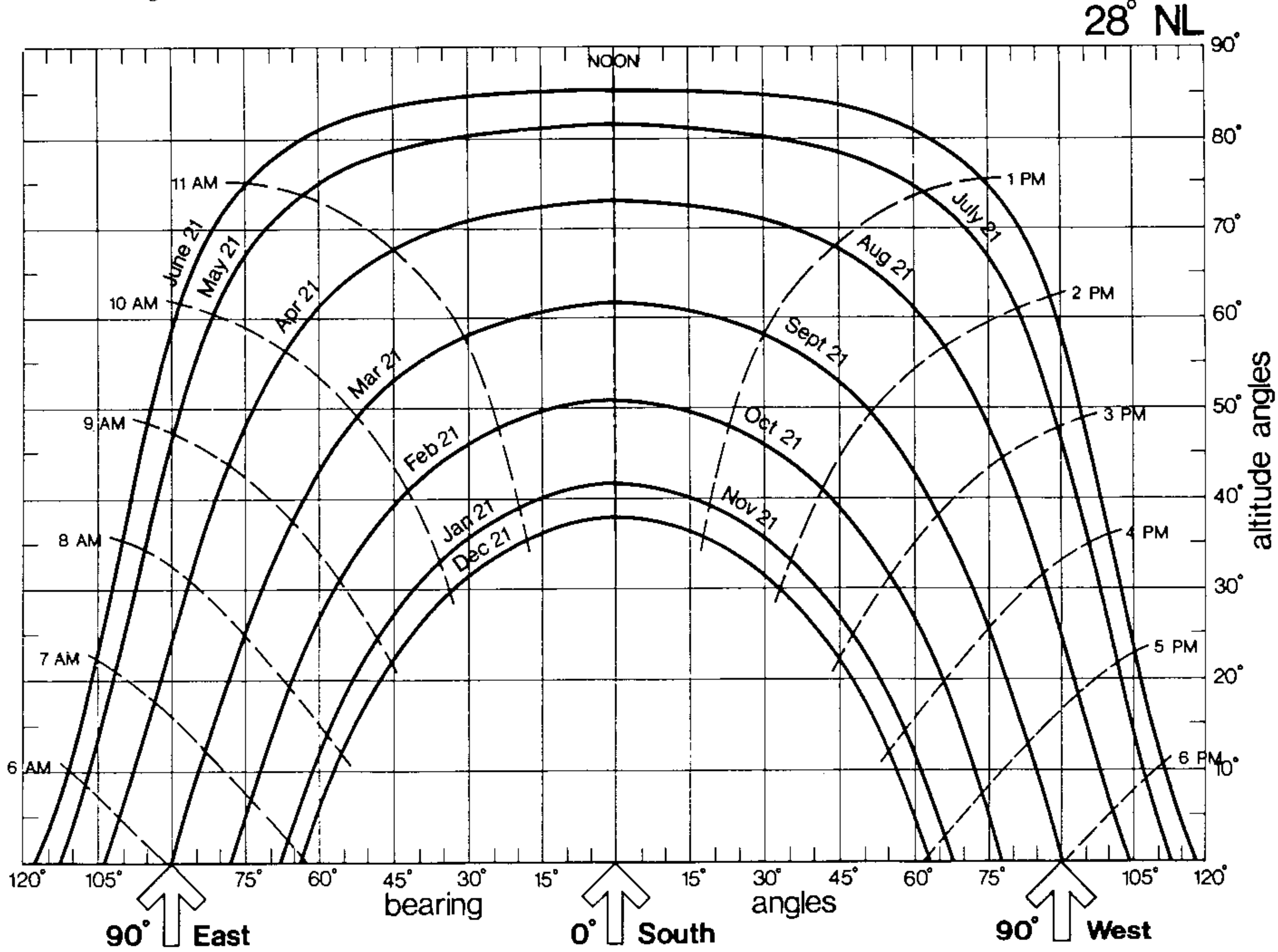
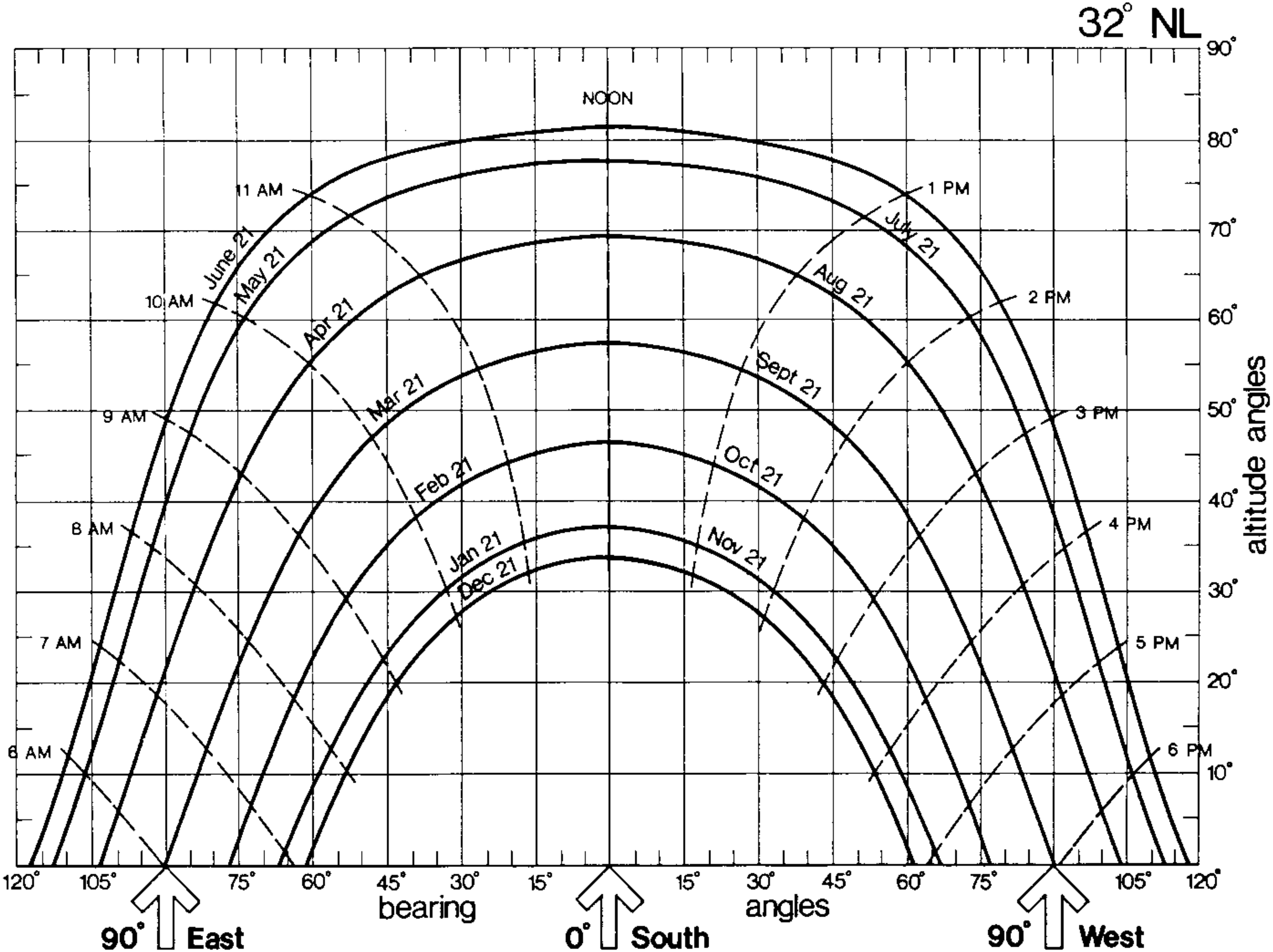


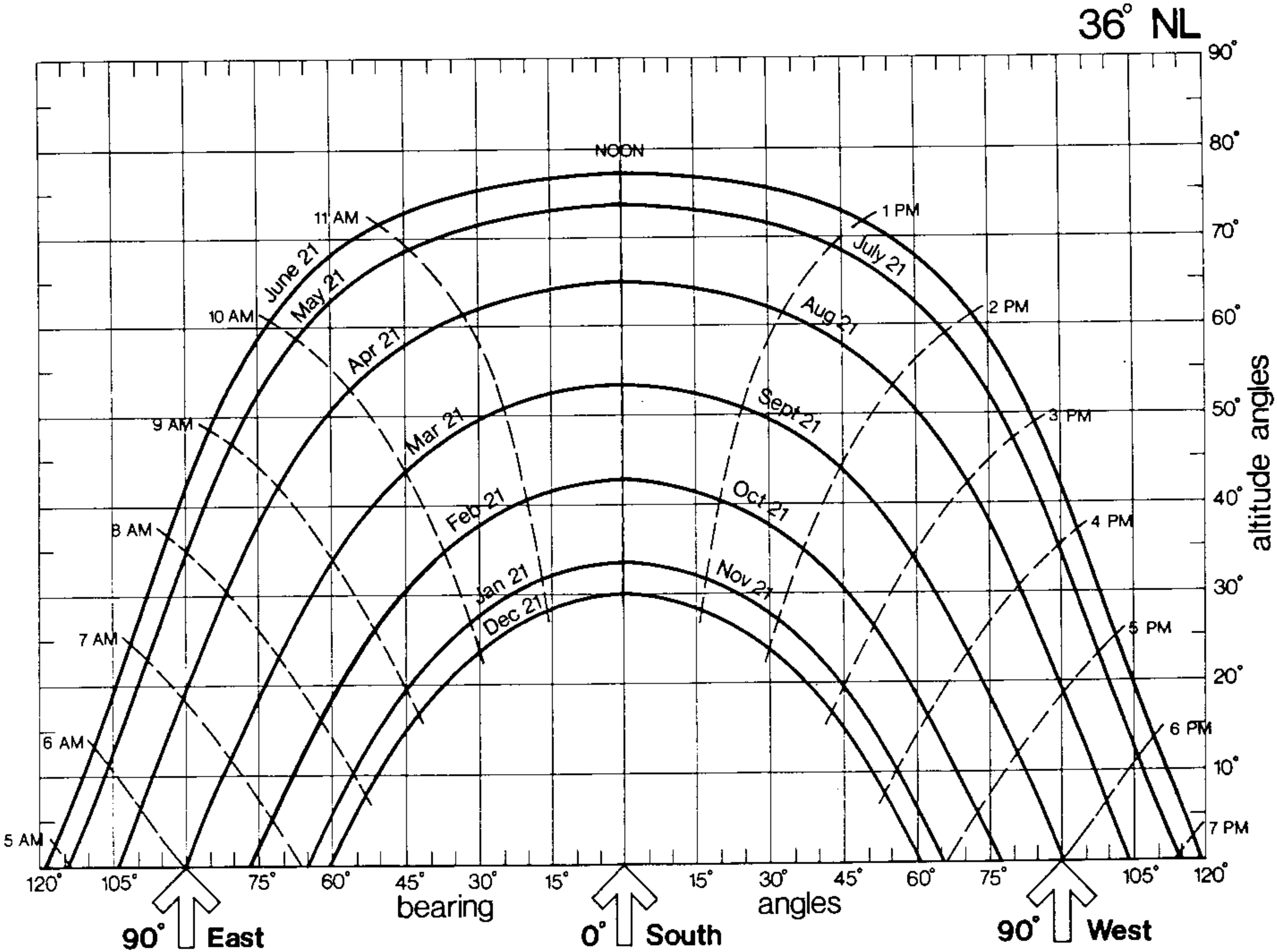
Fig. V–12: Completed sun chart.

Sun Charts

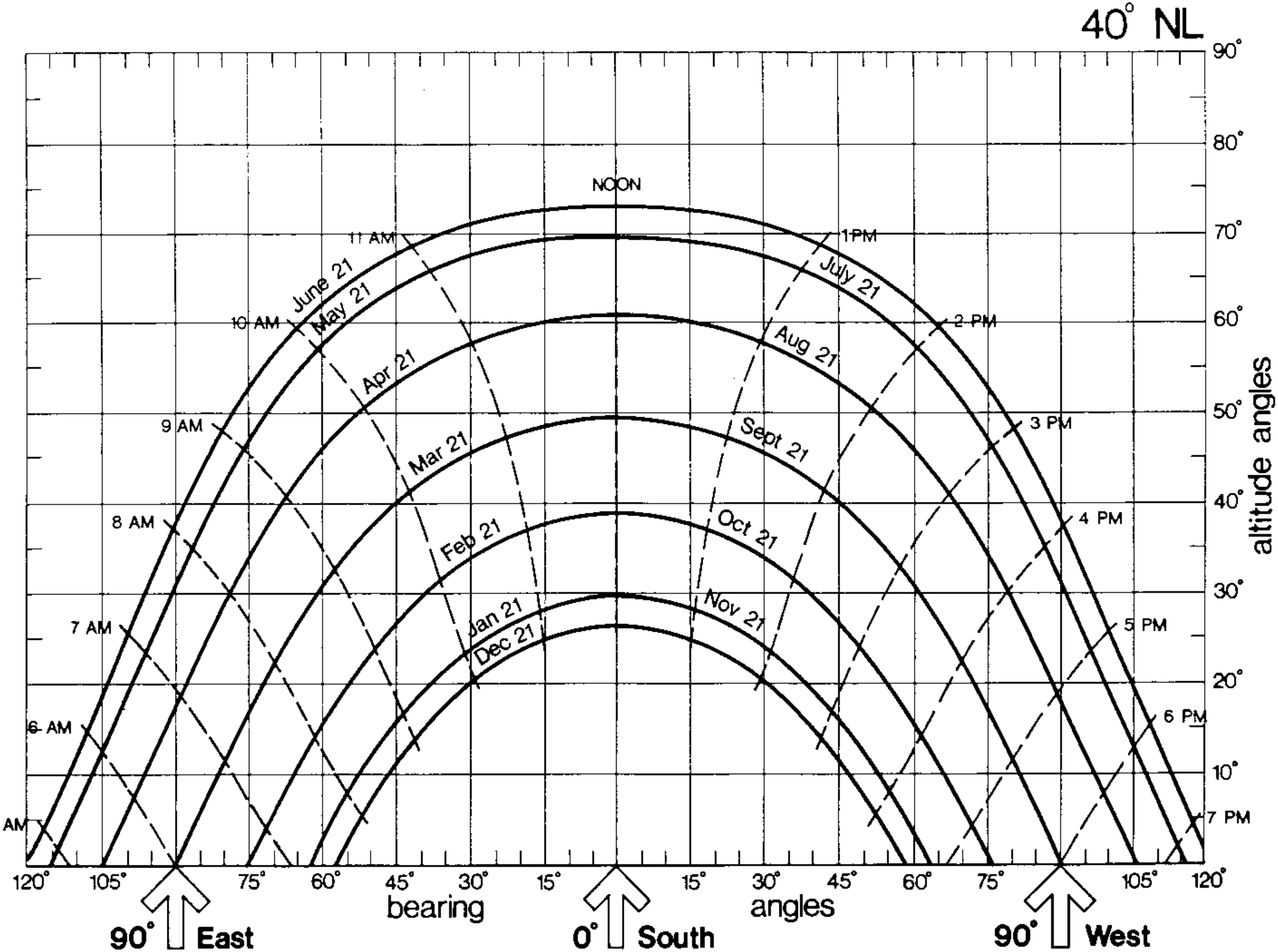
The following sun charts are for all latitudes from 28° to 56°NL at 4° intervals.

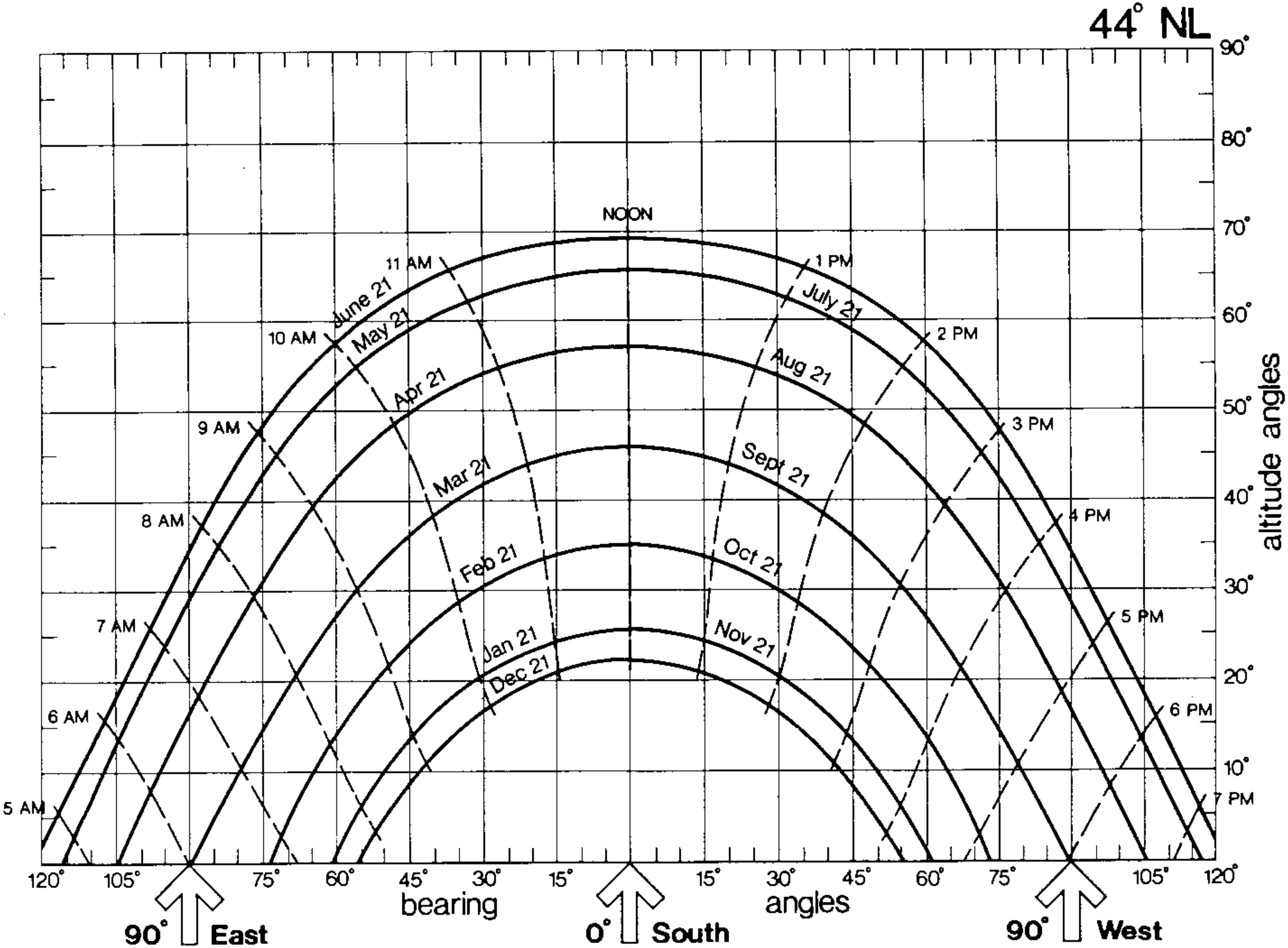



32° NL
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West

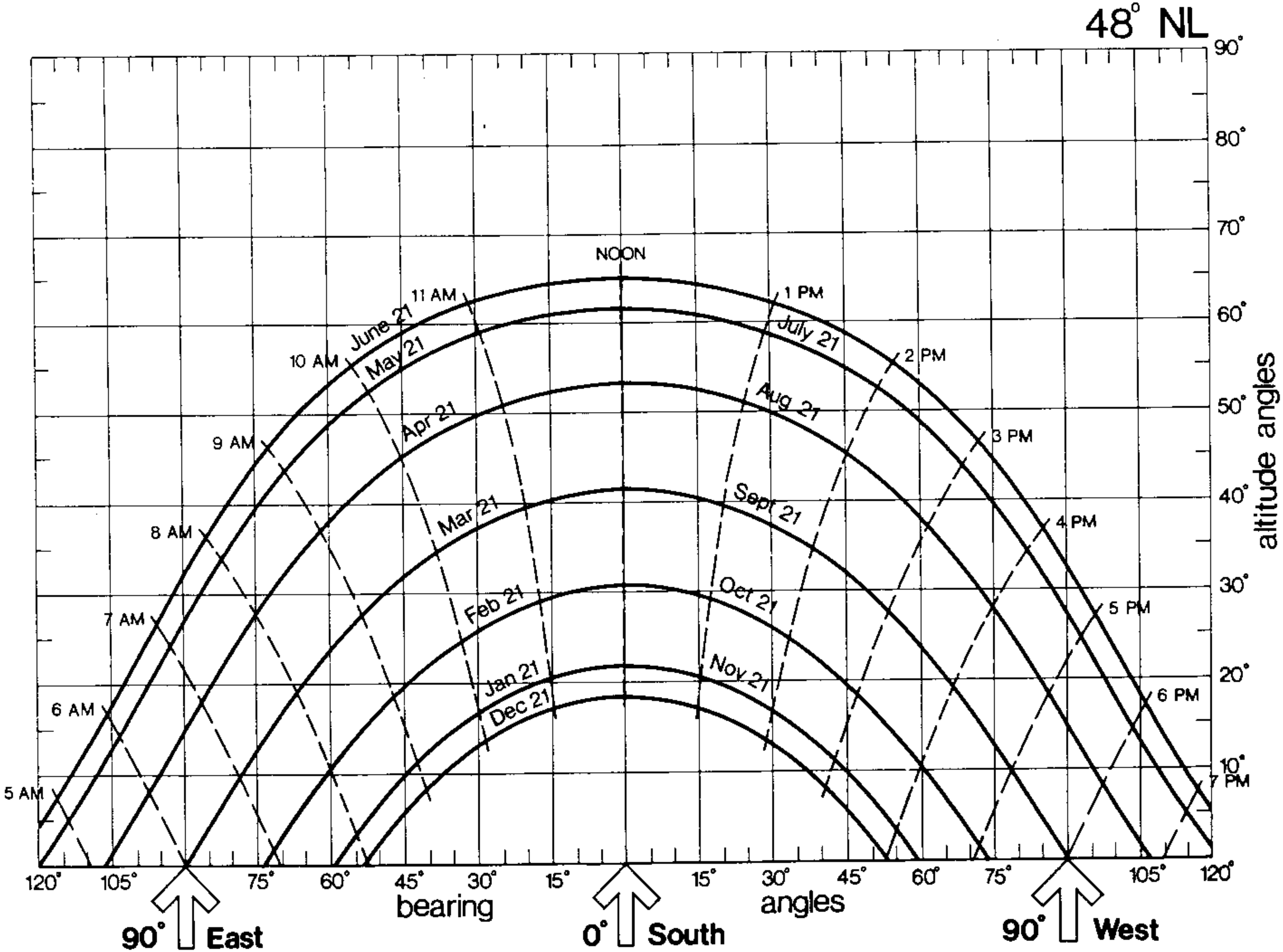


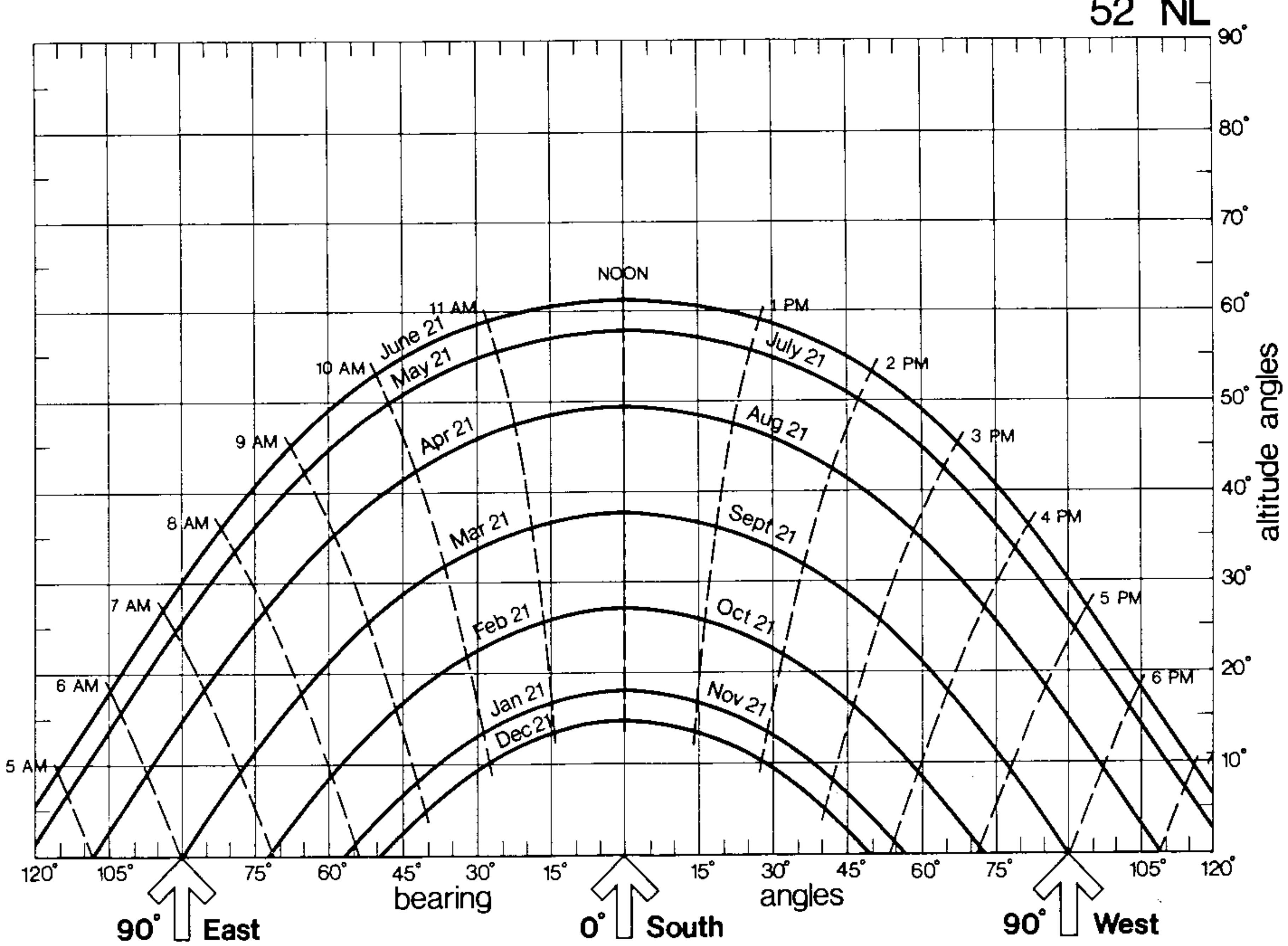
36° NL
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West


40° NL
NOON
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
June 21
May 21
July 21
Apr 21
Aug 21
Mar 21
Sept 21
Feb 21
Oct 21
Jan 21
Dec 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West

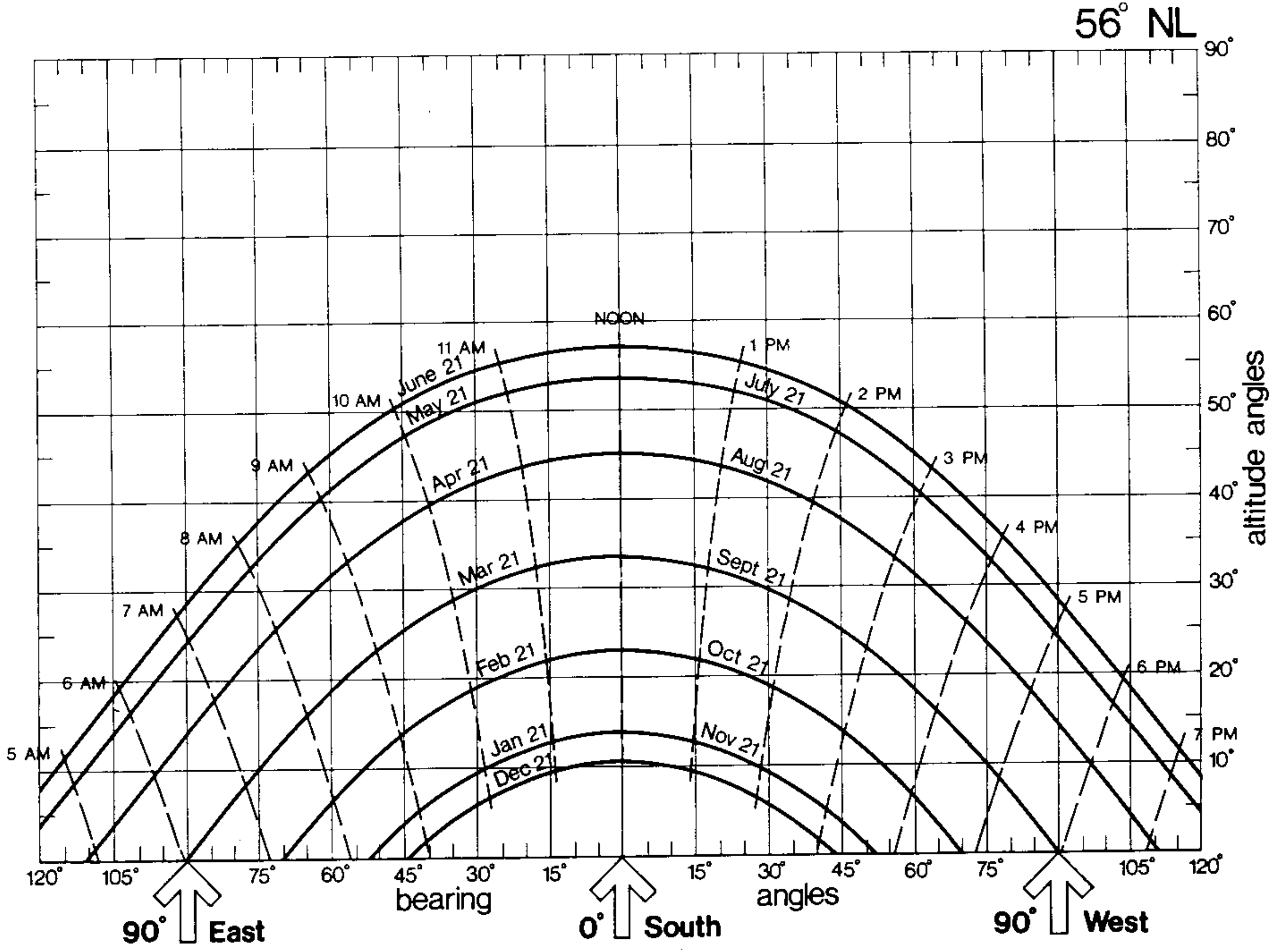


44° NL
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West


48° NL
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
120° 105° 75° 60° 45° 30° 15° 15° 30° 45° 60° 75° 105° 120°
bearing angles
90° East
0° South
90° West



52° NL
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West



56° NL
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
NOON
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
120°
105°
75°
60°
45°
30°
15°
bearing
angles
90° East
0° South
90° West

Sun Time

As the earth orbits the sun, its speed varies depending upon its distance from the sun. As we move closer to the sun, the earth slows down, and as we swing away from the sun, we speed up. This difference in the earth's speed is responsible for a variation between sun and earth time, since a man-made clock keeps time uniformly and does not take the earth's speed into account. From the sun chart, you can see that sun time is measured by the position of the sun above the horizon, solar noon corresponding to the sun at its highest position and due south. Figure V-13 gives values for the "equation of time," or the difference between sun time and earth clock time. The upper part of the chart (+) gives values when the sun is ahead of clock time, and the lower part (−) when the sun is behind.

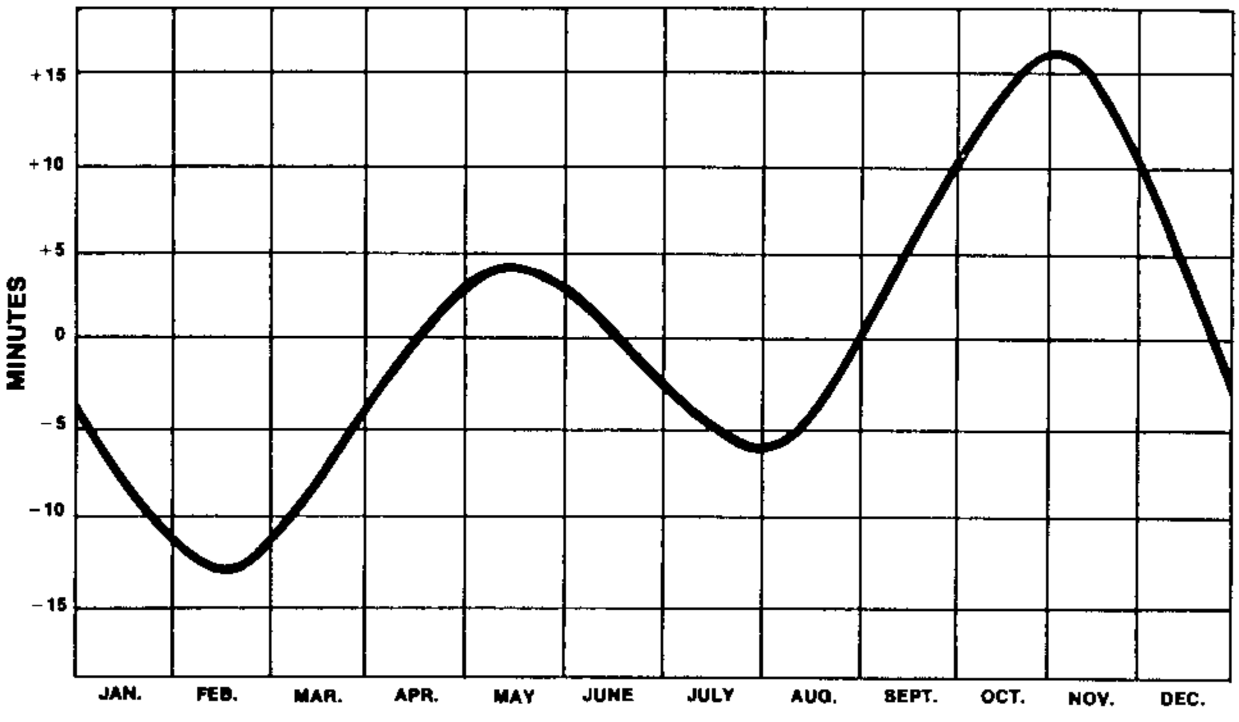


Fig. V–13: Equation of time.

For the purpose of telling time, the earth has been divided in 24 time zones (longitudinal segments) of 15° each (a total of 360°, or a complete circle) extending from the North Pole to the South Pole. This corresponds to 24 hours (1 hour for each 15° or 4 minutes for each 1°) for the earth to make one complete revolution about its axis. The time zones that affect the United States and southern Canada are eastern standard time at a longitude of 75°, central standard time at 90°, mountain standard time at 105° and Pacific standard time at 120°.

At any given location within the United States or Canada, sun time is found by starting with local standard time (if daylight savings time is in effect subtract 1 hour from your local time). Since it takes the sun 4 minutes to move 1° longitude, a correction needs to be made between the standard time longitude line and your local longitude. Find your location on the map in figure V-14 and subtract 4 minutes for every degree of longitude your location is west of your standard time longitude line or add 4 minutes for every degree of longitude your location is east of it. The equation of time adjustment is then added to this corrected time to find sun time.

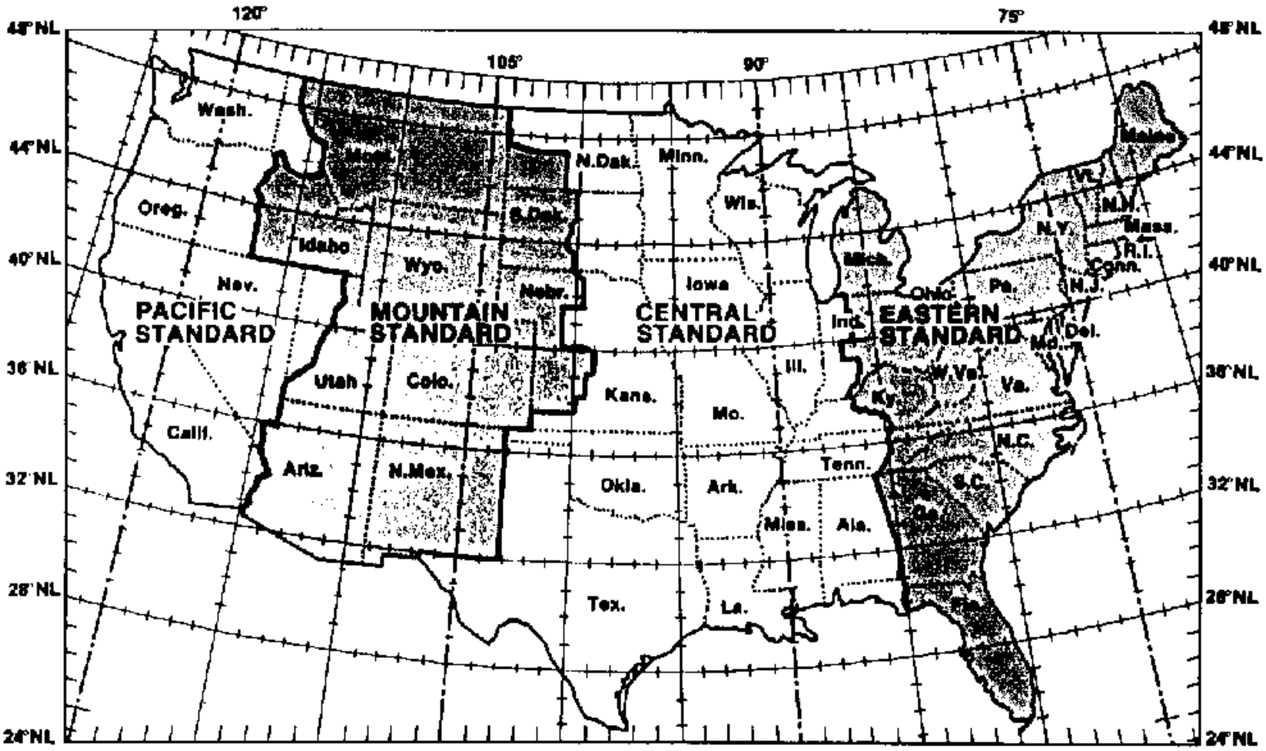


Fig. V–14: Standard time zones of the United States.

Then use this simplified equation to convert standard time to sun time:

$$\text{sun time} = \text{standard time} + E + 4(L_{st} - L_{loc})$$

where:
E = the equation of time, from figure V-13 in minutes
L_{st} = the standard time longitude line for your local time zone
L_{loc} = the longitude of your location

For example, what is the sun time corresponding to 11:30 a.m. central standard time on February 15 in Minneapolis?

To find sun time:

1. Locate Minneapolis on the map. Its longitude is 93° which is in the central standard time zone with a standard time longitude of 90°. Since the sun takes 4 minutes to move 1° longitude, the last term in the equation is 4(90−93) or 4(−3) or −12 minutes.
2. To correct for the time variation on February 15, the equation of time or E from figure V-13 is −14 minutes. Subtract another 14 minutes from standard time to obtain sun time.

sun time = standard time −14 −12
sun time = 11:30 a.m. − 26 min. = 11:04 a.m.

Plotting the Skyline

To accurately determine the times that direct sun is blocked from reaching any point on a site it is necessary to plot the obstructions as seen from that point. This is done by plotting the "skyline" directly on the sun chart. If the skyline to the south is low with no obstructions such as tall trees, buildings or abruptly rising hills, the following procedure is unnecessary as all points on the site will receive sun during the winter.

To plot the skyline, you will need either a transit or a compass (to find the azimuth angles of the skyline) and a hand level (to find the altitude angle of the skyline), and a copy of the sun chart for your location.

Next, place yourself at the approximate location on the site where you want to put the building. Plot the skyline (from that point) on the sun chart as follows:

1. Using the compass or transit, determine which direction is true south (remember magnetic variation; see fig. V-11).
2. Aiming the hand level or transit true south, determine the altitude (angle above the horizon) of the skyline. Plot this point on the sun chart above the azimuth angle 0° (true south).
3. Similarly, determine and record the altitude angle of the skyline for each 15° (azimuth angle) along the horizon, both to the east and west of south, to at least 120°. This is a total of 17 altitude readings. Plot these readings above their respective azimuth angles on the sun chart and connect them with a line.

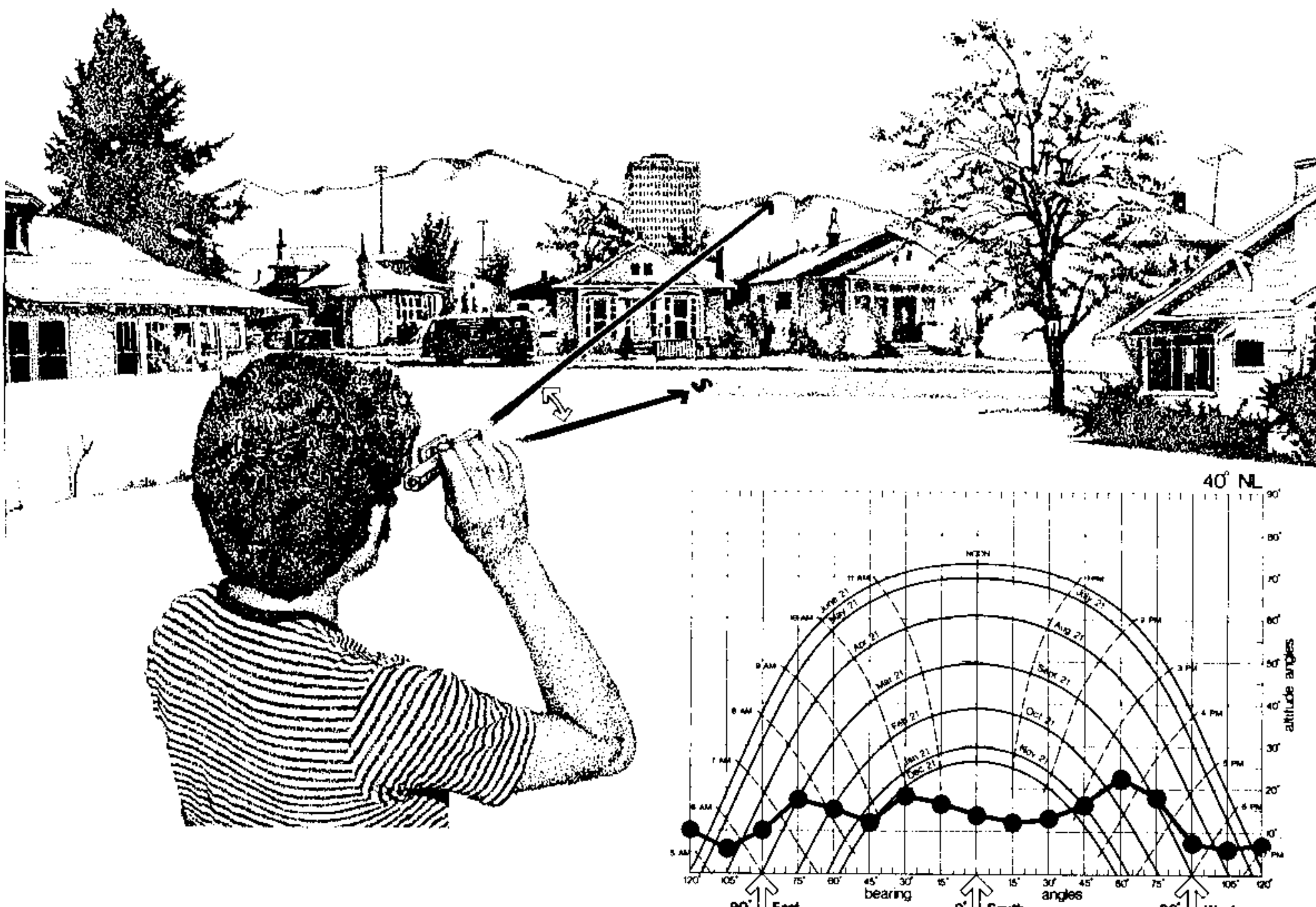
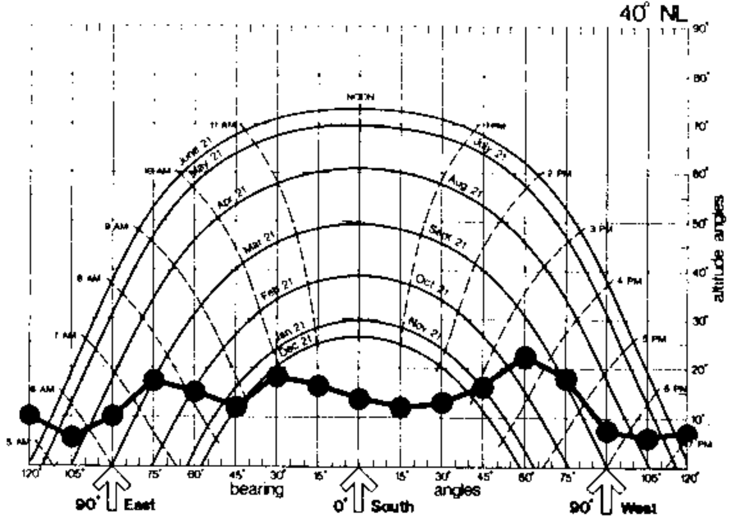


Fig. V–15: Plotting the skyline.



40° NL
NOON
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
2 PM
3 PM
4 PM
5 PM
6 PM
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
120°
105°
75°
60°
45°
30°
15°
bearing
angles
90° East
0° South
90° West

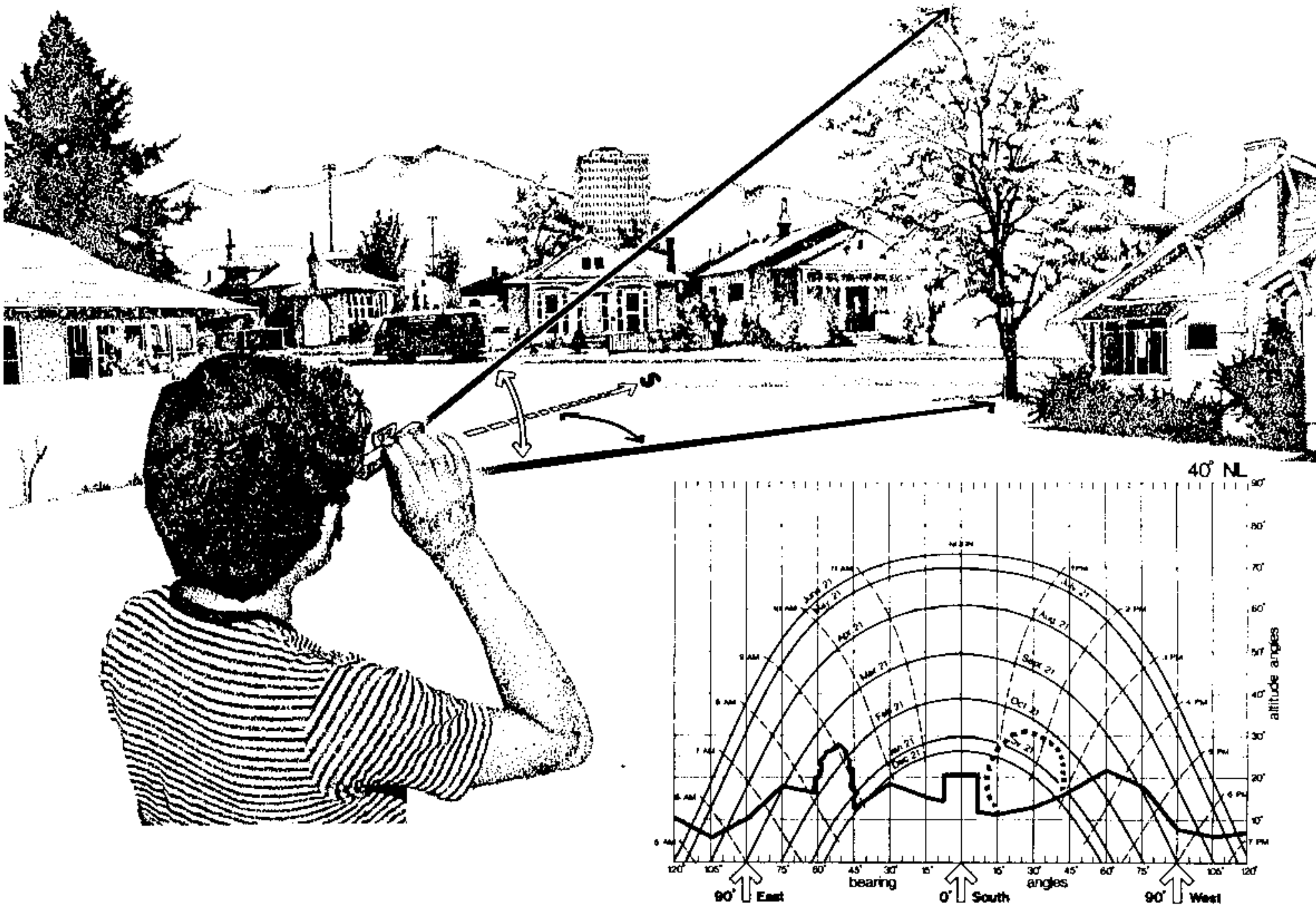
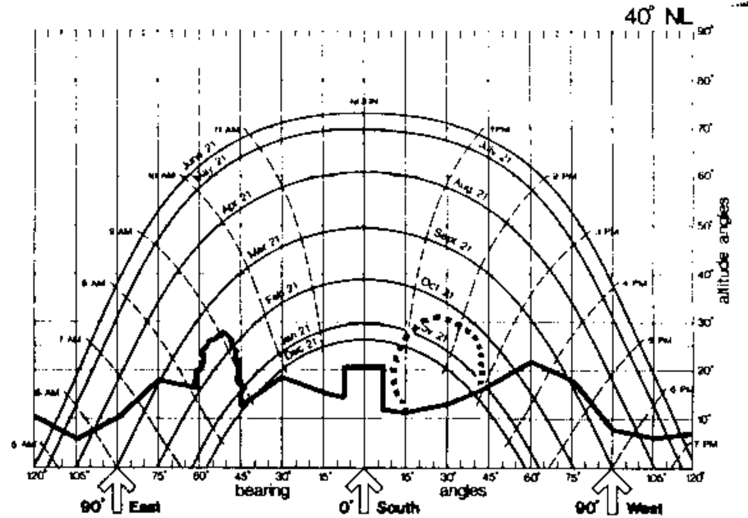


Fig. V–16: Plotting tall permanent objects.

4. For isolated tall objects that block the sun during the winter, such as tall evergreen trees, find both the azimuth and altitude angles for each object and plot them on the chart.
5. Finally, plot the deciduous trees in the skyline with a dotted line. These are of special nature, because by losing their leaves in the winter they let most of the sun pass through as long as they are not densely spaced.

This completes the skyline. The open areas on the sun chart are the times when the sun will reach that point on the site.



40° NL
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
90°
80°
70°
60°
50°
40°
30°
20°
10°
altitude angles
120°
105°
75°
60°
45°
30°
15°
15°
30°
45°
60°
75°
105°
120°
bearing
angles
90° East
0° South
90° West

The Solar Radiation Calculator

In the design of passive solar heating and cooling systems for buildings, it is important to know the amount of radiation or heat energy that strikes a surface on a winter-clear day, over an entire day, or at some particular hour.

After making some basic assumptions about the nature of the atmosphere and the nature of reflecting surfaces, it is possible to calculate the amount of radiation (sun's heat measured in Btu's) intercepted by a surface, on a clear day, for any position of the sun in relation to that surface. A computer program was developed * to plot all the possible positions of the sun where a square foot of surface would receive a fixed quantity of radiation, such as 50, 75 or 100 Btu's in one hour. The positions of the sun, for each quantity, were connected and drawn as four illustrations, that follow, called solar radiation calculators, to fit and be used with the sun chart.

The solar intensity masks are used to determine the amount of heat energy striking a surface. The lines on the masks represent *winter-clear day,* hourly totals of heat energy (in Btu's) striking a square foot of surface. The mask marked "90°" is for vertical surfaces, mask "60°" for inclined surfaces of 60° (as measured from the horizon), mask "30°" for inclined surfaces of 30° and mask "0°" for horizontal surfaces.

Transfer the mask you choose to transparent material and use the "center axis" and "base line" to align it with the sun chart. In order to find the amount of heat in Btu's per square foot per hour intercepted by a surface facing in any direction, set the base line of the mask directly over the base line of the sun chart. Using a compass, determine the direction that your surface faces to the east or west of true south. Keeping the base lines aligned, shift the pointer of the mask to line up with the number of degrees (azimuth angle) your surface faces to the east or west of true south. You are now ready to determine the solar intensity values for that surface.

Set the pointer on the mask to line up with 45° west on the base line of the sun chart. Be sure the base lines of both sheets are in line. The sun chart and mask are now aligned to read the solar intensity values.

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*Computer program was developed by Mark Steven Baker from solar radiation formulas found in the ASHRAE *Handbook of Fundamentals* (1972).

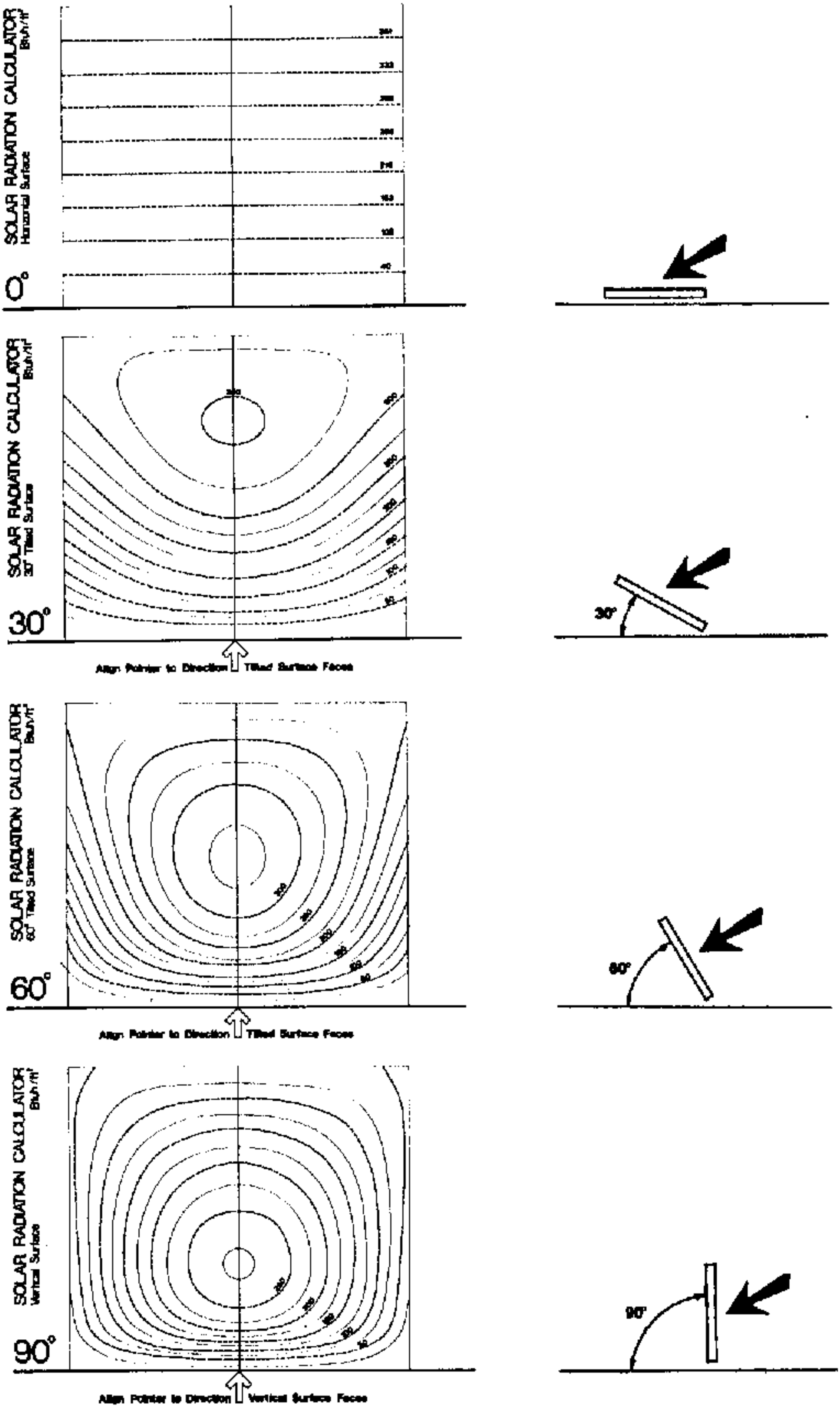


Fig. V–17: Solar radiation calculators.

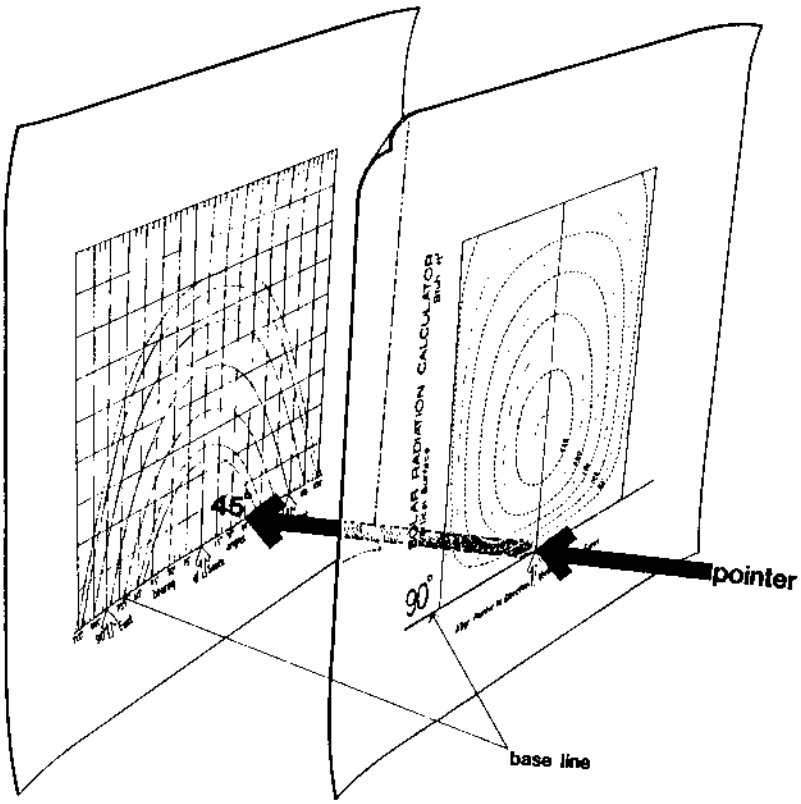


Fig. V–18: Alignment example for a vertical surface facing 45° west of south.

Hourly Radiation Totals

To determine the winter-clear day, hourly totals of heat energy, in Btu's per hour, striking each square foot of surface area:

1. Select the proper mask based on the slope of the surface (horizontal, 30°, 60° and vertical).
2. Select the proper sun chart for the latitude of your location (if your location is in between latitudes, choose the closest one).
3. Keeping the base lines aligned, set the pointer (center axis) of the mask on the azimuth angle that the surface faces to the east or west of true south.
4. Select the month you want to take the reading and use *that* sun's path to read the values.
5. Select the hour of the month in which you want the reading: the intersection of the hour line and the sun path will locate the position of

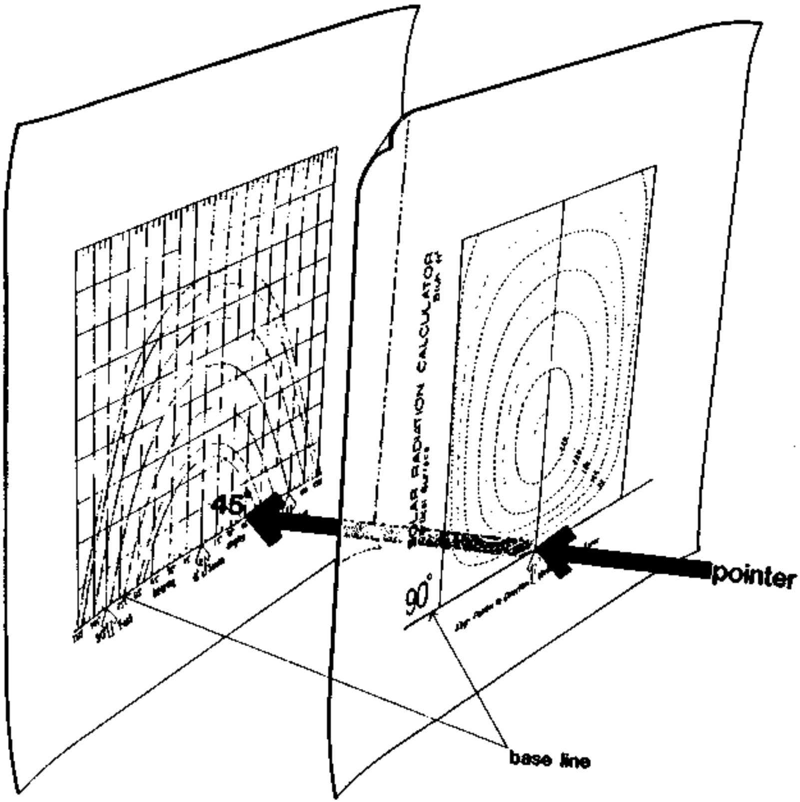


Fig. V–18: Alignment example for a vertical surface facing 45° west of south.

the sun. Read the number of Btu's for that sun's position from the radiation mask. If the point where you want the reading falls between radiation lines, interpolate to find the value.

Note: Because the value of atmospheric moisture content varies greatly across the United States, the solar intensity numbers need to be adjusted depending upon your location. A correction called the Clearness Factor must be applied to the clear-day values. The map in figure V-19 shows lines of equal clearness for winter conditions. Find the line and corresponding Clearness Factor closest to your area and multiply it by the hourly solar intensity numbers from the mask.

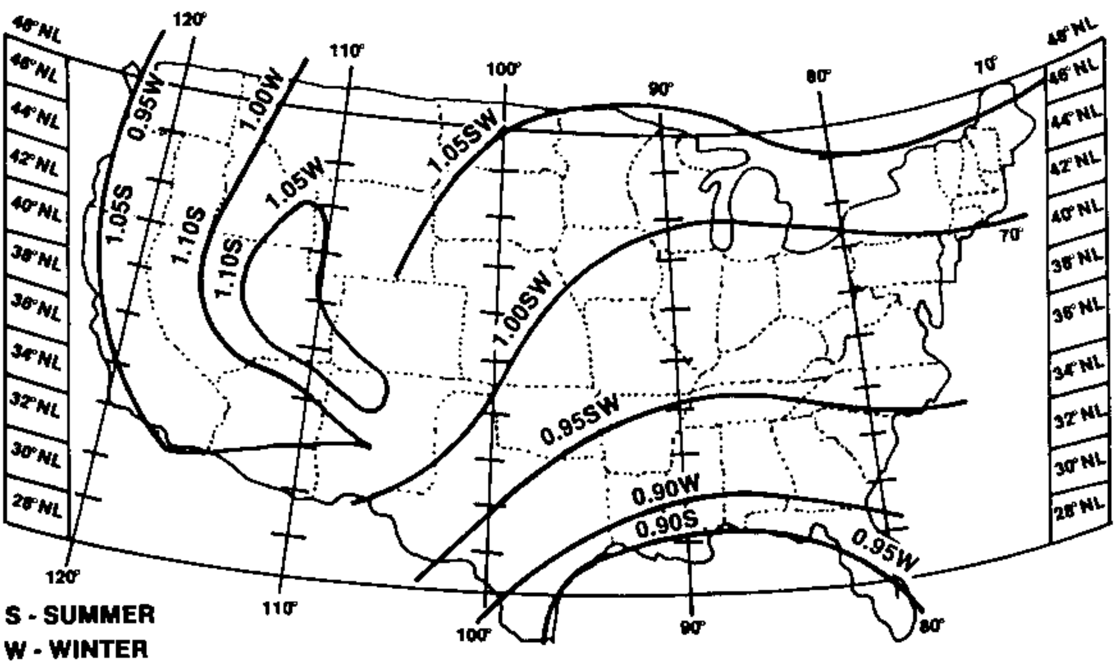
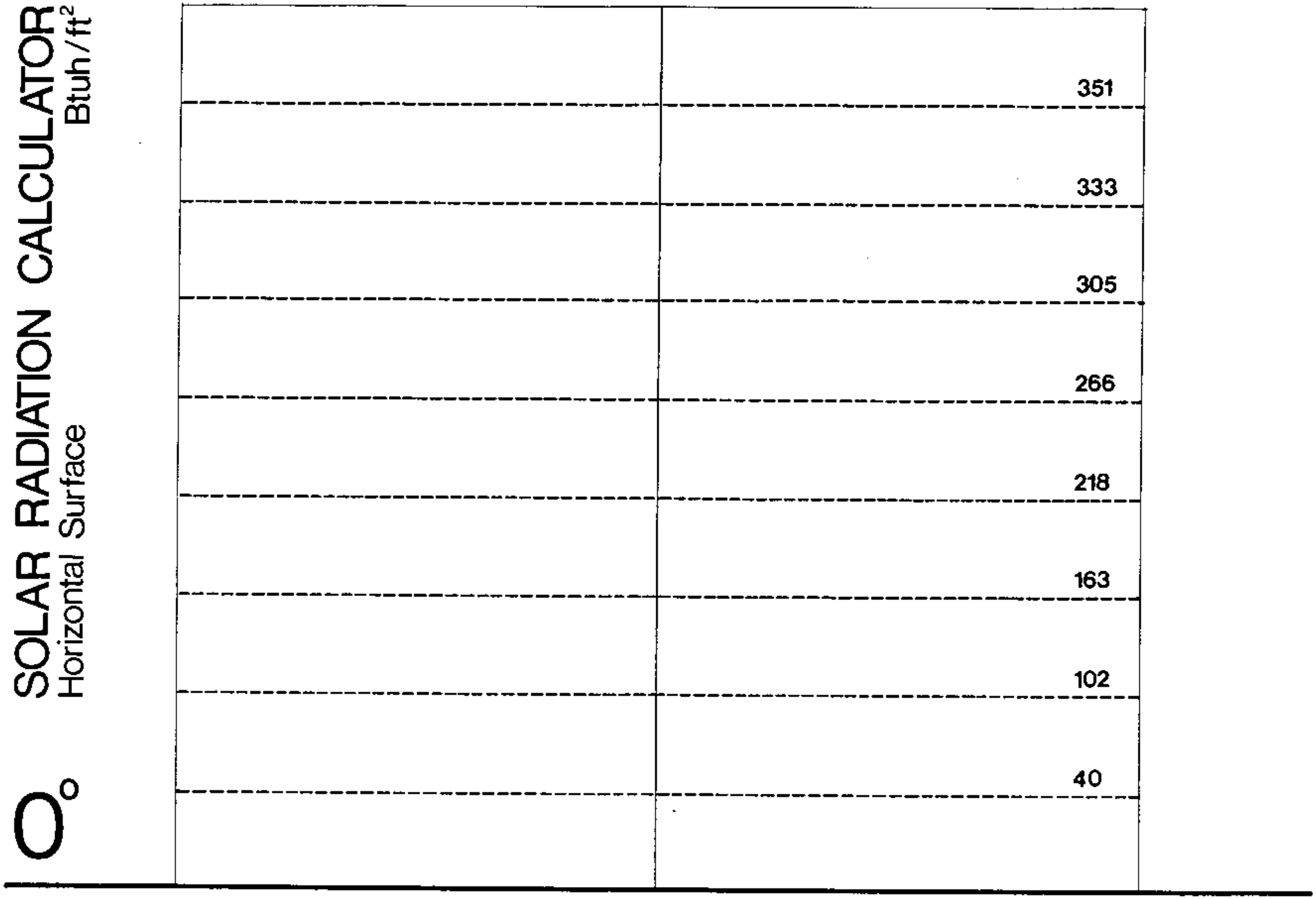


Fig. V–19: Map of clearness adjustment factors.

Source: ASHRAE, *Handbook of Fundamentals*, 1972.

Daily Radiation Totals

To determine the total daily amount of heat energy striking a surface, simply follow the procedure for hourly totals for each hour on the sun chart and total these to get the daily total. If the hourly totals have not been adjusted for your area, then adjust the daily total by multiplying it by the appropriate adjustment factor from the map.



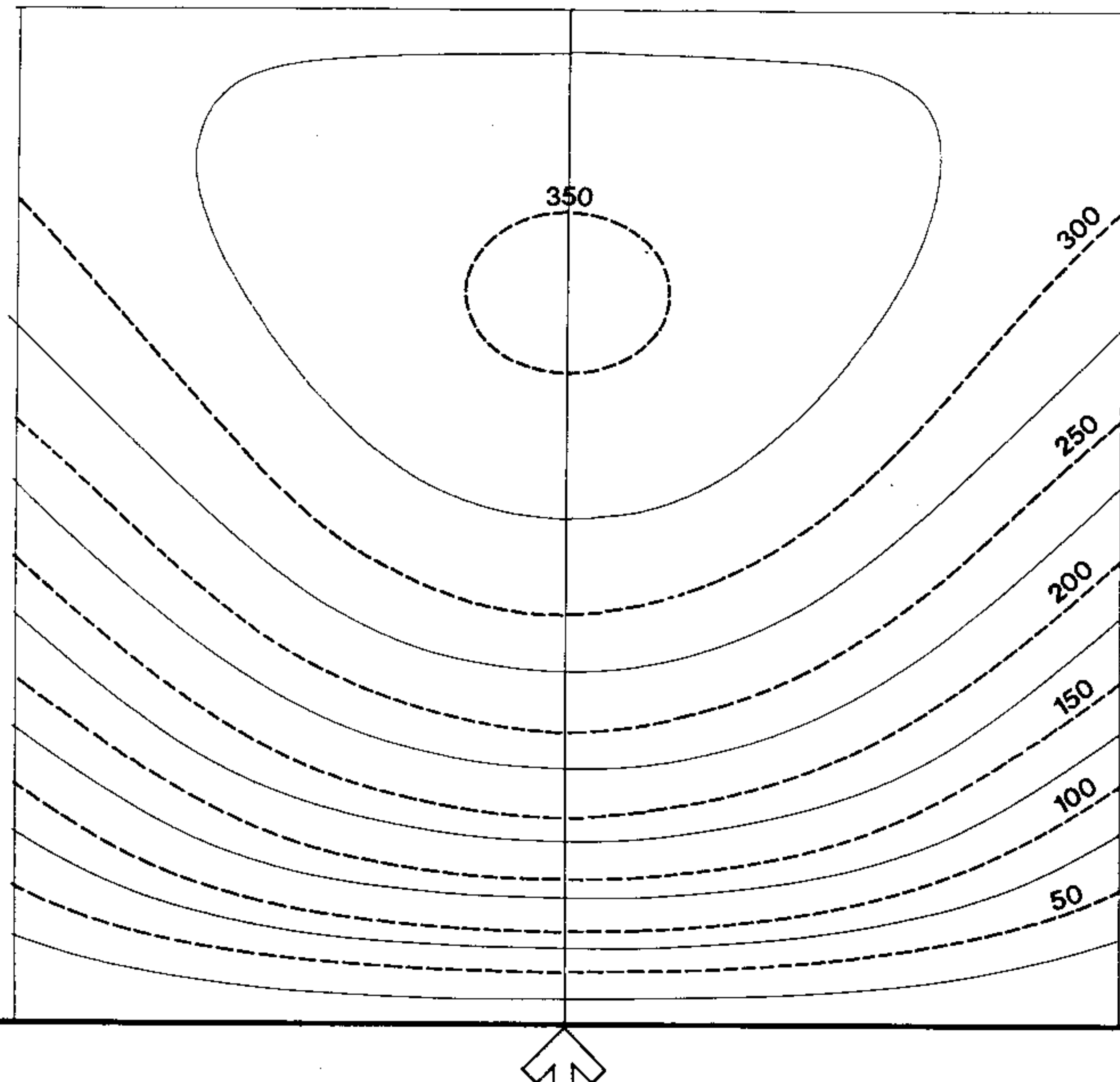
Solar Intensity Masks

The following solar intensity masks are for horizontal (0°), tilted (30° and 60°) and vertical (90°) surfaces:

SOLAR RADIATION CALCULATOR
Btuh/ft²

30° Tilted Surface

30°

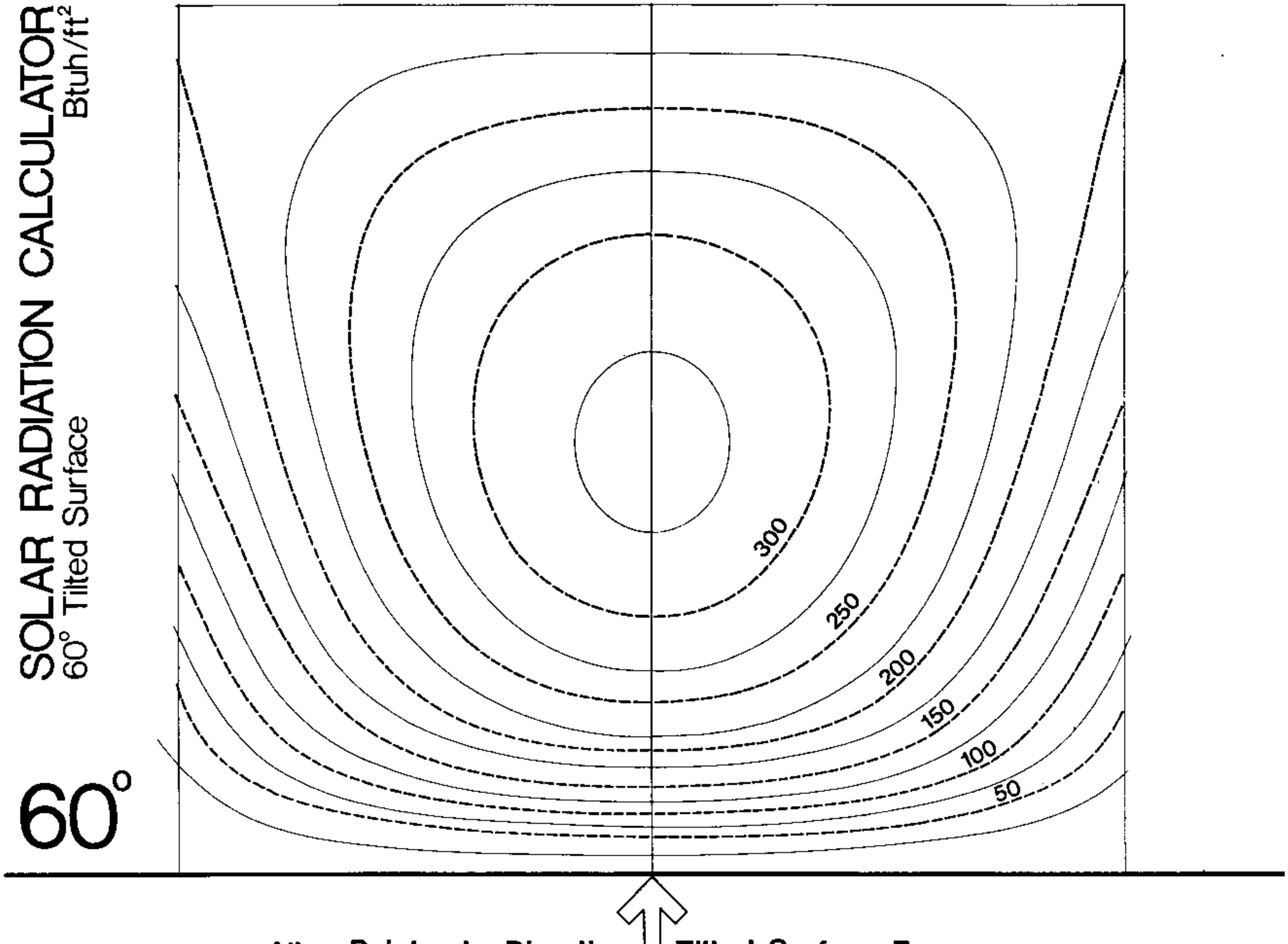


Align Pointer to Direction Tilted Surface Faces

SOLAR RADIATION CALCULATOR
Btuh/ft^2

60° Tilted Surface

60°

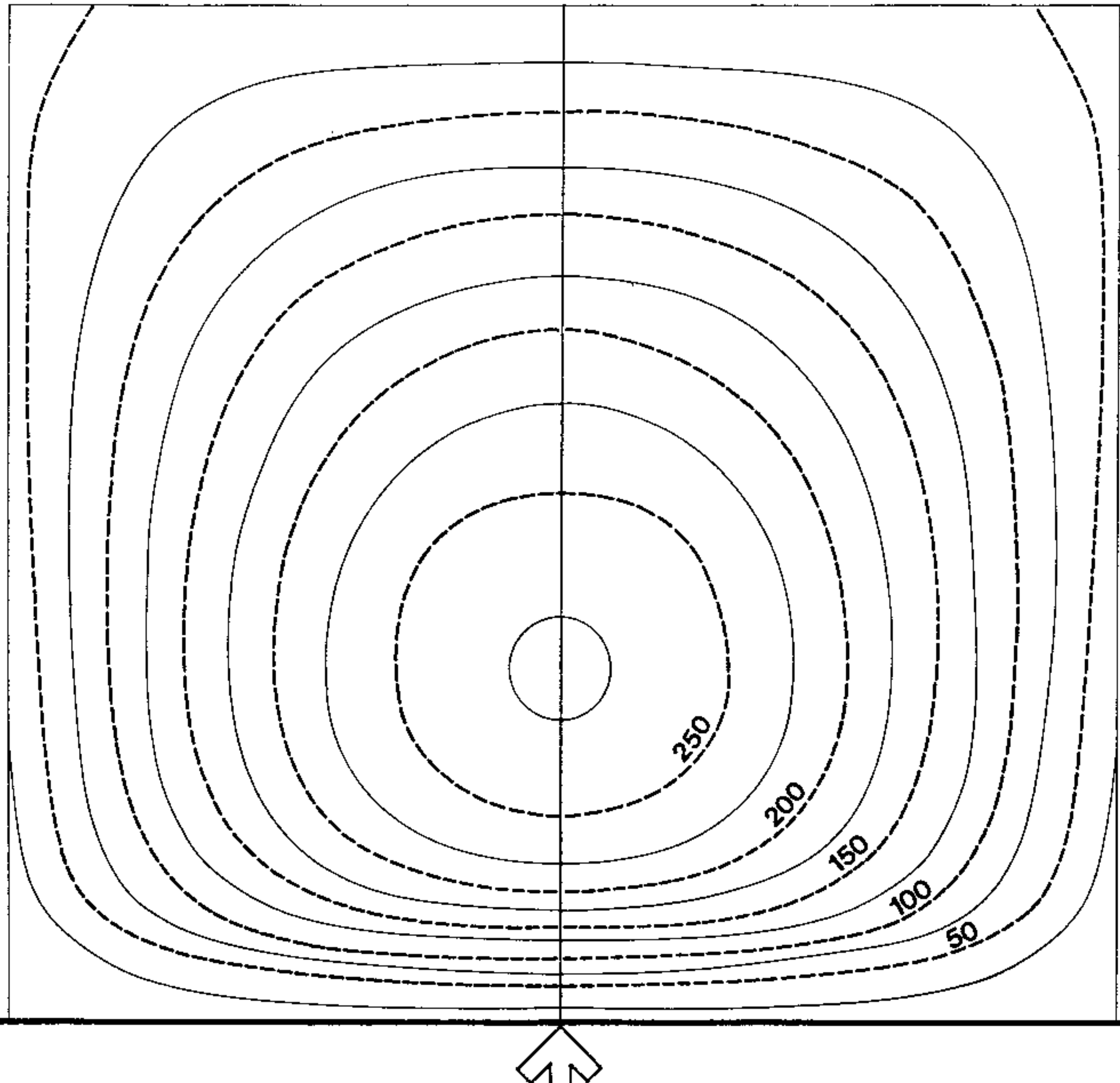


Align Pointer to Direction Tilted Surface Faces

SOLAR RADIATION CALCULATOR
Btuh/ft²

Vertical Surface

90°



Align Pointer to Direction Vertical Surface Faces

The Shading Calculator

Looking from a window, a shading device or any obstruction for that matter (such as a tree or building) will block part of the skydome from view. To put it another way, the window will be in shade when the sun travels across the obstructed part of the skydome.

For any surface (such as a window or clerestory), skydome obstructions and shading devices can be graphically plotted to construct a *shading mask*. This mask, when superimposed over a sun chart, accurately determines the times that direct sunlight is blocked from reaching that surface. Since the masks are geometric descriptions of the shading characteristics of a particular device or obstruction, they are not dependent on latitude, orientation or time. Once plotted for a particular device, they can be used over any sun chart.

Shading devices can be grouped into three categories: the horizontal overhang, vertical fin, and overhang/fin combination or eggcrate. The horizontal overhang is characterized by a shading mask with a curved shadow line running from one edge of the mask to the other;

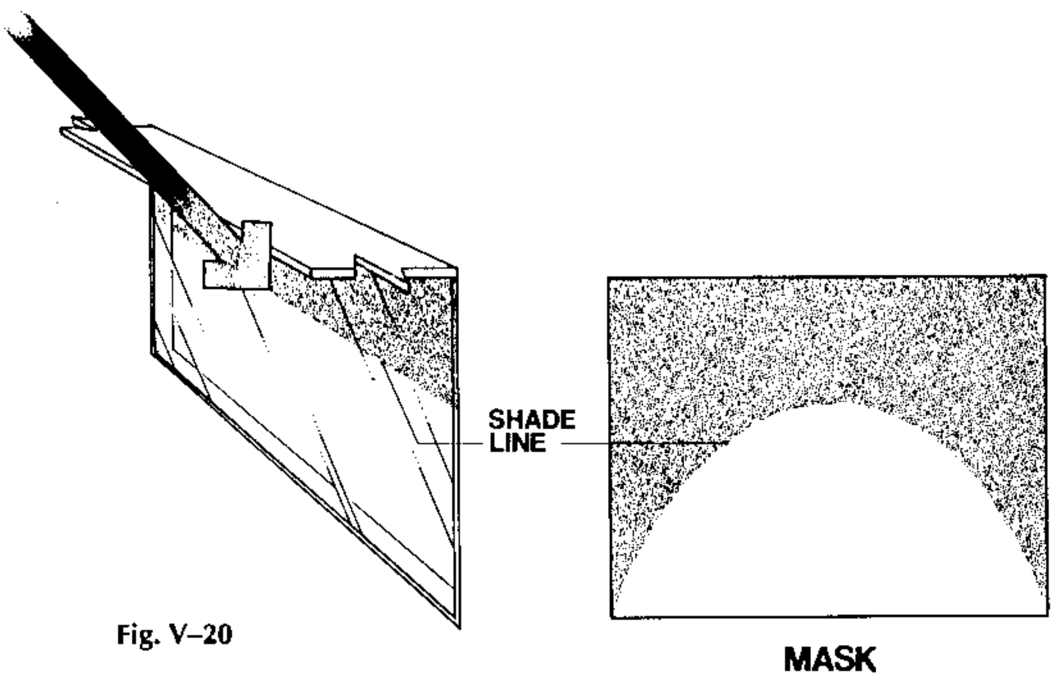


Fig. V–20

the vertical fin is characterized by a shading mask with a vertical shading line;

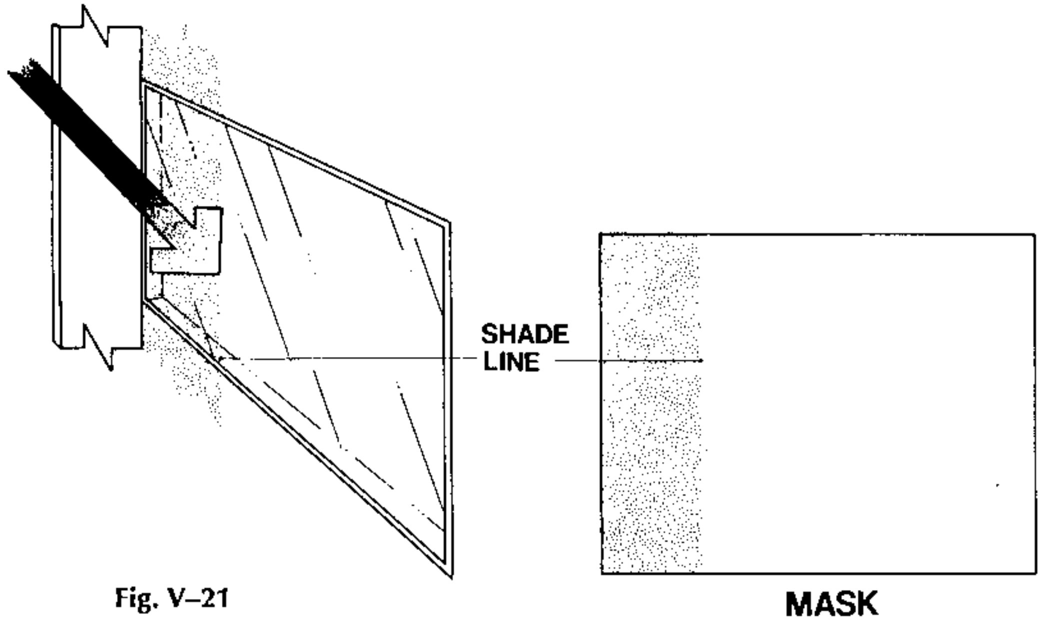


Fig. V–21

and the combination horizontal overhang/vertical fin is characterized by a combination of both curved and vertical shading lines.

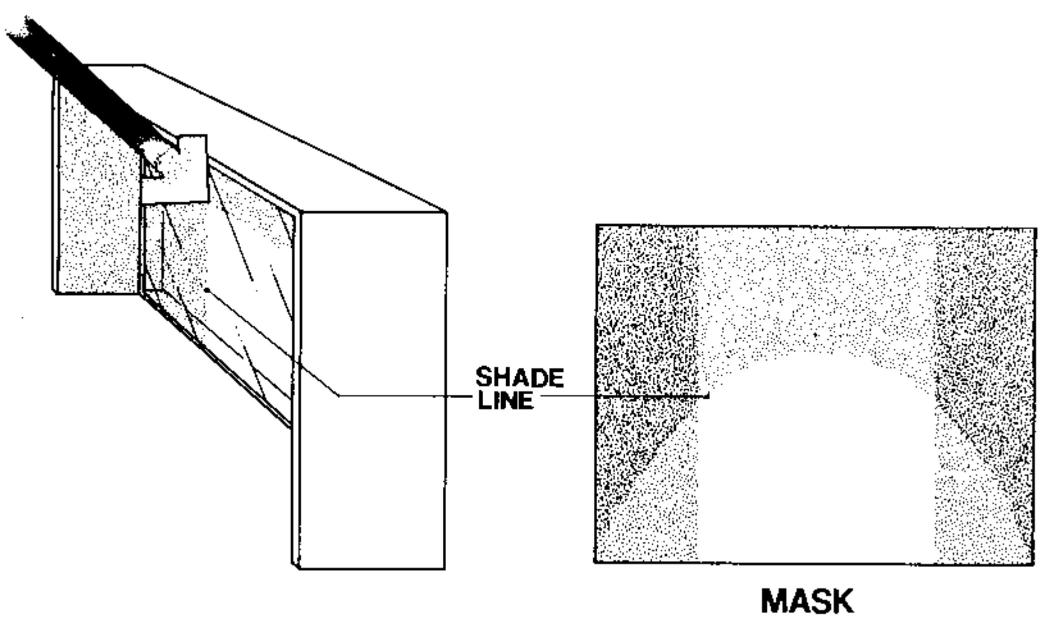


Fig. V–22

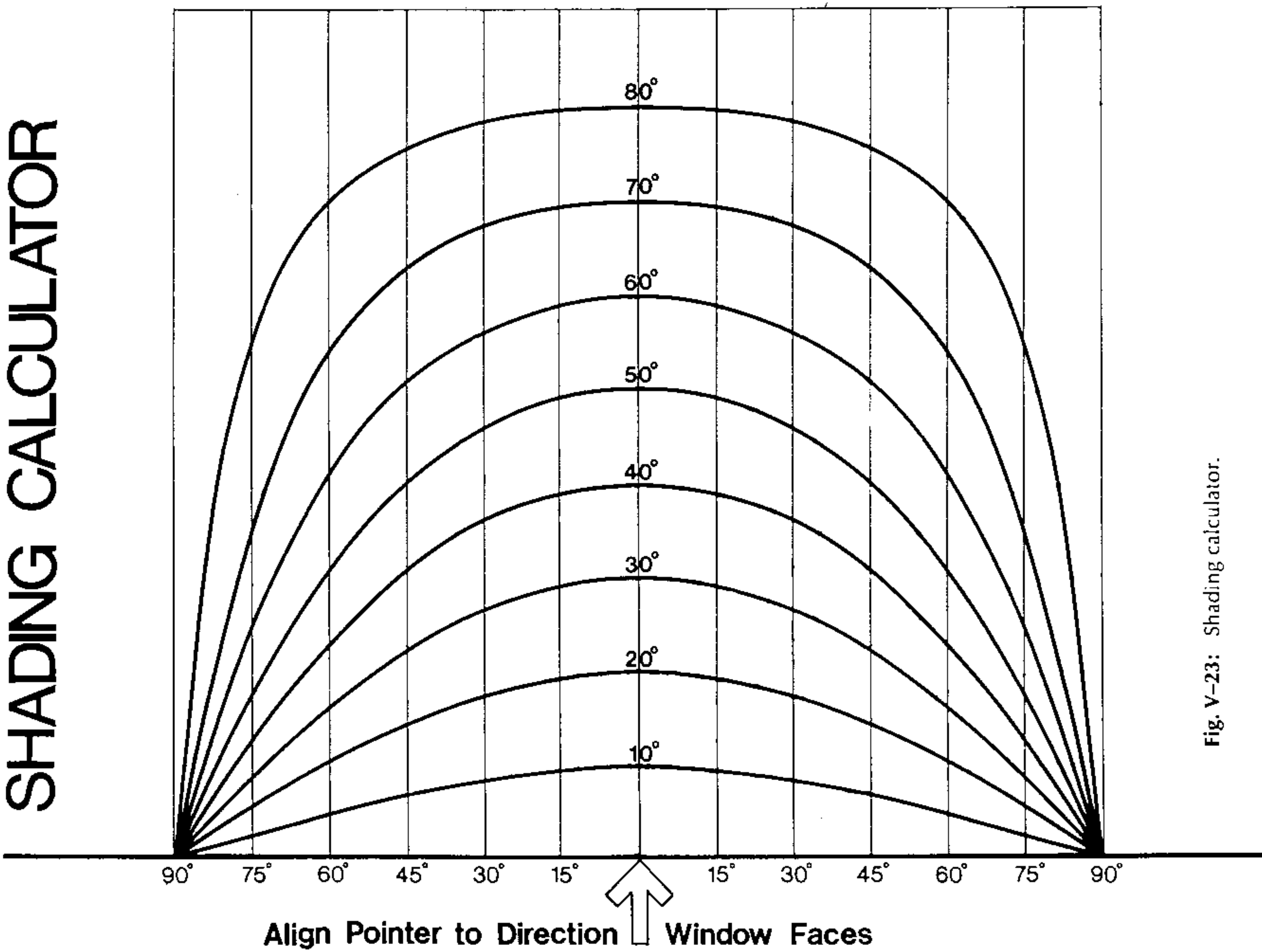


Fig. V-23: Shading calculator.

The shading masks are independent of the size of a shading device, but instead depend upon the ratios generated by the dimensions of the device and the window. These ratios are expressed as the angle the window makes with the shading device.

The *shading calculator* shown in figure V-23 will assist you in generating a shading mask.

The curved lines that run from the lower right-hand corner of the calculator to the lower left-hand corner are used to plot *horizontal* obstruction lines parallel to a window and the vertical lines on the calculator serve to plot *vertical* obstruction lines parallel to the window.

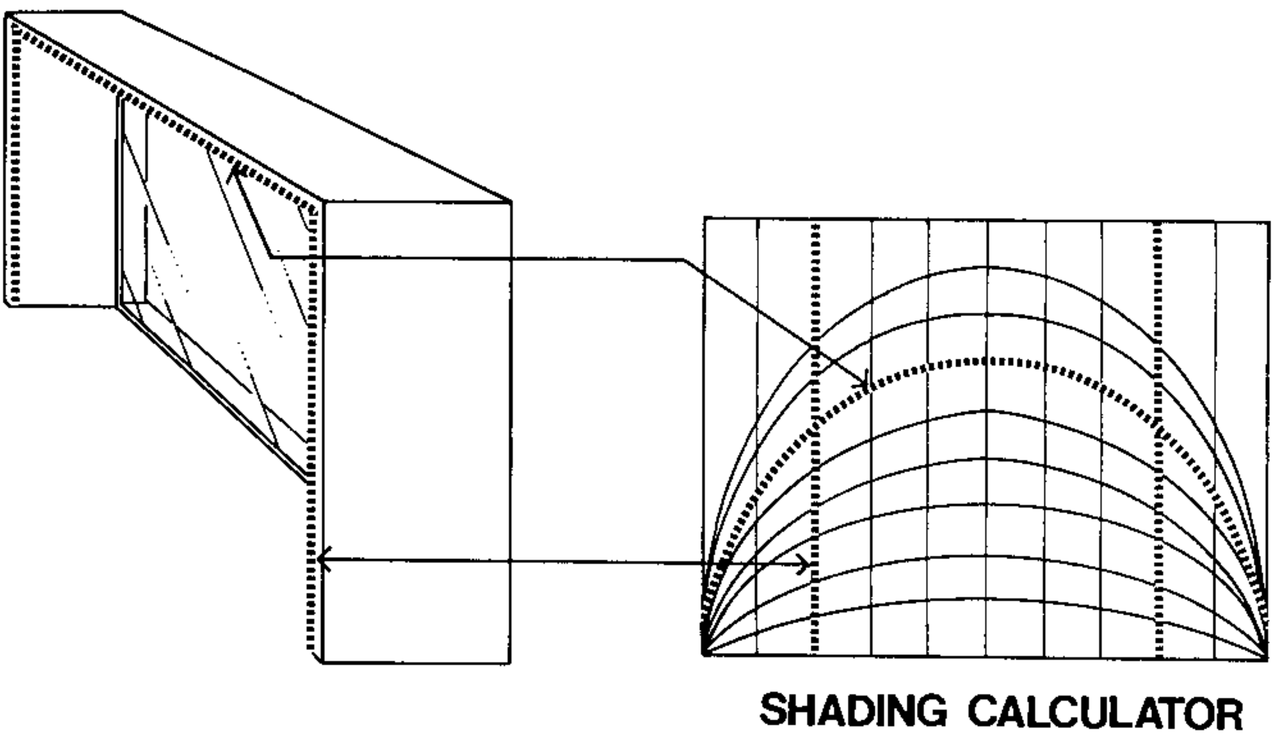
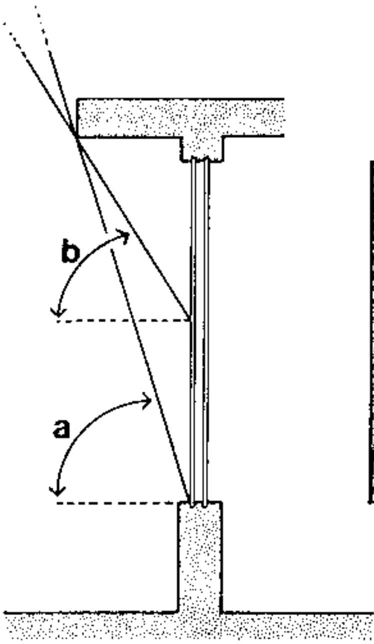


Fig. V–24

Plotting the Shading Mask

Horizontal Overhang

To construct a shading mask for a window with a horizontal overhang, first determine the angle from a line perpendicular to the bottom of the window to the edge of the overhang (angle a), and the angle from the *middle* of the window to the edge of the overhang (angle b). These angles represent 100% and 50% shading of the window. Then, using the shading calculator, draw in the shade lines that represent angle a and angle b.



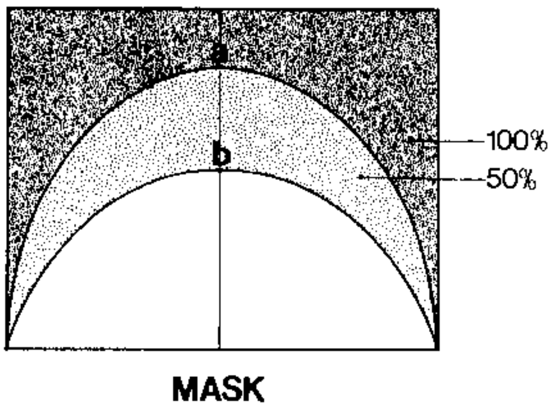


Fig. V–25

This completes the shading mask. The mask has a pointer and a base line for alignment with the sun chart. Select the sun chart for your latitude, then keeping the base line of the mask directly over the base line of the sun chart, shift the pointer of the mask to line up with the number of degrees (azimuth angle) your window faces to the east or west of true south. The window will be completely shaded during the times that the sun is above the 100% shading line, and partially shaded (50%) at the 50% shading line.

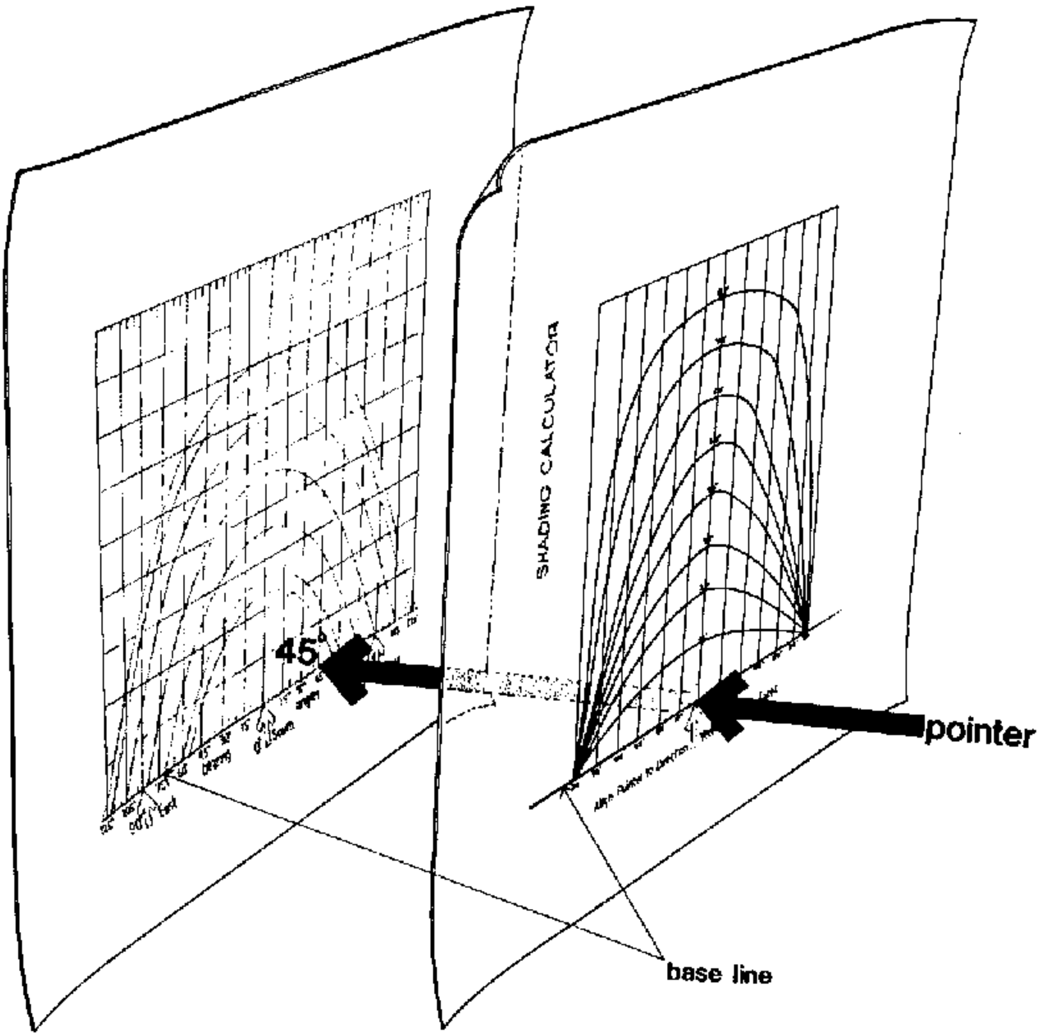


Fig. V–26: Alignment example for a window facing 45° west of south.

Although the mask plots 100% and 50% shading of a window, the procedure can be repeated to generate a more complete mask which includes 25% and 75% shading.

Vertical Fins

There are basically two types of vertical fin shading devices: those that project out perpendicular from the face of the window and those that project out at an angle. To construct a mask for either device:

First, determine angles a and b as shown in figure V-27. These angles represent the 100% shading lines. Then determine angles c and d; these represent the 50% shading lines. From the base line of the shading calculator draw vertical lines that correspond to angles a, b, c and d. This completes the shading mask.

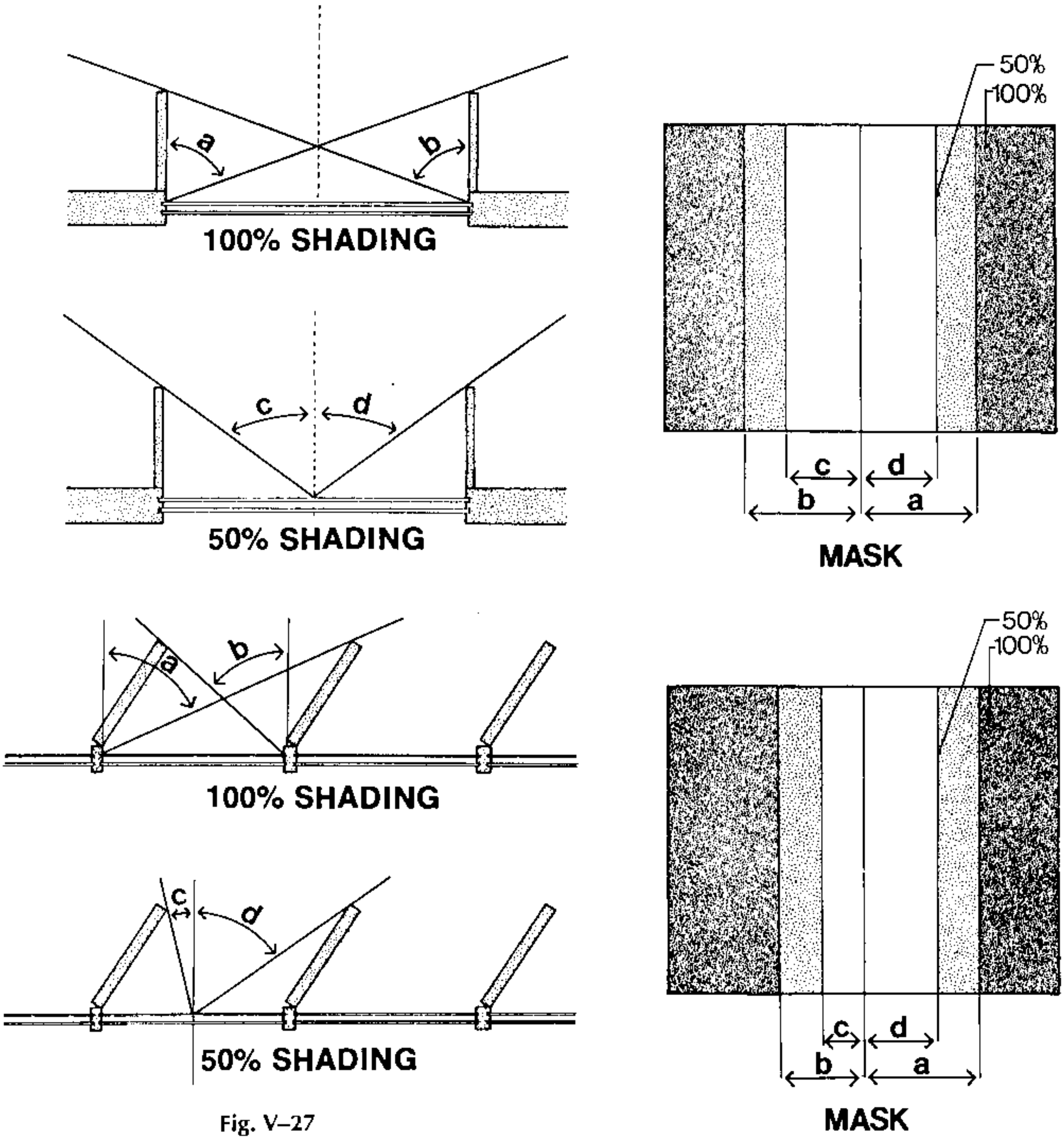


Fig. V–27

Then align the shading mask over the sun chart to the angle the window faces to the east or west of true south. The window will be completely shaded during the times the sun is outside of the 100% shading lines and partially shaded (50%) at the 50% shading lines.

Combination Horizontal Overhang/Vertical Fin

To construct the shading mask for a combination horizontal overhang/vertical fin, simply combine the shading masks for each device.

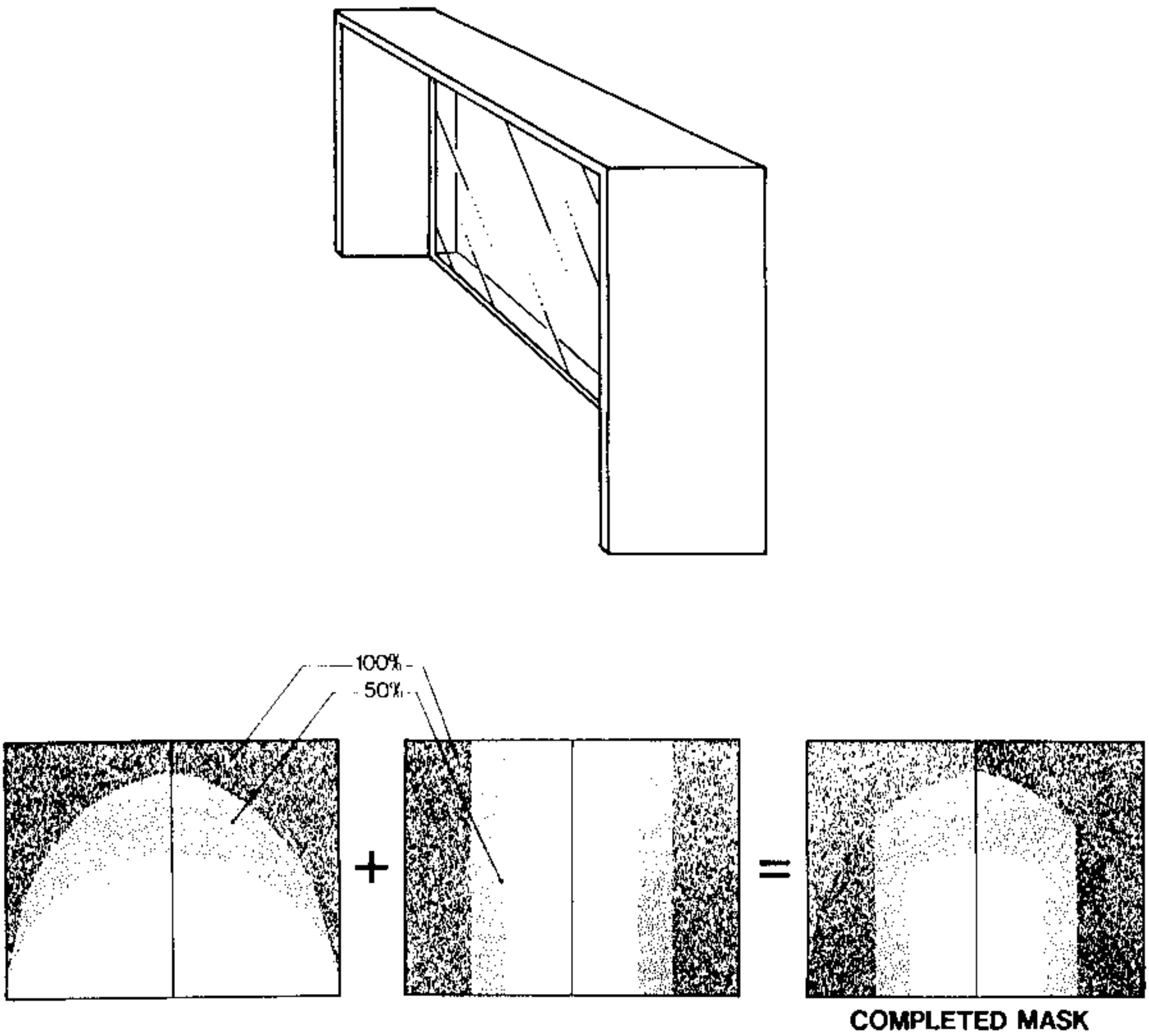


Fig. V–28

Percentage of Solar Radiation Absorbed by Various Surfaces

(Figures are expressed as the percentage of the intensity of solar radiation striking the surface.)

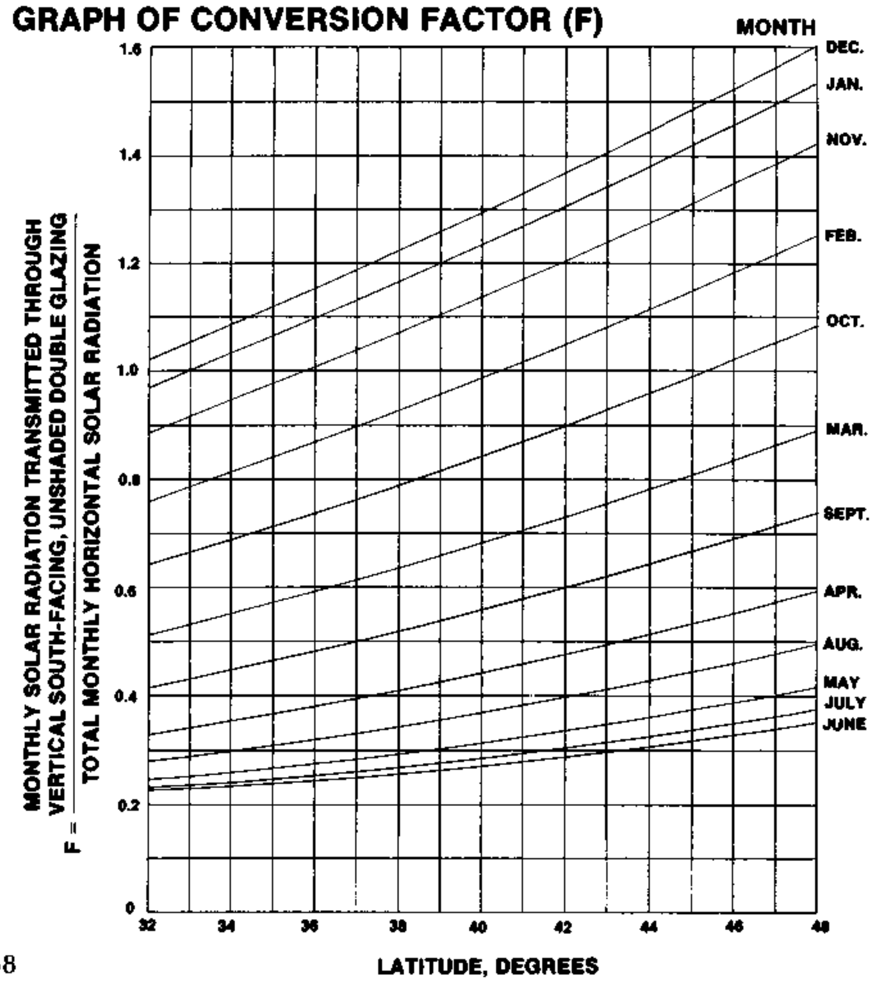
Reflective surfaces	0.20
For white, smooth surfaces	0.25 to 0.40
For grey to dark grey	0.40 to 0.50
For green, red and brown	0.50 to 0.70
For dark brown to blue	0.70 to 0.80
For dark blue to black	0.80 to 0.90

2. Horizontal to Vertical Conversion

Average solar radiation values generally available in tables and maps are measured on a horizontal surface; however, the values required for passive solar calculations are the actual solar energy transmitted through vertical south-facing glass. The following formula can be used to convert horizontal incident solar energy to the amount of energy transmitted through two sheets of vertical south-facing glass:

$$\frac{\text{solar energy transmitted}}{\text{through south double glass}} = F \times \frac{\text{solar energy incident on}}{\text{a horizontal surface}}$$

where: F = conversion factor from the following graph:



The conversion factor (F) is the ratio of the monthly solar radiation transmitted through vertical south-facing double glazing to the monthly total horizontal solar radiation. For vertical single glazing use 1.213 (F) and for vertical triple glazing use 0.825 (F).

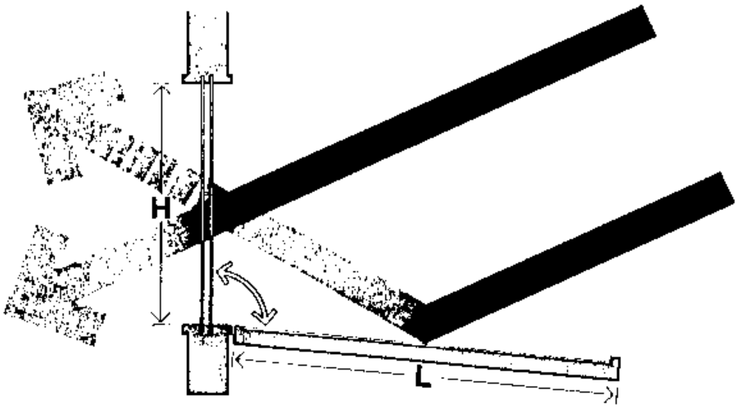
For glazing other than vertical or at orientations different than true south, a correction to the value calculated must be made. It is recommended that the clear-day radiation tables in Appendix 6 be used. To establish a Correction Factor (CF), use the following formula:

$$CF = \frac{\text{clear-day transmitted radiation for tilt and orientation of glazing}}{\text{clear-day transmitted radiation for vertical, south glazing}}$$

Next, multiply the *average* solar radiation value transmitted through vertical glazing by the Correction Factor.

SOURCE: Adapted from J. D. Balcomb and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type," *Proceedings of the Second National Passive Solar Conference*, Philadelphia, March 16–18, 1978 (Washington D.C.: U.S. Energy Research and Development Administration, 1978).

Percentage of Enhancement of Solar Heat Gain with Specular Reflectors for Vertical South-Facing Glazing (reflectance 0.8)



$$\frac{\text{reflector length (l)}}{\text{glazing height (h)}} = 1.0$$

Latitude	28°		32°		36°		40°		44°		48°		52°		56°	
Reflector/ Collector Tilt Angle	90°	95°	90°	95°	90°	95°	90°	95°	95°	100°	95°	100°	100°	105°	100°	105°
January	48	49	42	46	37	42	31	37	32	37	28	33	29	33	25	30
February	62	48	58	50	51	50	45	48	43	43	38	41	37	38	33	36
March	68	37	68	42	67	46	66	49	51	34	53	38	41	26	44	30
April	74	12	74	21	73	29	72	36	42	14	46	21	27	8	32	13
May	76	0	76	2	75	9	75	17	26	2	33	6	11	0	18	2
June	78	0	77	0	76	2	76	8	17	0	25	1	5	0	11	0
July	77	0	76	0	76	5	75	12	21	0	29	3	8	0	14	1
August	75	5	75	13	74	21	73	29	36	8	42	14	21	4	27	8
September	71	30	70	37	70	42	69	46	49	28	52	33	38	20	41	25
October	64	46	63	48	59	50	51	51	48	41	43	43	41	35	37	38
November	52	49	45	48	40	44	34	39	34	39	30	35	31	35	27	32
December	44	48	39	43	33	38	28	34	29	34	25	31	27	32	23	28

SOURCE: Taken from computer studies by M. Steven Baker, University of Oregon, Eugene, Oregon, 1977.

Performance Calculations

So far, general rules of thumb for designing and sizing a passive solar-heating system have been given in the form of patterns. The patterns make it possible to integrate passive solar concepts when designing a building. They give enough detailed information to size a system that will function effectively. After a preliminary design for the building is complete, it is then possible to calculate the thermal performance of each space and make adjustments to the system, if necessary.

The patterns give rules of thumb for sizing a system based on clear-day solar radiation and average outdoor temperatures for the winter months. Essentially, this sizing procedure balances the heat lost from a space (kept at 70°F) over the day with the energy collected from the sun (when shining) that same day. This condition is referred to as the design-day. Because design-day data have been used, it can be expected that the system will not perform as effectively under more severe conditions, although the massive nature of passive buildings tends to moderate the effects of weather extremes. It is reasonable to expect that a sizing procedure for the worst possible winter weather conditions is usually not practical. To do that would result in spaces that are uncomfortably warm during periods of normal sunny weather and would lead to a design that is oversized, and most likely uneconomical to build. For this reason, some form of back-up heating system is desirable in most passive solar heated buildings. Due to the complicated nature of energy flows in a passive building, calculating system performance is a difficult and tedious process, usually requiring the use of a computer. However, by compressing this process into a few relatively simple calculations, it was found that only a small degree of accuracy was sacrificed. Since even the most sophisticated calculation procedures are subject to error due to the large number of unpredictable variables associated with passive systems (such as occupant space use, interior furnishings and surface colors, estimating infiltration rates), this simplified procedure is appropriate for most small-scale applications of passive systems.

There are six steps involved in calculating a system's performance:

1. Calculating the rate of space heat loss.
2. Calculating space heat gain.
3. Determining the average daily indoor temperature.
4. Determining the daily indoor temperature fluctuation.
5. Calculating the auxiliary space heating requirements.
6. Determining the cost effectiveness of the system.

Step 1.
Calculating Space Heat Loss in Winter

The quantity of solar energy needed by a space in winter is dependent upon the hourly rate of heat loss through the exterior skin of the building. Heat is lost through the skin of a building by two methods: heat loss through the walls, floor, roof and windows (conduction losses) and the heat loss through the exchange of warmed indoor air with cold outdoor air (infiltration losses). The total space heat loss is then the sum of the conduction losses plus the infiltration losses. In calculating heat loss, it is necessary to compute the hourly rate for each space in the building separately.

The hourly rate, when divided by the floor area of the space and then multiplied by 24 hours, gives an overall space U value expressed in Btu's per day per square foot of floor area per °F (Btu/day-sq ft_{floor}-°F):

$$U_{sp} = \frac{HL_{total}}{A_{floor}} \times 24 \text{ hours}$$

This is a convenient figure to use when calculating indoor air temperatures and the yearly contribution of solar energy.

It is reasonable to expect that the overall space U value for a well-insulated residence will be between 6 and 12 Btu/day-sq ft_{fl}-°F, and for a greenhouse between 20 and 40 Btu/day-sq ft_{fl}-°F. Table 1-1 is included here to provide you with a quick and easy method of arriving at U_{sp}. The table should be used for estimating purposes only. For a description of detailed heat loss calculations, see the *professional edition* of *The Passive Solar Energy Book* or the ASHRAE *Handbook of Fundamentals*.

Table 1-1 Short-Cut Heat Loss Estimating

Space[1]	Window Glazing Details	Overall Space Heat Loss[2] U_{sp} (Btu/day-sq ft_{fl}-°F)			
		Direct Gain System[3]		Space w/ a Thermal Storage Wall System[4]	Space Adjacent to an Attached Greenhouse[5]
		1 Exposed Wall	2 or More Exposed Walls		
First-floor space w/ heated space above	Single glazing	8.1	12.2	7.2	6.6
	Double glazing or single glazing w/ insulating shutters	5.6	8.9	5.5	4.9
Upper-floor space or one-story-type space	Single glazing	8.9	13.0	8.0	7.4
	Same as above but a 1 1/2-story-high space	12.4	18.1	12.5	11.9
	Double glazing or single glazing w/ insulating shutters	6.4	9.7	6.3	5.7
	Same as above but a 1 1/2-story-high space	9.1	13.7	9.9	9.2

NOTES: 1. Values apply to a well-insulated space with 3 1/2 to 6 inches of insulation in the walls, 6 inches or more in the ceiling, 3 1/2 inches or more under floors above grade or 2 inches of perimeter insulation for a slab on grade.

2. Accuracy is believed to be within 15%; this table is recommended for estimates only.

3. Area of glazing is roughly 20 to 30% of the space floor area.

4. Assumes no heat loss through the thermal wall.

5. Assumes no heat loss through the common wall between the space and greenhouse.

Step 2.
Calculating Space Heat Gain in Winter

Heat Gain Formulas

- *Direct Solar Heat Gain (HG_{sol})*—All of the sunlight transmitted through a window is collected by a space, as heat. However, the amount transmitted through each square foot of glass depends upon many factors, such as the location or latitude of the building, the orientation of the window, the number and type of window glazing used, and the shading of a window by nearby obstructions, including shading devices.

Appendix 6 lists daily totals of clear-day, solar heat gain (I_t) transmitted through double glass at various latitudes and window orientations. To calculate solar heat gain, first select the proper table for your location. For instance, at 40°NL, if a vertical window is oriented due south, the solar heat gain through a square foot of unshaded

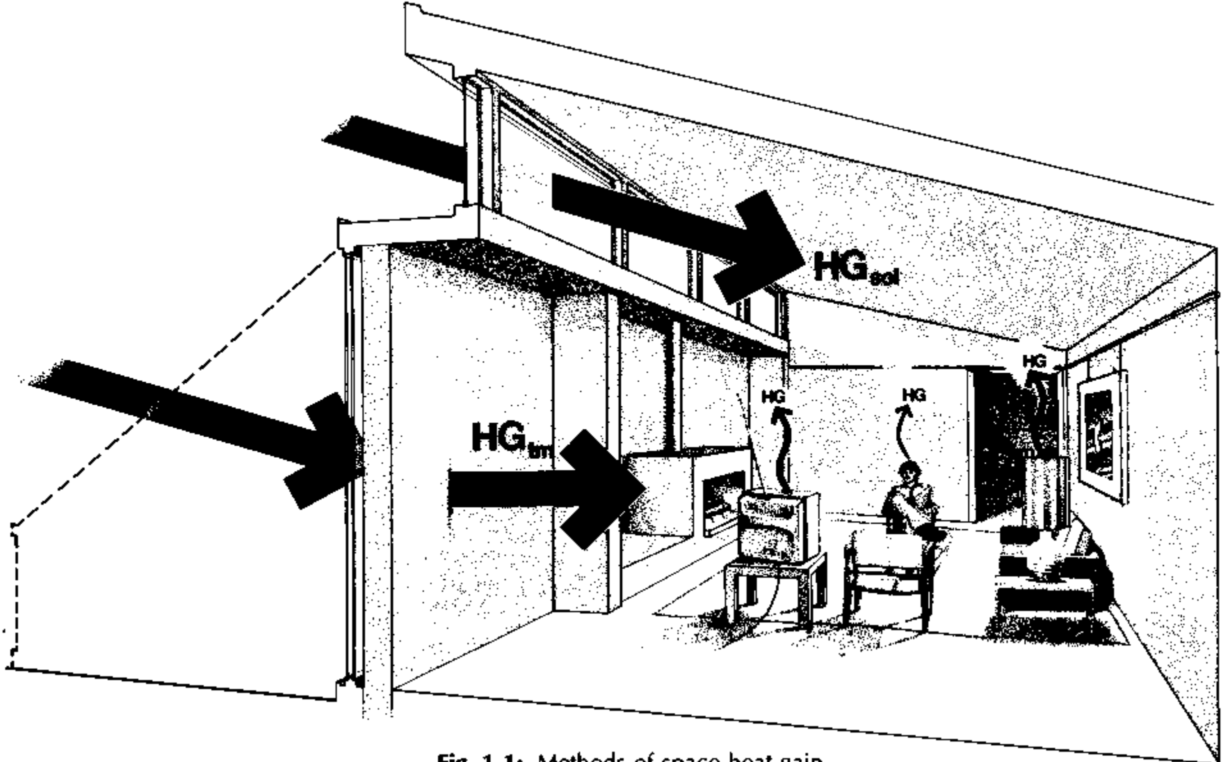


Fig. 1-1: Methods of space heat gain.

double pane glass during the month of January is 1,415 Btu/day or 1,506 × .94 (6% absorption loss) = 1,415. Knowing the solar heat gain through one square foot of window, the heat gain through an entire section of window (HG_{sol}) is calculated using the following equation:

$$HG_{sol} = A_{gl} \times I_t$$

where: A_{gl} = surface area of the unshaded portion of the glazing in square feet

I_t = solar heat gain through one square foot of glazing in Btu/day

One important note: This formula is used to calculate the *direct* solar heat gain in a space including greenhouses, attached or freestanding. The solar heat gain for glazing used with a reflector will be greater than the value given for I_t. Appendix 7 gives the percentage of enhancement of solar heat gain for different latitudes and reflector/collector tilt angles.

• *Heat Gain from a Thermal Storage Wall, Roof Pond or Attached Greenhouse (HG_{tm})*—The heat gain into a space from a thermal storage wall, roof pond or attached greenhouse (HG_{tm}) can be calculated using the following formula:

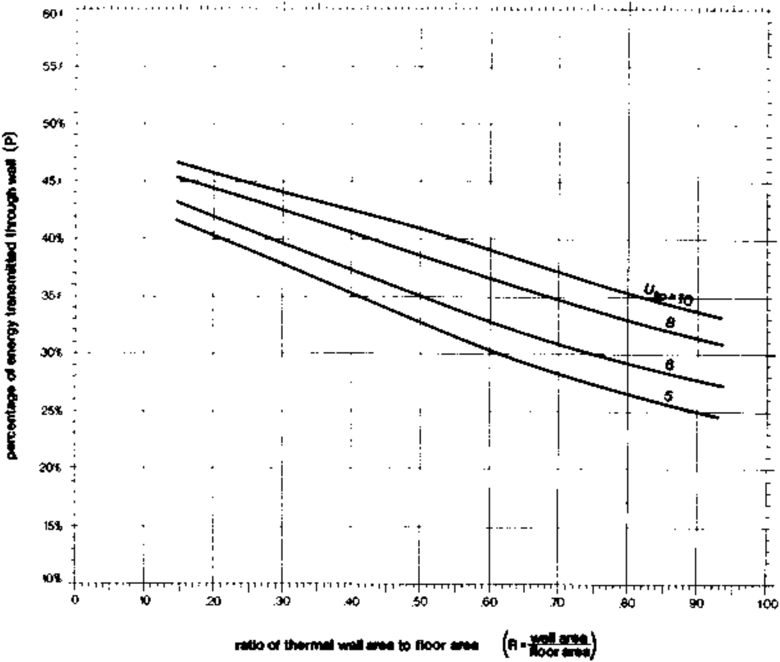
$$HG_{tm} = A_{gl} \times I_t \times P$$

where: A_{gl} = surface area of the unshaded portion of the glazing in square feet

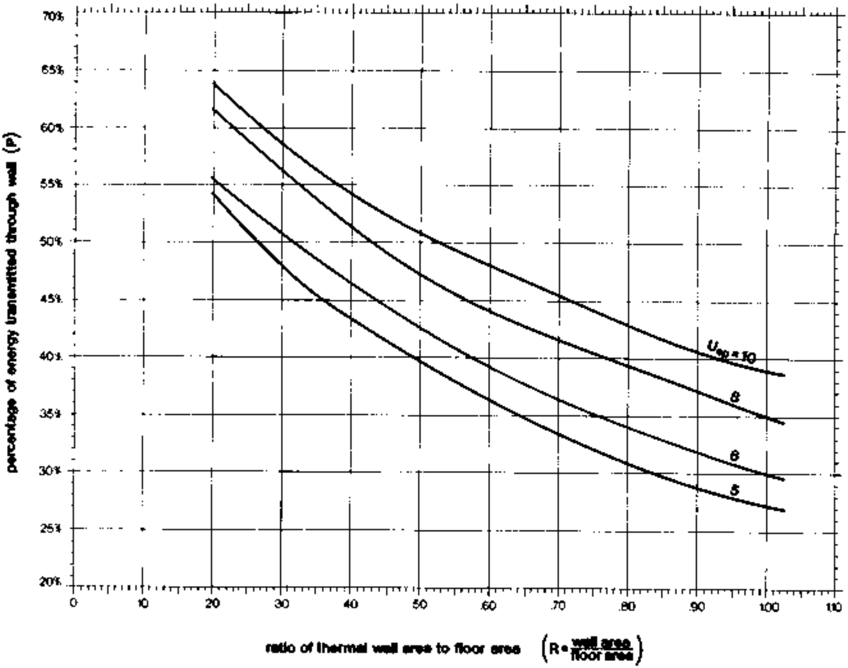
I_t = solar heat gain through one square foot of glazing in Btu/day

P = the percentage of incident energy on the face of a thermal wall or roof pond that is transferred to the space

Values of P for double-glazed thermal storage walls (black exterior wall surface color) and roof ponds are plotted for a variety of conditions in figure 1-2. To find the value of P, first determine the ratio of thermal wall or roof pond area to space floor area. For example, a 200-square-foot space with a 100-square-foot concrete thermal wall has a ratio of 100/200 or 0.50. Then, from .50 on the horizontal scale, follow a vertical line until it intersects the curve for the overall U value (U_{sp}) of the space you calculated in Step 1, Calculating Space Heat Loss in Winter. From this intersection move horizontally to the left and read the percentage of energy transmitted through the wall on the vertical scale. If, for example, the 200-square-foot space had an overall U value of 6 Btu/day-sq ft-°F, then P will equal 35% or 0.35. When using movable insulation over glazing at night, add 5% to the value of P.



CONCRETE THERMAL STORAGE WALL (1 FT THICK)



WATER THERMAL STORAGE WALL AND ROOF POND (ANY THICKNESS)

Fig. 1-2: Percentage of incident energy transferred through thermal storage walls and roof ponds.

Note: Graphs are plotted for storage walls with a black exterior surface color.

For a space adjacent to an attached greenhouse, the percentage of energy transferred through the common wall is difficult to predict because of the many variables involved in heat transfer between the spaces. In this case, only a very rough estimate can be given. Table 1-2 lists values of P for common walls constructed of either masonry or water. Select a value based on the overall rate of heat loss (U_{sp}) calculated for the greenhouse in Step 1.

Table 1-2 Percentage* of Energy (P) Transferred through the Common Wall between an Attached Greenhouse and Adjacent Space

Rate of Heat Loss from the Greenhouse U_{sp} (Btu/day-sq ft_{fl}-°F)	One-Foot-Thick Concrete Wall	Water Wall (all thicknesses)
24	22%	30%
36	17%	24%
48	14%	21%

NOTE: *For estimating purposes only. These percentages apply to a well-insulated space with a heat loss of 6 to 8 Btu/day-sq ft_{fl}-°F, and a thermal wall-to-glass-area ratio of approximately 1 to 1. The greenhouse side of the thermal wall is assumed to be a dark color, and in direct sunlight. If the wall is shaded or not in direct sunlight, the value of P will be considerably less.

Calculating Heat Gain

To find the total daily solar heat gain for each space, first establish the design-day conditions. An average sunny January day is a reasonable condition to illustrate a system's performance. For a Direct Gain System, using clear-day January values for solar heat gain through glass (I_t) from Appendix 6, calculate the heat gain through *each* unshaded skylight, clerestory and window opening:

$$HG_{sol} = I_t \times A_{gl}$$

The total space heat gain, in Btu's per day, is simply the sum of these values.

And, similarly, calculate the space heat gain, in Btu's per day, from a thermal storage wall, roof pond or wall adjacent to an attached greenhouse.

$$HG_{tm} = I_t \times A_{gl} \times P$$

When more than one system provides heat to a space, add the heat gains from each system to arrive at the total space heat gain.

To convert the total space heat gain into units that are convenient to use (Btu/day-sq ft_{fl}) simply divide HG_{sol} and HG_{tm} by the floor area of the space:

$$HG_{sp} = \frac{HG_{sol}}{A_{floor}} + \frac{HG_{tm}}{A_{floor}}$$

where: HG_{sp}= total space heat gain per square foot of floor area

Step 3.
Determining Average Indoor Temperature

After 1 to 3 days of similar weather conditions (clear or cloudy days in a row) a space will stabilize as a thermal system. This means that temperatures in the space remain roughly the same from day to day. Finding the daily average space temperature for this condition is relatively straightforward.

Using the rate of space heat loss (U_{sp}) and daily heat gain (HG_{sp}) calculated in Steps 1 and 2, the average daily indoor temperature (t_i) is found by dividing HG_{sp} by U_{sp} and adding the result to the average daily outdoor temperature (t_o)* for the design-day.

$$t_i = \frac{HG_{sp}}{U_{sp}} + t_o$$

where: HG_{sp} = rate of space heat gain in Btu/day-sq ft_{fl}

U_{sp} = rate of space heat loss in Btu/day-sq ft_{fl}-°F

t_o = average daily outdoor temperature

Remember that this calculation must be done for each space. The use of January clear-day solar radiation and temperature data is recommended as input, however, average indoor temperatures can be found for any month. Simply use solar heat gain and outdoor temperature data for the month you want to calculate.

Figure 1-3 presents a simple graphic method for calculating the average daily indoor temperature. Knowing the rate of space heat loss (U_{sp}) and daily heat gain (HG_{sp}), the graph can be used to determine the number of degrees the average indoor

*Average daily outdoor temperatures (t_o) for each month are given in Appendix 4.

temperature will be *above* the average outdoor temperature. Suppose, for example, a space located in New York City (average January temperature, 35°F) has a heat loss of 8 Btu/day-sq ft_{fl}-°F and a daily heat gain in January of 300 Btu/day-sq ft_{fl}. To determine the average indoor temperature for this condition, first follow a vertical line from 300 on the horizontal scale (HG_{sp}) to where it intersects the curve that represents the overall U value of the space (U_{sp} = 8). From this intersection draw a straight line to the scale on the left and read the number of degrees the average indoor air temperature will be above the average outdoor temperature; +38°F or, simply, the average indoor temperature is 35°F + 38°F or 73°F.

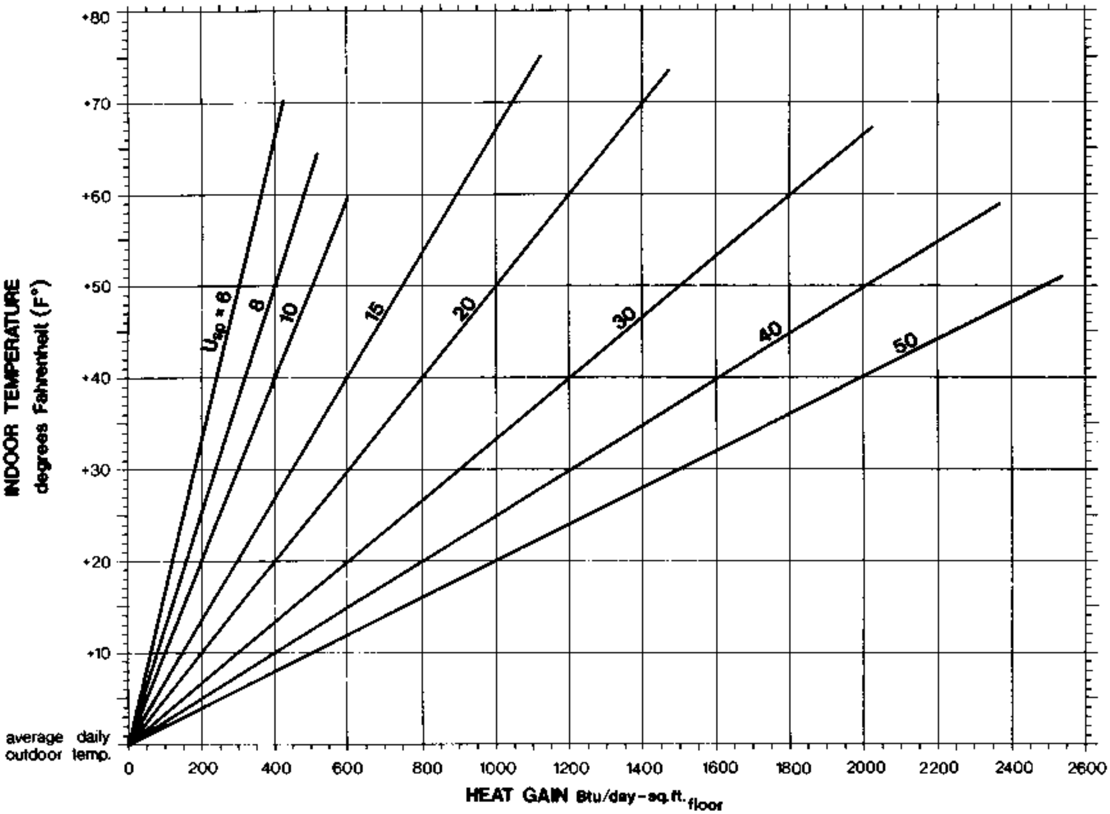


Fig. 1-3: Determining the average indoor temperature.

Until now only the heat gain from passive systems (the sun) has been considered. However, heat from lights, people and equipment can be considerable. In certain building types, like theaters and educational facilities, this heat gain is very complex and will not be discussed here. In a residence, though, these sources of heat are intermittent and do not appreciably affect indoor temperatures over the day. To account for this heat gain, add 2° to 4°F to the average daily indoor temperature. Although the average temperature will be slightly higher over the day, the nighttime low temperature in the space will not be affected since there is very little activity in a residence during the late evening and early morning hours.

Because of the complicated nature of building design, there is no ideal average indoor temperature, but as the average temperature approaches 70°F, enough heat is admitted into a space to supply it with all its heating needs for that day. If the average indoor temperature is too low, it can be raised by reducing the rate of space heat loss (U_{sp}), increasing the area of south-facing glass or supplying heat to the space from an auxiliary heating system.

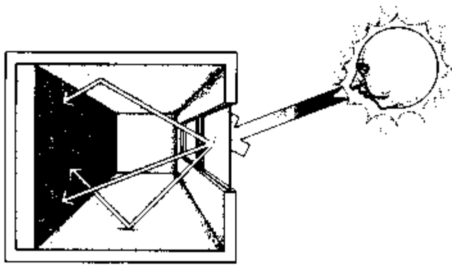
Step 4.
Determining Daily Space Temperature Fluctuations

Having a good idea of how a system will perform on a sunny winter day, the air temperature fluctuations in the space over that same day can now be determined. A space may have different heating requirements at various times of the day, depending upon occupant use. An office, for example, should be kept at about 70°F during working hours, but at night, when the space is not in use, it can be kept at a much lower temperature. It is, therefore, important to know at what time, and by how much, the indoor air temperature will swing above and below the daily average. In this way a system can be designed to meet the thermal requirements of a space.

The effect of thermal mass on indoor temperature fluctuations is explained at length for Direct Gain Systems in MASONRY HEAT STORAGE(11) and INTERIOR WATER WALL(12), for Thermal Storage Wall Systems in WALL DETAILS(14), for spaces adjacent to an attached greenhouse in GREENHOUSE CONNECTION(16), and for attached or freestanding greenhouses in GREENHOUSE DETAILS(20). But since indoor temperature fluctuations are not always symmetrical about the daily average (an equal number of degrees above and below the average), a series of graphs plotting hourly temperatures for a variety of systems (figs. 1-4, 5, 6, 7 and 8) is included in this appendix. To determine hourly indoor temperatures for a design-day, first select the graph that corresponds to your system. Then, using the average indoor temperature that you calculated in Step 3 as a reference point, plot the number of degrees the indoor air temperature is above or below the average for each hour.

Direct Gain System

• *Masonry Heat Storage*—Since the relationship between sunlight and thermal mass greatly influences indoor air temperatures, two cases, each representing a different relationship, are presented in figure 1-4. Choose the case that most clearly rep-



CASE 1

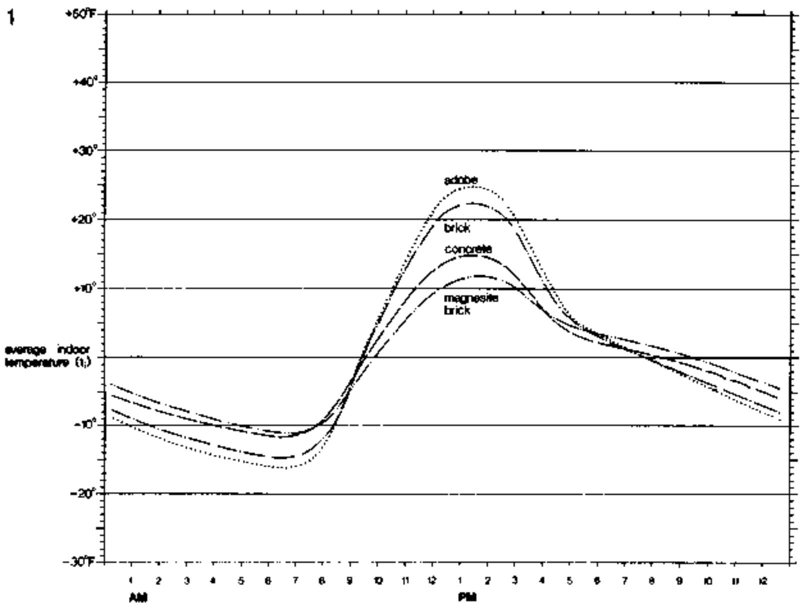
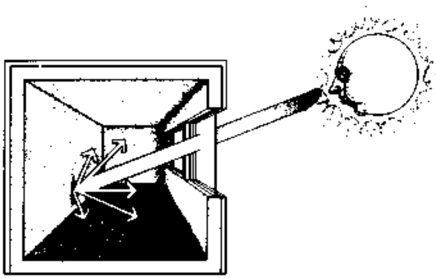
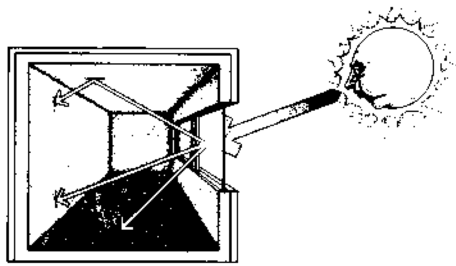


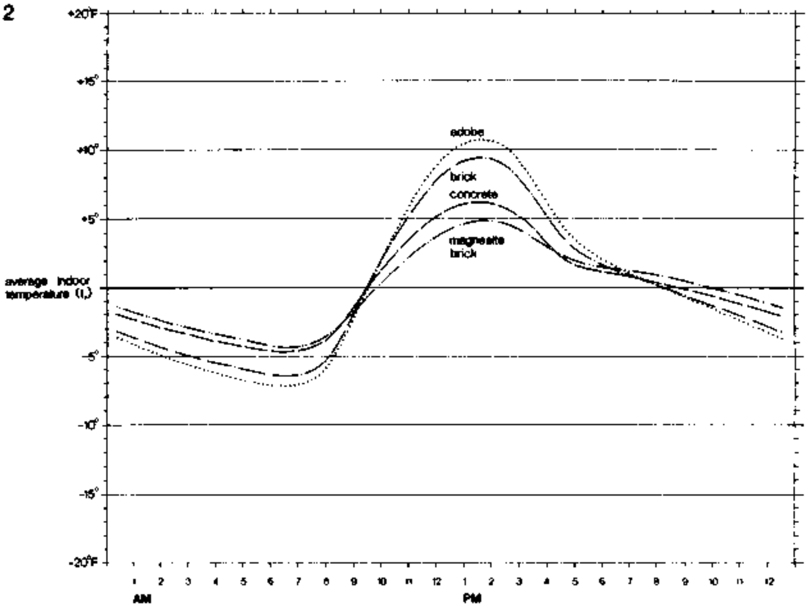
Fig. 1-4: Hourly indoor temperatures for direct gain systems with masonry heat storage (here and on next page).

resents the way sunlight interacts with masonry located in the space. A graph corresponding to each case gives hourly indoor temperatures above and below the daily average (t_i) for four masonry materials. If a space falls between the two cases, then interpolate between the graphs plotted for each case. Also, it is probable that a space may not be constructed of just one material. Therefore, when more than one material is used, for example, concrete walls and a brick floor, take the hourly temperature somewhere between the values given for each material.





CASE 2



• *Interior Water Wall*—In the case of an interior water wall, the volume of water in direct sunlight is the major determinant of space temperature fluctuations over the day. Figure 1-5 plots indoor temperatures for various quantities of water per square foot of south-facing glass. To compute this value, simply take the volume of water (cu ft) in the space and divide it by the area of south-facing glass (sq ft). One important note: The surface of the water wall is assumed to be a dark color. If the wall is painted a light color, then air temperature fluctuations in the space will be higher than those given.

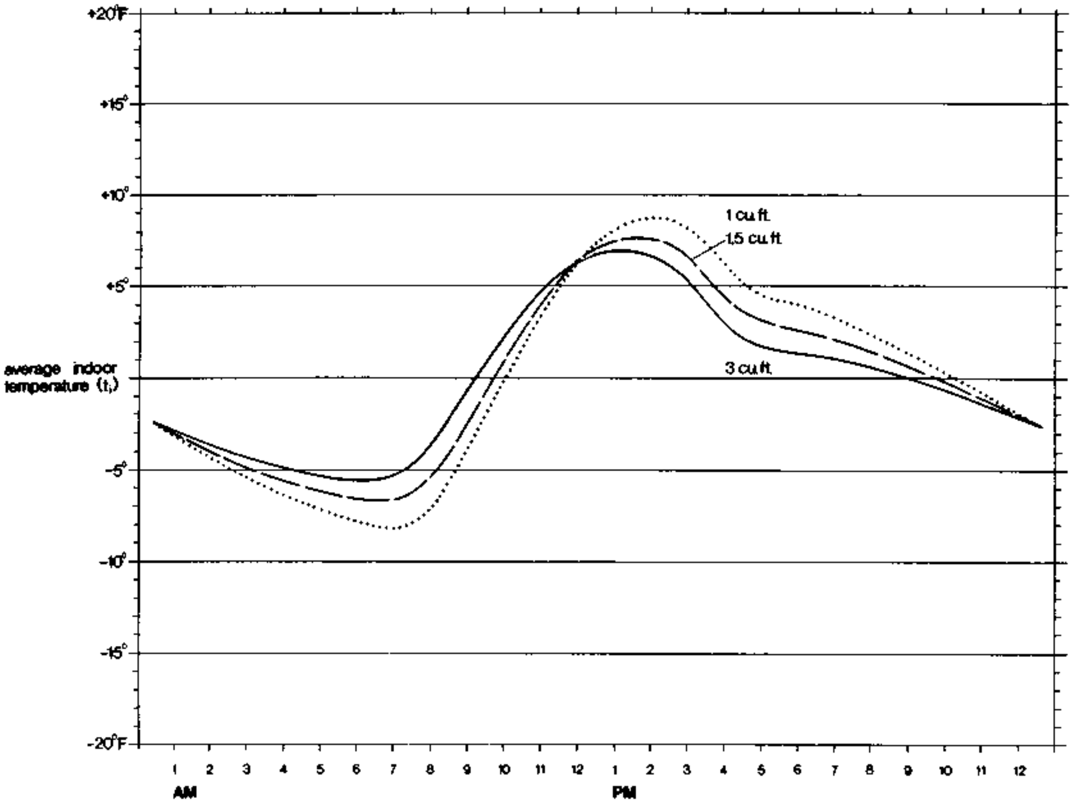
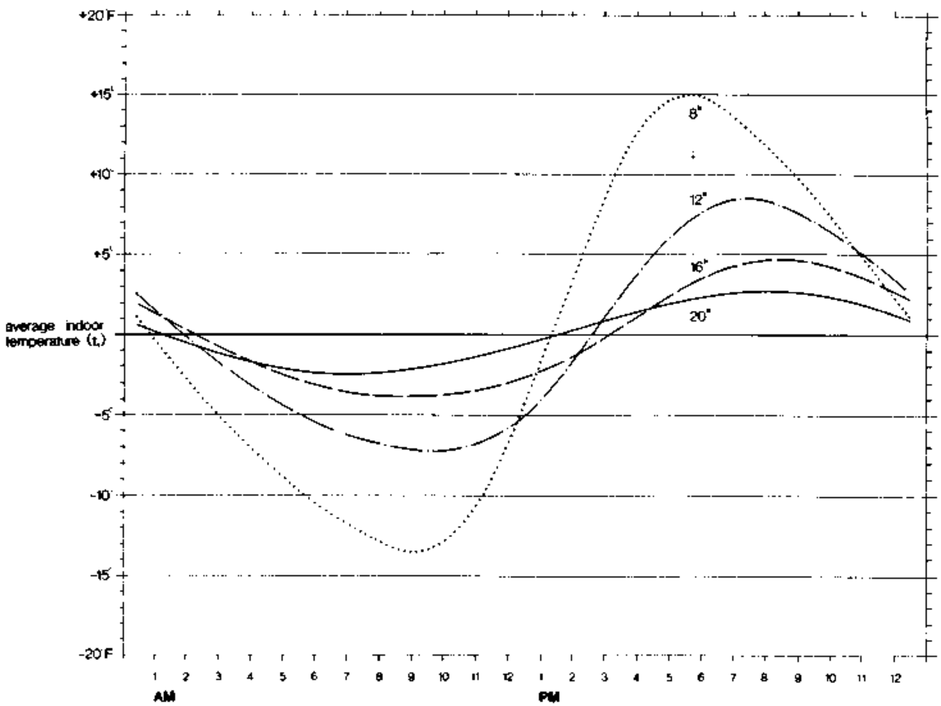


Fig. 1-5: Hourly indoor temperatures for direct gain systems with various volumes of water storage per square foot of south-facing glass.

Thermal Storage Wall System and Spaces Adjacent to an Attached Greenhouse

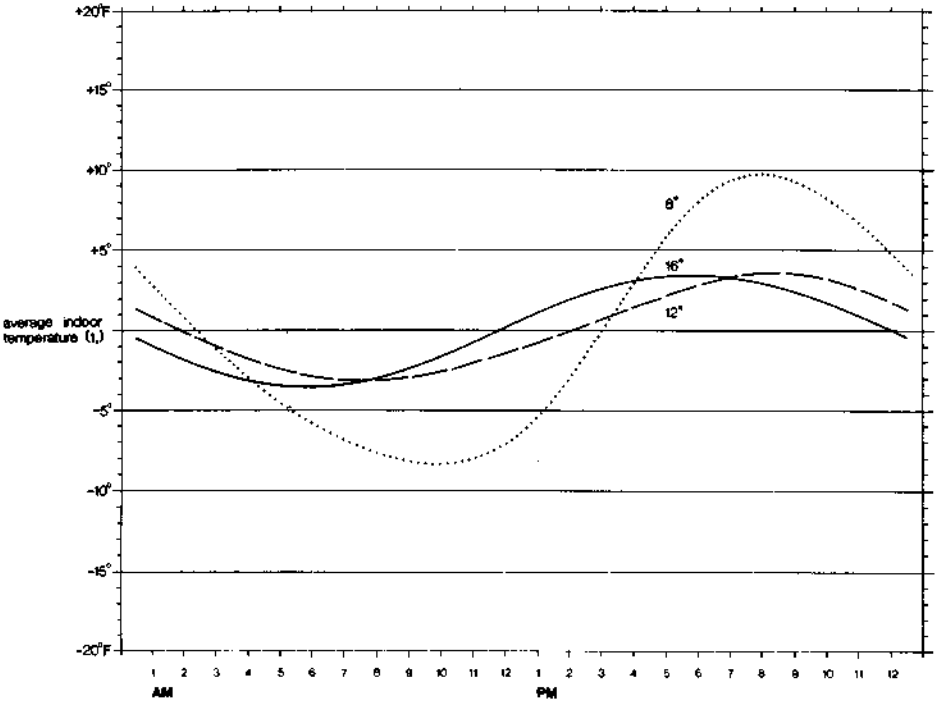
The material used to construct a thermal storage wall and the thickness of the wall are the major influences on indoor air temperature fluctuations. Figure 1-6 graphs indoor air temperatures for various thicknesses of four commonly used wall materials: concrete, brick, adobe and water. Daytime temperatures can be increased above those indicated on the graphs if warm air from the greenhouse or face of a masonry thermal wall is allowed to circulate into the space. However, nighttime temperatures in the space will remain the same. Notice that maximum and minimum space temperatures are reached at different times of the day for different thicknesses of wall.



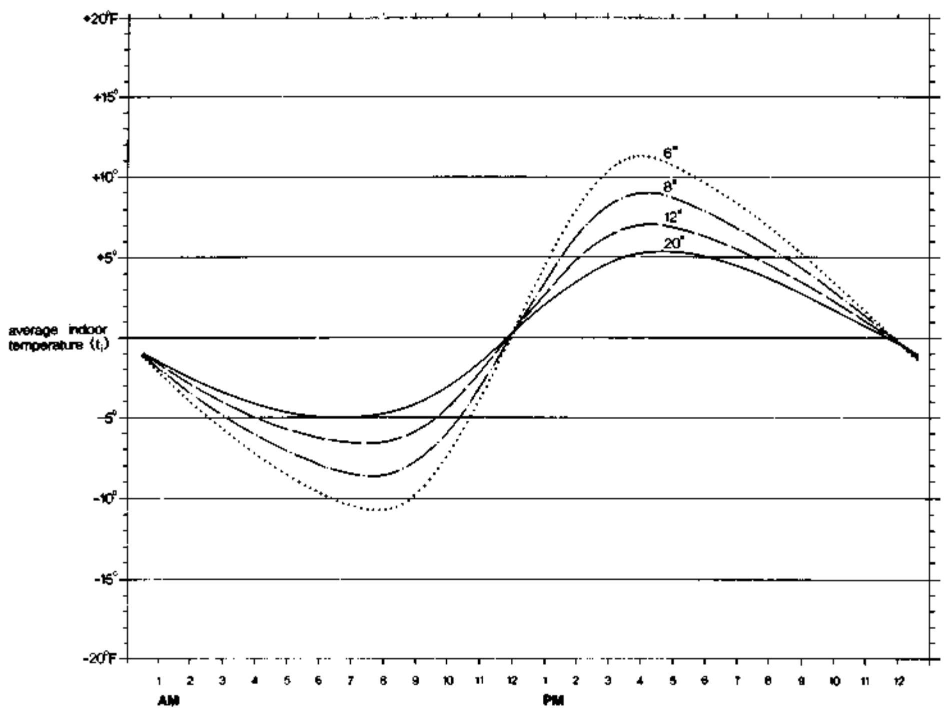
CONCRETE WALL

Fig. 1-6: Hourly indoor temperatures for thermal storage walls of various thicknesses (here and next two pages).

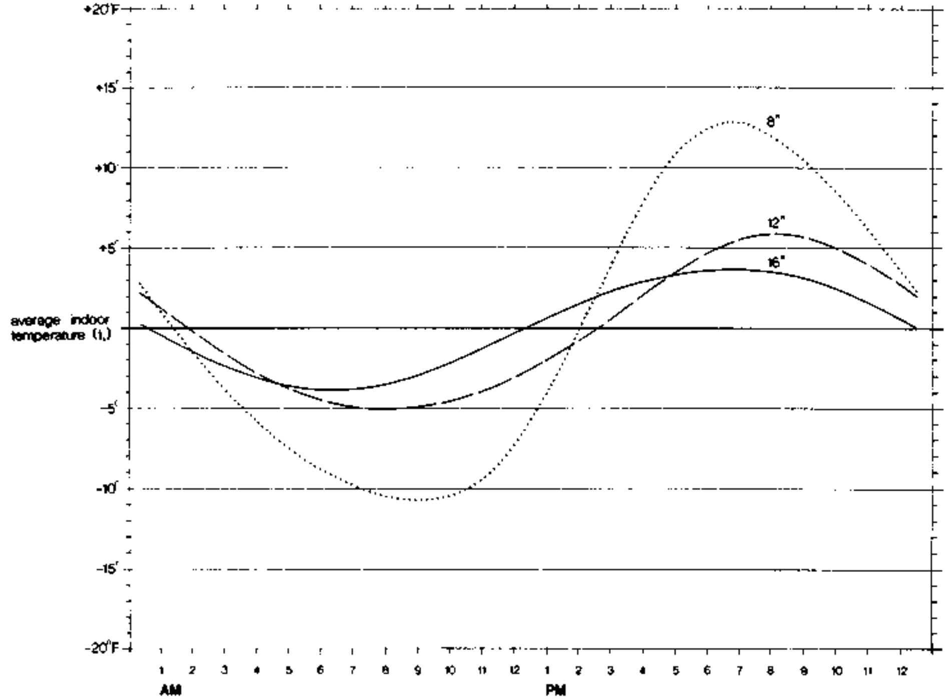
Note: Temperature fluctuations will be less if additional mass is located in the space, i.e., a masonry wall and floor.



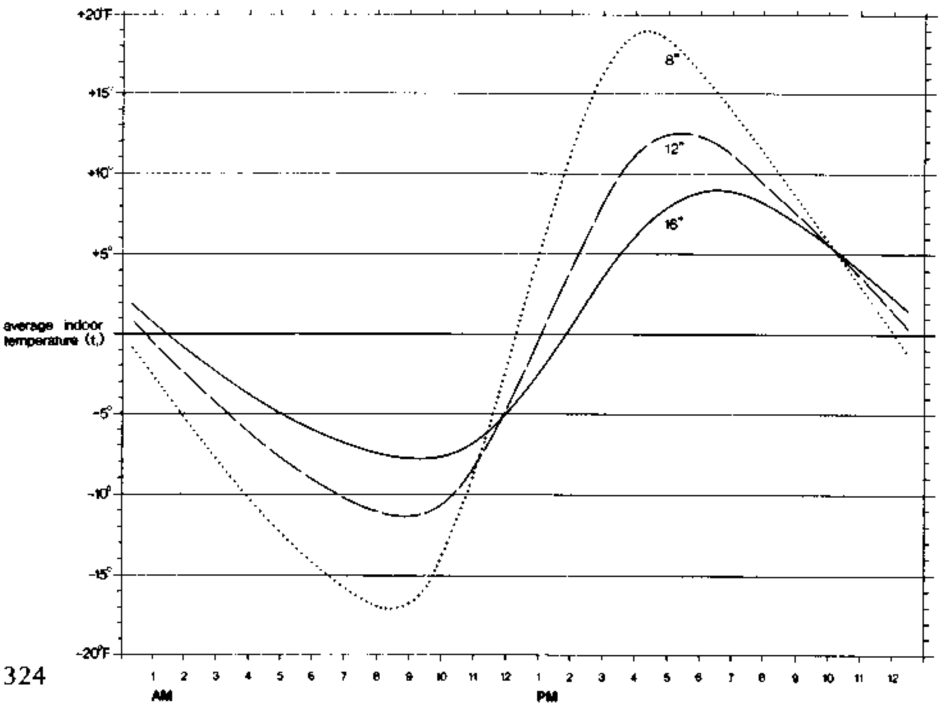
ADOBE WALL



WATER WALL



BRICK WALL



MAGNESITE BRICK WALL

Roof Pond System

Space temperature fluctuations for a Roof Pond System are proportional to the depth of the pond. As the depth increases, the fluctuation decreases. Figure 1-7 plots hourly indoor temperatures for various depths of roof ponds.

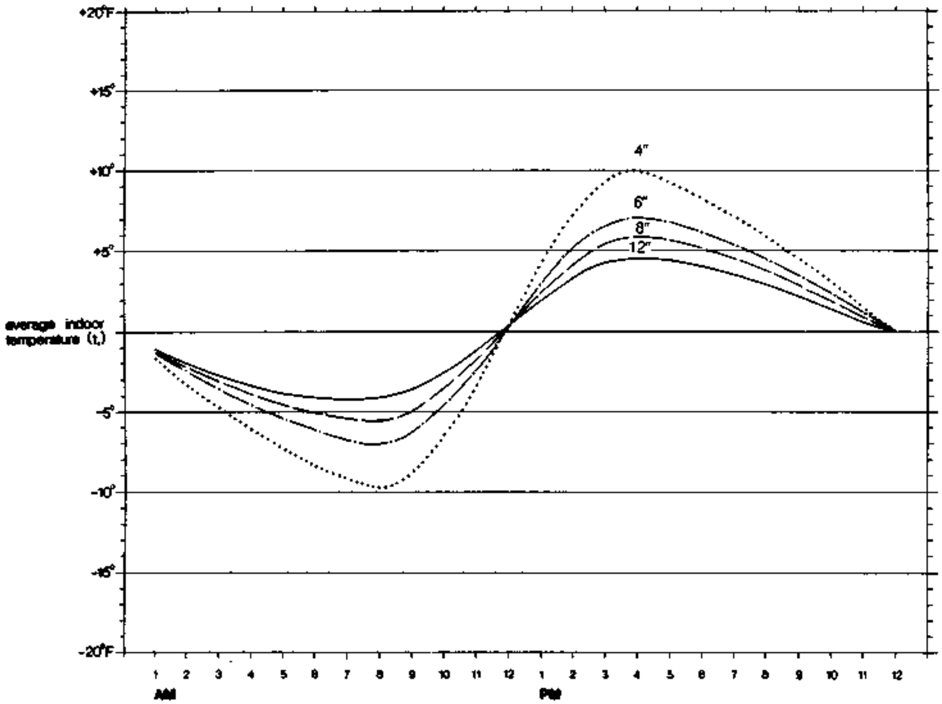


Fig. 1-7: Hourly indoor temperatures for roof ponds of various depths.

Note: Temperature fluctuations will be less if additional mass is located in the space, i.e., a masonry floor.

Greenhouse (attached or freestanding)

• *Solid Masonry Walls and Floor*—In a greenhouse constructed of solid masonry walls and/or floor, many factors influence indoor temperature fluctuations. The rate of greenhouse heat loss, the area of south-facing glass and the type of masonry material all contribute to the extent of greenhouse temperature fluctuations. All this implies that it is virtually impossible to generate a simple graph to predict indoor hourly temperatures. In this case, the daily range of indoor fluctuations for various greenhouse conditions can only be estimated—GREENHOUSE DETAILS(20).

• *Water Storage Wall*—Since a greenhouse is essentially a Direct Gain System, the quantity of water in the greenhouse (in direct sunlight) largely determines the indoor temperature fluctuations. Figure 1-8 graphs hourly indoor temperatures for various quantities of water (cu ft) per square foot of south-facing greenhouse glass. The

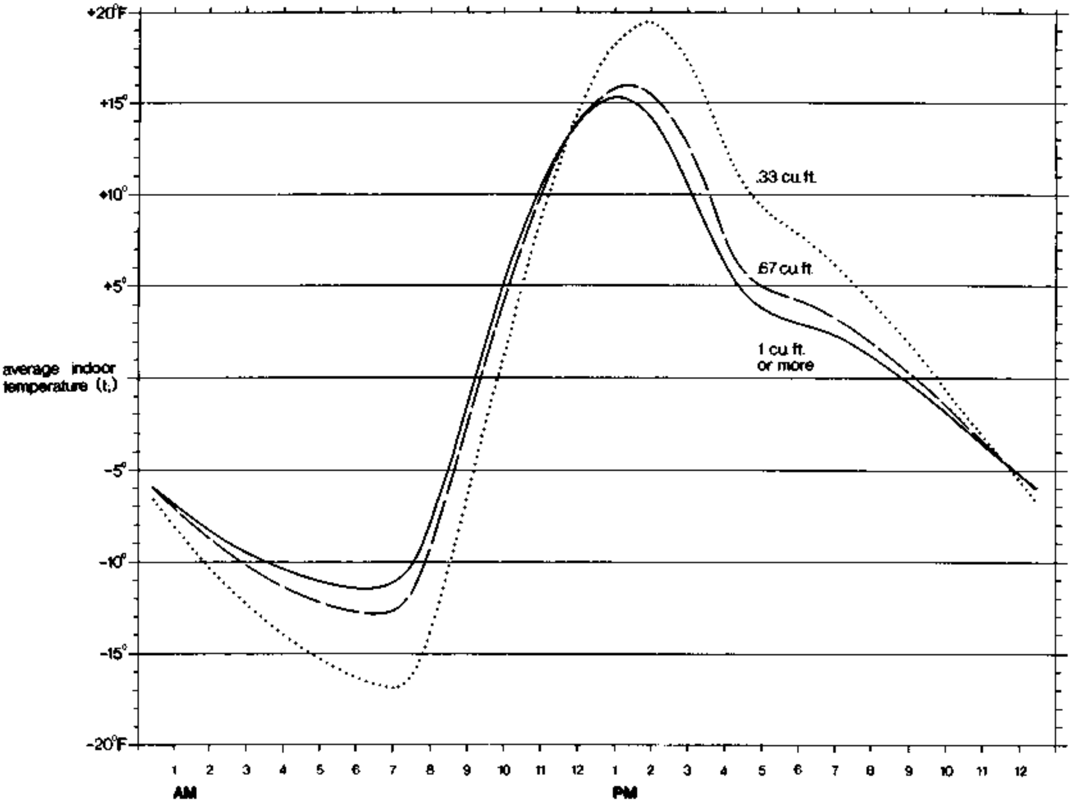


Fig. 1-8: Hourly greenhouse temperatures for various volumes of water storage per square foot of south-facing glass.

exposed surface of the water wall is assumed to be a dark color and in direct sunlight most of the day.

One final word about indoor temperature fluctuations. Figures 1-4 through 8 plot hourly temperatures for a space with no additional thermal mass other than that indicated for the system. If additional mass is located in a space, then fluctuations will be less than those graphed. For instance, a space constructed of lightweight materials (wood frame) with an 8-inch Thermal Water Wall System will have a daily temperature fluctuation of approximately 12°F (from fig. 1-6). If the entire space were constructed of masonry materials (walls and floor), then the daily fluctuation might be only 5° or 6°F. As a general rule, additional thermal mass distributed in a space will reduce indoor temperature fluctuations from those indicated on the graphs.

Step 5. Calculating Auxiliary Space Heating Requirements

The auxiliary energy required to heat a space is the amount needed, in addition to that provided by the solar system, to keep the space at a desired temperature (usually 70°F). The auxiliary energy requirement (Q_{aux}) is estimated on an annual basis for the entire building. It can be calculated by the equation:

$$Q_{aux} = Q_{r\ year} - Q_{c\ year}$$

where: $Q_{r\ year}$ = annual space heating requirements in Btu's

$Q_{c\ year}$ = annual solar heating contribution in Btu's

Annual Space Heating Requirements ($Q_{r\ year}$)

To determine the annual space heating requirements in Btu's, multiply the overall space U value by the floor area of the space and the number of heating degree-days* for the year:

$$Q_{r\ year} = U_{sp} \times A_{floor} \times DD_{year}$$

*Experience has shown that the heating requirements of a space kept at approximately 70°F is directly proportional to the number of degrees the average daily outside temperature falls below 65°F. The degree-day is based on this fact. Thus, the number of degree-days per day is the number of degrees the average outdoor temperature is below 65°F or, to put it another way, the number of degree-days *for a given day* equals 65°F minus the daily average outdoor temperature. The number of degree-days for a longer period of time is then the sum of the degree-days for each day in that period.

where: U_{sp} = rate of space heat loss in Btu/day-sq ft_{fl}-°F

A_{floor} = floor area of the space in square feet

DD_{year} = degree-days per year

Degree-days for major cities in United States and Canada are given in Appendix 5.

Annual Solar Heating Contribution ($Q_{c\ year}$) for Thermal Storage Walls, Roof Ponds and Direct Gain Systems*

Three computations are necessary to determine the annual solar heating contribution for passive systems:

a. Calculating the space Load Collector Ratio
b. Determining the fraction of the total yearly space heating requirement supplied by solar energy
c. Computing the annual solar heating contribution in Btu's.

• a. *Load Collector Ratio (LCR)*

The LCR is calculated by the formula:

$$LCR = \frac{U_{sp} \times A_{floor}}{\text{solar collection area (sq ft)}}$$

where: U_{sp} = rate of space heat loss in Btu/day-sq ft_{fl}-°F (exclusive of the south glazing)

A_{floor} = floor area of the space in sq ft

solar collection area = the actual solar collection arperture

• b. *Fraction of the Total Yearly Space Heating Requirement Supplied by Solar Energy (SHF)*—Table 1-3 lists by city the estimated fraction of the total yearly space heating requirement supplied by solar energy (SHF) for properly sized water and masonry thermal storage walls, roof ponds and direct gain systems, with and without night insulation (R=10). Locate the city and system type of interest in the table. If the LCR calculated above is exactly one of the values listed in the table, then read the corresponding SHF. If the LCR does not exactly match one of the values listed, then interpolate between the two closest values.

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*Adapted from J. D. Balcomb and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type." *Proceedings of the Second National Passive Solar Conference*, Philadelphia, March 16–18, 1978.

• c. *Annual Solar Heating Contribution* ($Q_{c\ year}$) *in Btu's*—To compute the annual solar heating contribution in Btu's, multiply $Q_{r\ year}$ by the fraction of the total yearly space heating requirement supplied by solar energy determined in the previous computation:

$$Q_{c\ year} = Q_{r\ year} \times SHF$$

Table 1-3 Fraction of the Total Yearly Space Heating Requirement Supplied by Solar Energy

DD = degree-days
WW = water wall, roof pond or direct gain
WWNI = water wall, roof pond or direct gain with night insulation
TW = masonry thermal storage wall (Trombe)
TWNI = masonry thermal storage wall (Trombe) with night insulation

Page, Ariz.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	196	88	54	37	27	19	13	7	
6,632 DD	WWNI	312	145	91	65	49	38	29	22	15
	TW	195	94	56	37	25	17	11	6	
37°N	TWNI	304	141	89	63	46	35	26	18	12
Phoenix, Ariz.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	626	294	188	135	102	78	60	44	29
1,765 DD	WWNI	863	407	261	189	145	114	90	69	49
	TW	577	287	179	123	88	64	47	33	21
33°N	TWNI	819	386	247	176	132	101	76	56	38
Tucson, Ariz.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	631	291	184	132	100	77	59	43	29
1,800 DD	WWNI	871	403	256	185	142	112	89	68	49
	TW	578	284	176	121	87	63	46	33	21
32°N	TWNI	825	383	243	173	130	99	75	56	38
Little Rock, Ark.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	239	108	66	46	33	24	17	11	
3,219 DD	WWNI	365	172	107	76	57	44	35	26	18
	TW	232	112	67	44	30	21	14	9	
35°N	TWNI	356	165	103	73	54	40	30	22	14

Sault St. Marie, Mich.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	100	40	21	11					
9,048 DD	WWNI	193	87	53	36	26	19	13	9	5
	TW	110	49	26	15	7				
46°N	TWNI	192	87	53	36	25	18	13	8	4
St. Cloud, Minn.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	96	39	21	11					
8,879 DD	WWNI	189	85	52	36	26	19	14	9	5
	TW	108	48	26	15	7				
46°N	TWNI	189	86	52	36	25	18	13	8	5
Columbia, Mo.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	175	77	46	31	21	14	8		
5,046 DD	WWNI	287	133	82	57	43	33	25	18	12
	TW	177	83	49	31	20	13	8		
39°N	TWNI	281	129	80	55	41	30	22	15	10
Glasgow, Mont.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	168	75	44	29	19	12	6		
8,996 DD	WWNI	277	130	81	56	41	31	23	17	10
	TW	171	80	47	30	19	12	7		
48°N	TWNI	272	126	78	54	39	29	21	14	9
Great Falls, Mont.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	143	63	37	23	14	8			
7,750 DD	WWNI	246	115	71	49	36	27	20	14	8
	TW	149	69	40	25	15	9			
47°N	TWNI	243	112	69	48	34	25	18	12	7
Lincoln, Nebr.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	175	77	45	30	21	14	8		
5,864 DD	WWNI	288	133	82	57	42	33	25	18	12
	TW	176	83	48	31	20	13	8		
41°N	TWNI	280	129	79	55	40	30	22	16	10
Ely, Nev.	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	172	80	50	35	25	18	12	6	
7,733 DD	WWNI	282	134	85	61	47	36	28	21	14
	TW	178	86	52	34	23	16	10	6	
39°N	TWNI	277	131	83	59	44	33	25	18	11

Step 6. Determining Cost Effectiveness*

The important economic consideration when designing a passive solar heated building is the trade-off between the cost of extra thermal mass and movable insulation (less the installed cost of the conventional construction it replaces) and the future cost of the fuel saved by the system over its lifetime. Operating and maintenance cost must also be included; however, for most passive systems this cost is negligible. The cost of solar heat can be estimated by the following formula:

$$\text{cost of solar heat} = \frac{\begin{pmatrix}\text{solar} & & \\ \text{system} & \times & \text{capital recovery} \\ \text{cost} & & \text{factor}\end{pmatrix} + \begin{matrix}\text{annual operating} \\ \text{and maintenance} \\ \text{cost}\end{matrix}}{\text{annual solar heating contribution } (Q_{c\ year})}$$

---

*Adapted from Los Alamos Scientific Laboratory, *Pacific Regional Solar Heating Handbook*. ERDA, San Francisco, California, 1976.

The *capital recovery factor* is determined from bankers' tables or formulas. It is defined as the value of capital to the individual. It may be the interest rate that your money would earn if you invested it, or the annual cost of a loan made to finance the extra cost of the passive system. For example, the capital recovery factor of a 10% 30-year loan is 0.106.

To illustrate the use of the formula, if we assume, for example, that

—the passive solar heating system costs $5,000 above installed conventional construction costs,

—the capital recovery factor is 0.106 for a 30-year loan at 10% interest,

—the operating and maintenance cost for the system is $25 a year, and

—the annual solar heating contribution is 100 million Btu's,

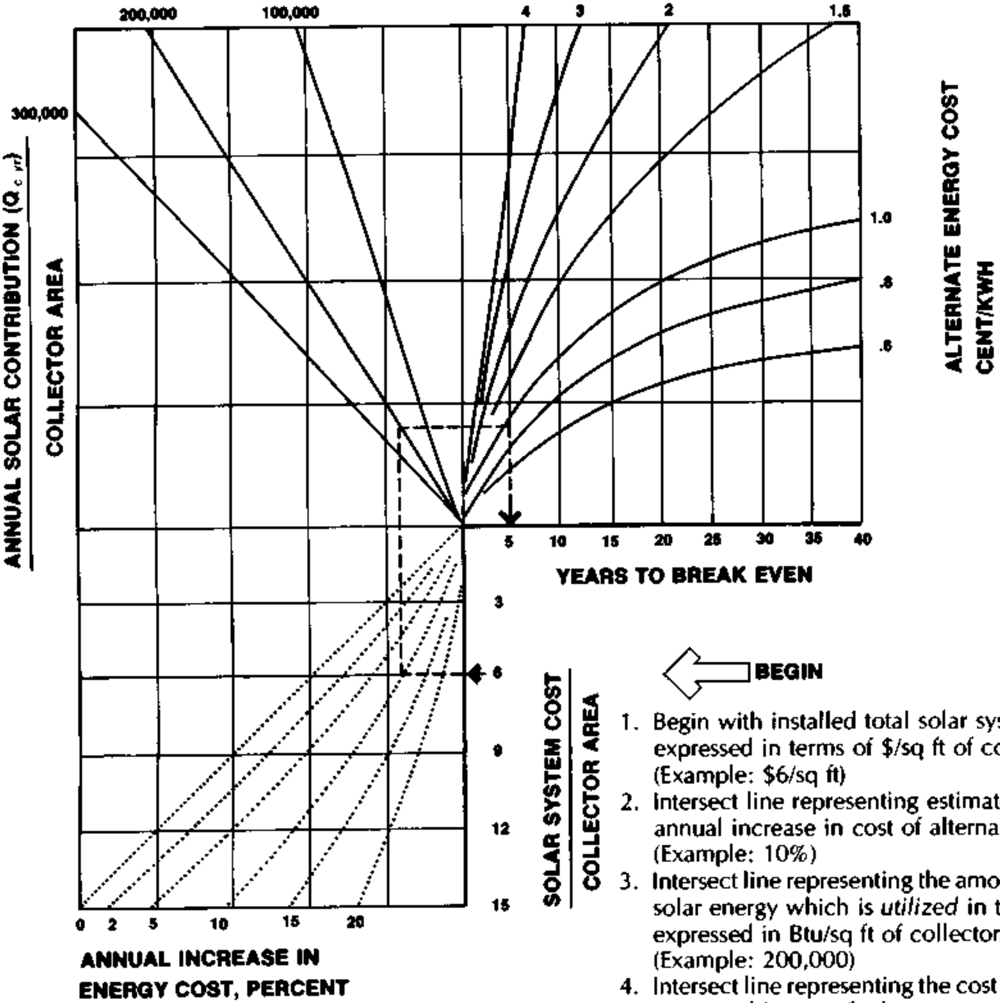
from the formula, the cost of solar heat is then:

$$\text{cost of solar heat} = \frac{(\$5{,}000 \times 0.106) + \$25}{100 \text{ million Btu's}}$$

$$= \$5.55 \text{ per million Btu's.}$$

This figure does not take into account considerations that would make the cost less expensive, such as tax incentives, deduction of interest payments and business depreciation, or considerations that can make it more expensive, such as property tax evaluation increases and fuel cost deductions (business expense).

Another method for calculating the cost effectiveness of a system is the nomograph in figure 1-9. This method allows for the increase in future annual fuel costs to be included in the procedure. By plotting the cost of the system, the annual projected increase in energy costs, the annual solar heating contribution and the cost of conventional fuel, the nomograph computes the break-even time on the system's initial cost.



1. Begin with installed total solar system cost, expressed in terms of $/sq ft of collector. (Example: $6/sq ft)
2. Intersect line representing estimated average annual increase in cost of alternate fuels. (Example: 10%)
3. Intersect line representing the amount of collected solar energy which is *utilized* in the building, expressed in Btu/sq ft of collector/year. (Example: 200,000)
4. Intersect line representing the cost of alternate fuels expressed in cents/kwh. (Example: Gas at 1.0 cent/kwh)
5. Read the number of years to break even on the initial investment. (Example: 5 years)

Based on 8% interest, 1% maintenance/year.

Fig. 1-9: Solar system cost nomograph.

Source: Adapted from GSA, "Energy Conservation Design Guidelines for New Office Buildings," as quoted by P.D. Maycock in "Solar Energy: The Outlook for Widespread Commercialization of Solar Heating and Cooling," ERDA.

Table 1-4 Capital Recovery Factors

Years	Interest Rate						
	5½%	6%	7%	8%	10%	12%	15%
1	1.055 00	1.060 00	1.070 00	1.080 00	1.100 00	1.120 00	1.150 00
2	0.541 62	0.545 44	0.553 09	0.560 77	0.576 19	0.591 70	0.615 12
3	0.370 65	0.374 11	0.381 05	0.388 03	0.402 11	0.416 35	0.437 98
4	0.285 29	0.288 59	0.295 23	0.301 92	0.315 47	0.329 23	0.350 27
5	0.234 18	0.237 40	0.243 89	0.250 46	0.263 80	0.277 41	0.298 32
6	0.200 18	0.203 36	0.209 80	0.216 32	0.229 61	0.243 23	0.264 24
7	0.175 96	0.179 14	0.185 55	0.192 07	0.205 41	0.219 12	0.240 36
8	0.157 86	0.161 04	0.167 47	0.174 01	0.187 44	0.201 30	0.222 85
9	0.143 84	0.147 02	0.153 49	0.160 08	0.173 64	0.187 68	0.209 57
10	0.132 67	0.135 87	0.142 38	0.149 03	0.162 75	0.176 98	0.199 25
11	0.123 57	0.126 79	0.133 36	0.140 08	0.153 96	0.168 42	0.191 07
12	0.116 03	0.119 28	0.125 90	0.132 70	0.146 76	0.161 44	0.184 48
13	0.109 68	0.112 96	0.119 65	0.126 52	0.140 78	0.155 68	0.179 11
14	0.104 28	0.107 58	0.114 34	0.121 30	0.135 75	0.150 87	0.174 69
15	0.099 63	0.102 96	0.109 79	0.116 83	0.131 47	0.146 82	0.171 02
16	0.095 58	0.098 95	0.105 86	0.112 98	0.127 82	0.143 39	0.167 95
17	0.092 04	0.095 44	0.102 43	0.109 63	0.124 66	0.140 46	0.165 37
18	0.088 92	0.092 36	0.099 41	0.106 70	0.121 93	0.137 94	0.163 19
19	0.086 15	0.089 62	0.096 75	0.104 13	0.119 55	0.135 76	0.161 34
20	0.083 68	0.087 18	0.094 39	0.101 85	0.117 46	0.133 88	0.159 76
21	0.081 46	0.085 00	0.092 29	0.099 83	0.115 62	0.132 24	0.158 42
22	0.079 47	0.083 05	0.090 41	0.098 03	0.114 01	0.130 81	0.157 27
23	0.077 67	0.081 28	0.088 71	0.096 42	0.112 57	0.129 56	0.156 28
24	0.076 04	0.079 68	0.087 19	0.094 98	0.111 30	0.128 46	0.155 43
25	0.074 55	0.078 23	0.085 81	0.093 68	0.110 17	0.127 50	0.154 70
26	0.073 19	0.076 90	0.084 56	0.092 51	0.109 16	0.126 65	0.154 07
27	0.071 95	0.075 70	0.083 43	0.091 45	0.108 26	0.125 90	0.153 53
28	0.070 81	0.074 59	0.082 39	0.090 49	0.107 45	0.125 24	0.153 06
29	0.069 77	0.073 58	0.081 45	0.089 62	0.106 73	0.124 66	0.152 65
30	0.068 81	0.072 65	0.080 59	0.088 83	0.106 08	0.124 14	0.152 30
31	0.067 92	0.071 79	0.079 80	0.088 11	0.105 50	1.123 69	0.152 00
32	0.067 10	0.071 00	0.079 07	0.087 45	0.104 97	0.123 28	0.151 73
33	0.066 33	0.070 27	0.078 41	0.086 85	0.104 50	0.122 92	0.151 50
34	0.065 63	0.069 60	0.077 80	0.086 30	0.104 07	0.122 60	0.151 31
35	0.064 97	0.068 97	0.077 23	0.085 80	0.103 69	0.122 32	0.151 13

Solar Home Book. Anderson, Riordan. Cheshire Bks USA 1976. 0-917352-01-7.

Solar Position

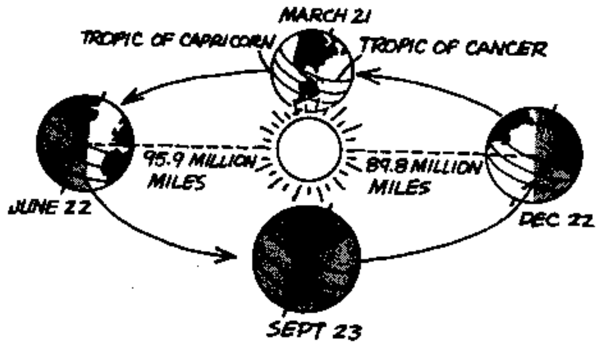
Most people have probably noticed that the sun is higher in the sky in snmmer than in winter. Some also realize that it rises south of due east in winter and north of due east in summer. Each day the sun travels in a circular path across the sky, reaching its highest point at noon. As winter proceeds into spring and summer, this circular path moves higher in the sky. The sun rises earlier in the day and sets later.

The actual position of the sun in the sky depends upon the latitude of the observer. At noon on March 21 and September 23, the vernal and autumnal *equinoxes*, the sun is directly overhead at the equator. At 40°N latitude, however, its angle above the horizon is 50° (= 90° − 40°). By noon on June 22, the summer *solstice* in the Northern Hemisphere, the sun is directly overhead at the Tropic of Cancer, 23½°N latitude. Its angle above the horizon at 40°N is 73½° (= 90° + 23½° − 40°), the highest it gets at this latitude. At noon on December 22, the sun is directly overhead at the Tropic of Capricorn, and its angle above the horizon at 40°N latitude is only 26½°.

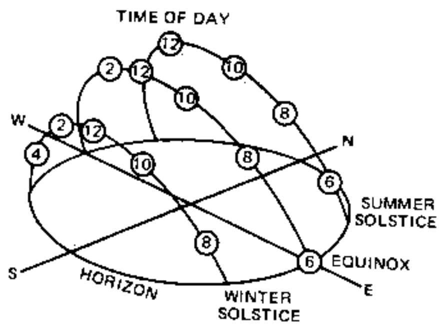
A more exact description of the sun's position is needed for most applications. In the language of trigonometry, this position is expressed by the values of two angles—the solar *altitude* and the solar *azimuth*. The solar altitude θ is measured up from the horizon to the sun, while the solar azimuth ϕ is the angular deviation from true south.

These angles need not be excessively mysterious—you can make a rough measurement of them with your own body. Stand facing the sun with one hand pointing toward it and the other pointing due south. Now drop the first hand so that it points to the horizon directly below the sun. The angle that your arm drops is the solar altitude θ and the angle between your arms in the final position is the solar azimuth ϕ. Much better accuracy can be obtained with better instruments, but the measurement process is essentially the same.

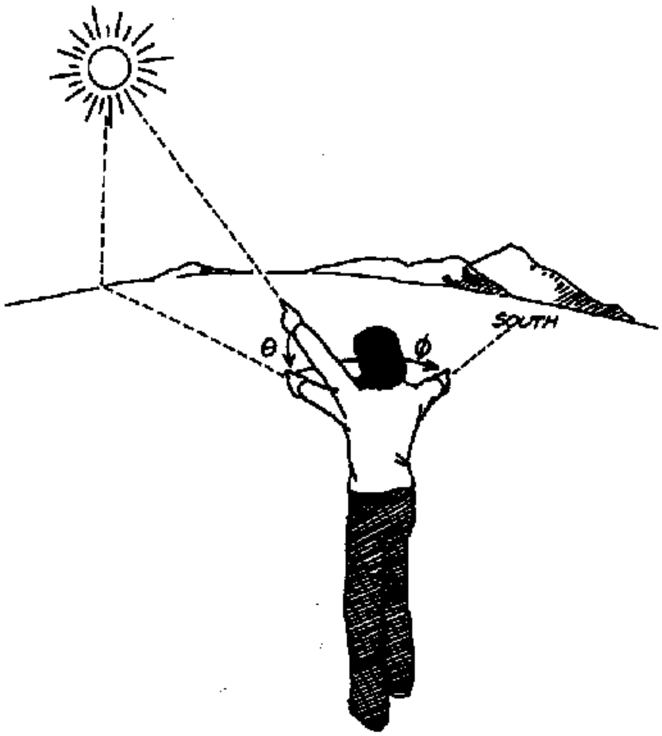
The solar altitude and azimuth can be calculated for any day, time, and latitude. For 40°N latitude (Philadelphia, for example),



The earth's elliptical path around the sun. The tilt of the earth's axis results in the seasons of the year.



The sun's daily path across the sky. The sun is higher in the sky in summer than in winter due to the tilt of the earth's axis.



Measuring the sun's position. The solar altitude θ is the angle between the sun and the horizon, and the azimuth ϕ is measured from true south.

the values of θ and ϕ are given at each hour for the 21st day of each month in the accompanying table. Note that ϕ is always zero at solar noon and that θ varies from 26.6° at noon on December 21 to 73.5° at noon on June 21. You can find similar data for latitudes 24°N, 32°N, 48°N, 56°N, and 64°N in the tables titled "Clear Day Insolation Data" in Appendix 1. This appendix also shows you how to calculate these angles directly for any day, time, and latitude.

SOLAR POSITIONS FOR 40°N LATITUDE

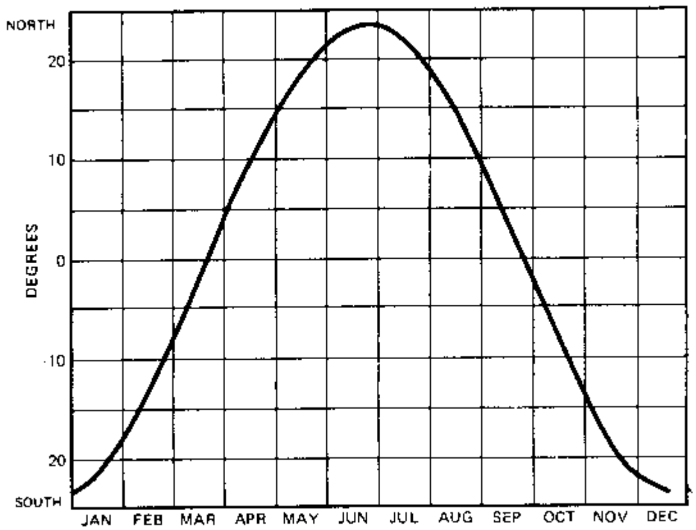
AM	PM	ANGLE	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
5	7	ALT θ					1.9	4.2	2.3					
		AZI ϕ					114.7	117.3	115.2					
6	6	ALT θ				7.4	12.7	14.8	13.1	7.9				
		AZI ϕ				98.9	105.6	108.4	106.1	99.5				
7	5	ALT θ		4.3	11.4	18.9	24.0	26.0	24.3	19.3	11.4	4.5		
		AZI ϕ		72.1	80.2	89.5	96.6	99.7	97.2	90.0	80.2	72.3		
8	4	ALT θ	8.1	14.8	22.5	30.3	35.4	37.4	35.8	30.7	22.5	15.0	8.2	5.5
		AZI ϕ	55.3	61.6	69.6	79.3	87.2	90.7	87.8	79.9	69.6	61.9	55.4	53.0
9	3	ALT θ	16.8	24.3	32.8	41.3	46.8	48.8	47.2	41.8	32.8	24.5	17.0	14.0
		AZI ϕ	44.0	49.7	57.3	67.2	76.0	80.2	76.7	67.9	57.3	49.8	44.1	41.9
10	2	ALT θ	23.8	32.1	41.6	51.2	57.5	59.8	57.9	51.7	41.6	32.4	24.0	20.7
		AZI ϕ	30.9	35.4	41.9	51.4	60.9	65.8	61.7	52.1	41.9	35.6	31.0	29.4
11	1	ALT θ	28.4	37.3	47.7	58.7	66.2	69.2	66.7	59.3	47.7	37.6	28.6	25.0
		AZI ϕ	16.0	18.6	22.6	29.2	37.1	41.9	37.9	29.7	22.6	18.7	16.1	15.2
12 noon		ALT θ	30.0	39.2	50.0	61.6	70.0	73.5	70.6	62.3	50.0	39.5	30.2	26.6
		AZI ϕ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

NOTES: Altitudes θ are measured from the horizon, and azimuths ϕ are measured from true south. Angles are given in degrees, and solar times are used.

SOURCE: Koolshade Corporation.

The sun's position in the sky is described by two angular measurements, the solar altitude θ and the solar azimuth ϕ. As explained in Chapter 3, the solar altitude is the angle of the sun above the horizon. The azimuth is its angular deviation from true south.

The exact calculation of θ and ϕ depends upon three variables: the latitude L, the declination δ, and the hour angle H. Latitude is the angular distance of the observer north or south of the equator—it can be read from any good map. Declination is a measure of how far north or south of the equator the sun has moved. At the summer solstice $\delta = +23\frac{1}{2}°$, while at the winter solstice $\delta = -23\frac{1}{2}°$ in the Northern Hemisphere; at both equinoxes, $\delta = 0°$. This qnantity varies from month to month and can be read directly from the graph below.



DECLINATION OF THE SUN

The hour angle H depends on Local Solar Time, which is the time that would be read from a sundial oriented south. Solar Time is measured from solar noon—the moment when the sun is highest in the sky. At different times of the year, the lengths of solar days (measnred from solar noon to solar noon) are slightly different from days measured by a clock running at a uniform rate. Local Solar Time is calculated taking this difference into account. There is also a correction if the observer is not on the standard time meridian for his time zone.

To correct local standard time (read from an accurate clock) to Local Solar Time, three steps are necessary:

1) If daylight savings time is in effect, subtract one hour.
2) Determine the longitude of the locality and the longitude of the standard time meridian (75° for Eastern ST, 90° for Central ST, 105° for Mountain ST, 120° for Pacific ST, 135° for Yukon ST, 150° for Alaska-Hawaii ST). Multiply the difference in longitudes by 4 minutes/degree. If the locality is east of the standard meridian, add the correction minutes; if it's west, subtract them.
3) Add the equation of time (from the next graph) for the date in question. The result is the Local Solar Time.

Once you know the Local Solar Time, you can obtain the hour angle H from:

$$H = 0.25 \times \text{(number of minutes from solar noon)}.$$

From the latitude L, declination δ and hour angle H, the solar altitude θ and azimuth ϕ follow after a little trigonometry:

$$\sin\theta = \cos L \cos\delta \cos H + \sin L \sin\delta\,;$$
$$\sin\phi = \cos\delta \sin H/\cos\theta\ .$$

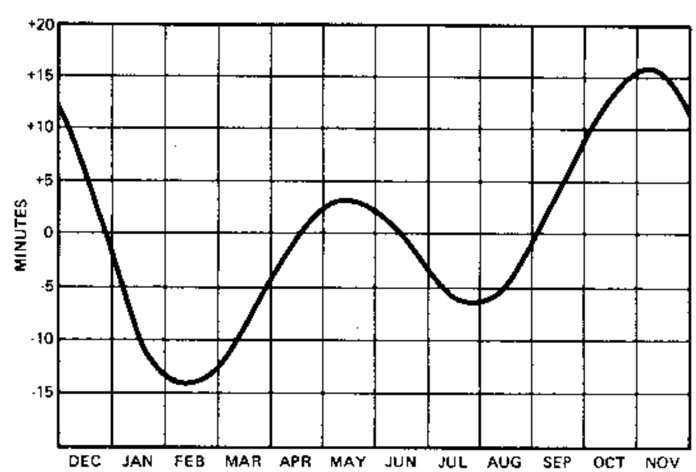
Example: Determine the altitude and azimuth of the sun in Abilene, Texas on December 1, when it is 1:30 p.m. (CST). First we need to calculate the Local Solar Time. It is not daylight savings time, so no correction for that is needed. Looking at a map we see that Abilene is on the 100°W meridian, or 10 degrees west of the standard meridian—90°W. We snbtract the $4 \times 10 = 40$ minutes from local time; 1:30 — 0:40 = 12:50 p.m. From the equation of time for December 1, we mnst *add* about 11 minutes. 12:50 + 0:11 = 1:01 Local Solar Time, or 61 minutes past solar noon. Consequently, the hour angle is $H = 0.25 \times 61$ or about 15°. The latitude of Abilene is read from the same map: L = 32°, and the declination for December 1 is $\delta = -22°$. We have come thus far with maps, graphs, and the back of an envelope, but now we need a pocket calculator or a table of trigonometric functions:

$$\begin{aligned}\sin\theta &= \cos(32°)\cos(-22°)\cos(15°) + \sin(32°)\sin(-22°)\\ &= 0.85 \times 0.93 \times 0.97 + 0.53 \times (-0.37)\\ &= 0.76 - 0.20 = 0.56\end{aligned}$$

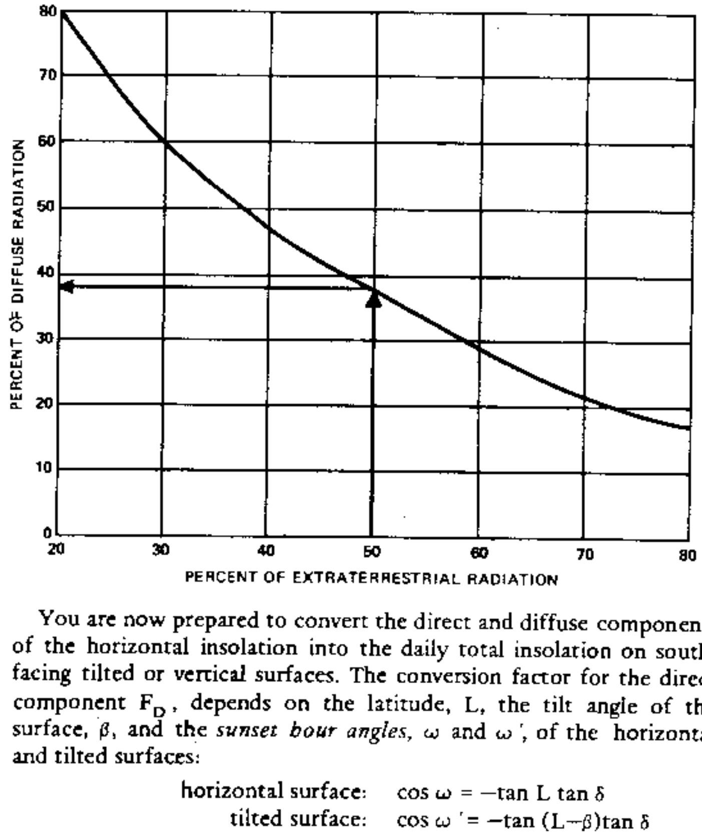
Then $\theta = \arcsin(0.56) = 34.12°$ above the horizon. Similarly:

$$\begin{aligned}\sin\theta &= \cos(-22°)\sin(15°)/\cos(34.12°)\\ &= (0.93 \times 0.26)/0.83 = 0.29\ .\end{aligned}$$

Then $\phi = \arcsin(0.29) = 16.85°$ west of true south. At 1:30 p.m. on December 1 in Abilene Texas, the solar altitude is 34.12° and the azimuth is 16.85° west.



The total solar radiation is the sum of direct, diffuse, and reflected radiation. At present, a statistical approach is the only reliable method of separating out the diffuse component of horizontal insolation. The full detail of this method is contained in an article by Liu and Jordan; we only summarize their results here. First we ascertain the ratio of the daily insolation on a horizontal surface (measured at a particular weather station) to the extraterrestrial radiation on another horizontal surface (outside the atmosphere). This ratio (usually called the *percent of Extraterrestrial radiation*, or % ETR) can be determined from the National Weather Records Center; it is also given in the article by Liu and Jordan. With a knowledge of the % ETR, you can use the accompanying graph to determine the percentage of diffuse radiation of a horizontal surface. For example, 50% ETR corresponds to 38% diffuse radiation and 62% direct radiation.



You are now prepared to convert the direct and diffuse components of the horizontal insolation into the daily total insolation on south-facing tilted or vertical surfaces. The conversion factor for the direct component F_D, depends on the latitude, L, the tilt angle of the surface, β, and the *sunset hour angles*, ω and ω', of the horizontal and tilted surfaces:

$$\text{horizontal surface:} \quad \cos\omega = -\tan L \tan\delta$$
$$\text{tilted surface:} \quad \cos\omega' = -\tan(L-\beta)\tan\delta$$

where the declination δ is found from the graph on page 252 and $\beta = 90°$ applies to vertical surfaces. Depending on the value of these two angles ω and ω', the calculation of F_D is slightly different. If ω is less than ω', then

$$F_D = \frac{\cos(L-\beta)}{\cos L} \times \frac{\sin\omega - \omega\cos\omega'}{\sin\omega - \omega\cos\omega}$$

If ω' is smaller than ω, then

$$F_D = \frac{\cos(L-\beta)}{\cos L} \times \frac{\sin\omega' - \omega'\cos\omega'}{\sin\omega - \omega\cos\omega}$$

The direct component of the radiation on a tilted or vertical surface is $I'_D = F_D \times I_D$, where I_D is the direct horizontal insolation.

The treatment of diffuse and reflected radiation is a bit different. The diffuse radiation is assumed to come uniformly from all corners of the sky, so one need only determine the fraction of the sky exposed to a tilted surface and reduce the horizontal diffuse radiation accordingly. The diffuse radiation on a surface tilted at an angle β is

$$I'_d = \frac{1+\cos\beta}{2} \times I_d$$

where I_d is the daily horizontal diffuse radiation. The reflected radiation on a tilted surface is

$$I'_r = \rho \times \frac{1-\cos\beta}{2} \times (I_D + I_d)$$

where ρ is the reflectance of the horizontal surface.

SOURCE: Liu, B.Y.H. and R. C. Jordan, "Availability of Solar Energy for Flat-Plate Solar Heat Collectors." in *Low Temperature Engineering Applications of Solar Energy*, edited by Richard C. Jordan, New York: ASHRAE, 1967.

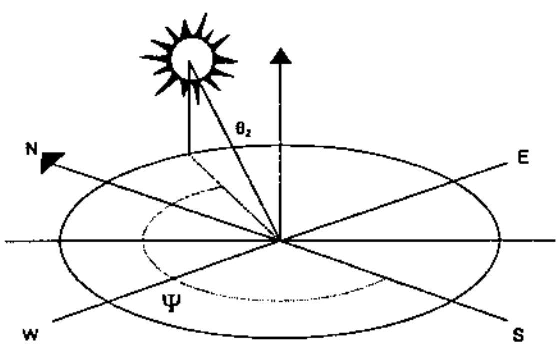
RAPS. University of Cape Town. South Africa 1992. 0-7992-1435-3.

EQUATIONS FOR CALCULATING THE POSITION OF THE SUN

Nomenclature:

ϕ	latitude
n	Julian day number
ω	hour angle
δ	solar declination angle
θ_z	solar zenith angle
ψ	solar azimuth

The apparent position of the sun in the sky can be defined by two angles: the solar zenith angle θ_z, and the azimuth angle ψ.



y is zero at solar noon, positive in the mornings and negative in the afternoons.

The sun's position relative to the earth depends on the time of day, the time of year, and the latitude.

The latitude ϕ is negative for the southern hemisphere. The time of year n is denoted by the Julian day number (1 to 365).

The hour angle of the sun ω is defined in terms of the number of hours from solar noon. ω changes by 15° every hour. It is zero at solar noon, positive in the mornings and negative in the afternoons. For a given time of day (solar time),

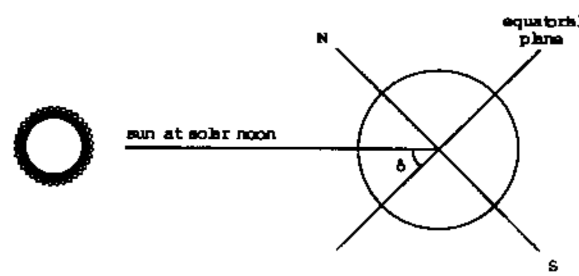
$$\omega = (noon - time) * 15°$$

Solar declination angle

The declination angle of the sun δ is the angle between the sun at solar noon and the equatorial plane. This varies from day to day. It is zero at the equinoxes, 23.45° at the June solstice and -23.45° at the December solstice.

δ can be calculated as follows:

$$\delta = 23.45° \times \sin\left(360° \times \frac{n + 284}{365}\right)$$



Solar zenith angle

The solar zenith angle can now be calculated:

$$\cos\theta_z = \sin\delta \sin\varphi + \cos\delta \cos\varphi \cos\omega$$

$$for\ \cos\omega > 0$$

Azimuth angle

The azimuth angle ψ is provided by

$$\cos\psi = \frac{\cos\theta_z \sin\varphi - \sin\delta}{\sin\theta_z \cos\varphi}$$

Appendix: Calculation of solar irradiation on inclined surfaces

NOMENCLATURE

Solar terms

D_h	=	diffuse radiation on the horizontal (W/m^2)
D_t	=	diffuse radiation on tilted plane (W/m^2)
G_h	=	global Radiation on the horizontal (W/m^2)
I	=	direct radiation on plane normal to sun's rays (W/m^2)
I_o	=	normal extraterrestrial radiation (I_o = 1367 W/m^2)
I_θ	=	direct radiation on plane with solar incidence = θ
Ref	=	reflected radiation on tilted plane (W/m^2)
m	=	relative air mass

Solar angles

A	=	solar azimuth
E	=	solar elevation
z	=	solar zenith
δ	=	declination angle
θ_t	=	solar incidence angle on tilted plane
θ_h	=	solar incidence angle on horizontal
ω	=	hour angle

Site dependent terms

A_t	=	azimuth of tilted plane
n	=	day number
β	=	tilt angle of plane from horizontal
ϕ	=	latitude ($\phi > 0$ in southern hemisphere)
σ	=	albedo of surrounding ground cover

Perez model variables

F1, F2, L	=	sky brightness parameters
Fij	=	coefficients describing sky brightness parameters
a′, b′	=	solid angles occupied by circumsolar zone and horizon band weighted by their average incidence on the slope
c′, d′	=	the equivalent of a and b for the horizontal
ϵ	=	describes relative importance of direct radiation at the earth's surface
d	=	normalised horizontal diffuse radiation
α	=	half angle of circumsolar zone ($\alpha = 25^o$)
ϕh	=	term used in the calculation of c′
ϕt	=	term used in the calculation of a′
Xh	=	term used in the calculation of c′
Xt	=	term used in the calculation of a′

The radiation received by an inclined surface is different to that received on the horizontal for three reasons. Firstly, the direct component is altered because of the change in surface area projected onto the plane normal to the sun's rays. Secondly an inclined surface will receive radiation reflected from the surrounding ground cover. Thirdly, the diffuse component changes as the fraction of the sky dome visible to the tilted surface is reduced. It is current practice to treat these three components independently.

The direct component

The treatment of the direct component is relatively straightforward and error free for flat surfaces.

If I is the intensity of the solar radiation falling on a plane normal to the sun's rays, then the direct radiation, I_θ, falling on a plane where the solar incidence angle is θ, is given by

$$I_\theta = I \cos \theta$$

If θ_t is the solar incidence angle on the inclined plane and θ_h is the solar incidence angle on the horizontal, then

$$I_{\theta t} = I \cos \theta_t$$

$$\text{and } I_{\theta h} = I \cos \theta_h$$

so

$$I_{\theta t} = (\cos \theta_t / \cos \theta_h)\, I_{\theta h}$$

The ratio $\cos \theta_t / \cos \theta_h$ may be written:

$$\frac{\cos \theta_t}{\cos \theta_h} = \frac{\sin\delta \sin(\phi-\beta) + \cos\delta \cos(\phi-\beta) \cos\omega}{\sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega}$$

where

δ = declination angle
ϕ = latitude
β = tilt of plane from horizontal
ω = hour angle

It is possible to repeat this calculation with data for each hour during the day and sum the results. The final figure represents the total direct radiation received during one day by the inclined plane.

The reflected component

The model employed to estimate ground reflected radiation assumes that the surrounding ground cover reflects radiation isotropically. This assumption is valid when global radiation is composed primarily of diffuse radiation and/or where the ground cover is a perfectly diffuse reflector. Although there do exist anisotropic models, these should only be used under specific conditions, for example where a surface exhibits strong directional reflectance or where local obstructions to the horizon occur.

For the isotropic model, the reflected component is given by:

$$Ref = 0.5\,\sigma\,(1 - \cos\beta)\,G_h$$

where

Ref	=	reflected component
σ	=	ground albedo
β	=	tilt of plane from horizontal
G_h	=	global radiation on the horizontal

The diffuse component

The available models

Estimation of the diffuse component of radiation received by an inclined plane is considered the largest potential source of error. There are a number of different models which may be used to predict the diffuse component.

Firstly, the isotropic model assumes that the intensity of the sky diffuse radiation is uniform over the entire sky dome. Research has shown that the assumption of isotropy of the sky provides a good fit to empirical data at low intensity conditions found during overcast skies; however the model underestimates the amount of solar radiation falling on tilted surfaces at higher solar intensities and in clear or partly clear sky situations where anisotropic conditions of circumsolar and horizon brightening are prevalent.

Various anistropic models have been developed to improve accuracy (Temps & Coulson, 1977; Klucher, 1979; Hay & McKay, 1985; and Perez et al, 1986). Comparisons of the performance of these models on two test data sets are presented in Perez (1987). The new version of the Perez model has been shown to perform more accurately than other models for a large number of locations. For this reason the new enhanced form of the Perez model has been selected to generate the diffuse radiation component.

Although Southern African sky conditions, being mostly clear and bright, resemble the conditions under which the Perez model performs well, it has not yet been validated locally.

Description of Enhanced Perez Model

The model is composed of two distinct elements:

i. a geometric representation of the sky dome

ii. a parametric representation of the insolation conditions.

The geometric framework

As shown in Figure 1, the sky hemisphere is divided into three zones: the horizon band, the circumsolar region and the rest of the sky. The diffuse radiation is assumed to be constant within each zone. Such a configuration helps to account for the two main types of anisotropy in the atmosphere: circumsolar and horizonal brightening. A 25° half angle for the circumsolar region was found by Perez to provide the best overall performance.

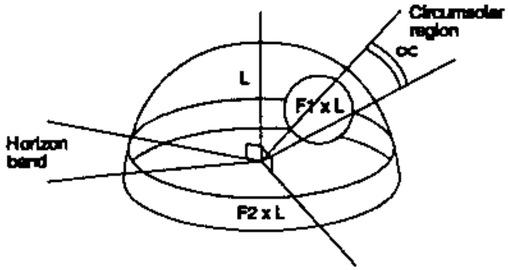


Figure 1: Geometric Representation of Sky Dome

If the diffuse radiances originating from the main portion of the dome, the circumsolar zone and the horizon band are L, F1 * L and F2 * L respectively, then the resulting diffuse radiation, D_t, received by an inclined plane can be expressed as:

$$D_t = D_h \{ 0.5 [1 + \cos\beta] [1 - F1 - F2] + F1 [a'/c'] + F2 [b'/d'] \}$$

where

D_t, D_h	=	diffuse radiation on incline, horizontal
β	=	tilt of plane from horizontal
F1, F2	=	diffuse radiation brightness coefficients
a′, b′	=	solid angles occupied by circumsolar zone and horizon band weighted by their respective incidence on the slope
c′, d′	=	the equivalent of a′ and b′ for the horizontal

The new simplified version of the model assumes that all the energy of the horizon band is contained in an infinitesimally thin region at 0°. The above equation then becomes:

$$D_t = D_h \{ 0.5[1 + \cos\beta] [1 - F1] + F1 [a'/c'] + F2 \sin\beta \}$$

The parametric representation of insolation conditions
This section of the model is empirical and establishes the value of the brightness coefficients, F1 and F2, as functions of the insolation conditions. The magnitude of these parameters are treated as functions of the following parameters:

i. the solar zenith angle, z

ii. the horizontal diffuse radiation (normalised to $d = D_h m / I_o$)

iii. the relative importance of direct radiation at the earth's surface,

expressed in the parameter = $[D_h + I] / D_h$.

where

m	=	relative air mass (m = 1 / cos z)
z	=	solar zenith angle
I	=	direct radiation normal to the sun's rays
I_o	=	normal extraterrestrial radiation (I_o = 1367 W/m^2)

The parameters F1 and F2 are expressed as:

F1	=	F11 + d F12 + z F13
F2	=	F21 + d F22 + z F23

The values of the parameters F11....F23 are presented in Table 1. These figures are for a 25° circumsolar half angle and are obtained from experimental data. Tests using these figures for a range of sites indicate that they are not site dependent (Perez, 1987).

Calculation method for Perez model

In summary, the calculation procedure follows the steps outlined below (note that in this example all angles are in radians and all insolation measurements must be in kJ/hr/m^2):

1. Input Data:

G_h	=	global radiation on the horizontal
D_h	=	diffuse radiation on the horizontal
ω	=	hour angle
	=	(solar time - 12.00) * 15 * π / 180
φ	=	latitude (positive for southern hemisphere)
α	=	circumsolar half angle (α = 25° = 0.436 rad)
n	=	Julian day, Jan 1st = 1 .... Dec 31st = 365
β	=	tilt of plane from horizontal
A_t	=	Plane azimuth (A_t = 0° for a north facing plane)

2. Calculate sky parameters:

δ	=	declination angle
	=	$-0.4093 \sin\{360/365 * (n + 284) * \pi / 180\}$
E	=	solar elevation
	=	$\arcsin(\sin\delta \sin\phi + \cos\delta \cos\phi \cos\omega)$
z	=	solar zenith
	=	$\pi/2 - E$
A	=	solar azimuth
	=	$\arccos\{(\sin E \sin\phi - \sin\delta) / (\cos E \cos\phi)\}$
θ_t	=	incidence angle of sun's rays on tilted plane
	=	$\arccos(\sin\beta \cos E \cos(A - A_t) + \cos\beta \cos E)$

3. Calculate model parameters:

I	=	$(G_h - D_h) / \sin(E)$
d	=	$D_h / [\cos(z) * I_o]$, $I_o = 4921.2$ kJ/hr/m^2
ϵ	=	$(D_h + I) / D_h$

4. Calculate Xh

If $z < \pi / 2 - \alpha$ then

$\phi h = 1$

$Xh = \cos(z)$

else

$\phi h = (\pi / 2 - z - \alpha) / (2 * \alpha)$

$Xh = \phi h * \sin(\phi h * \alpha)$

5. Calculate Xt

If $\theta_t \le \pi / 2 - \alpha$ then

$Xt = \phi h * \cos(\theta_t)$

else

if $\theta_t \le \pi / 2 + \alpha$ then

$\phi t = (\pi / 2 - \theta_t + \alpha) / (2 * \alpha)$

$Xt = \phi h * \phi t * \sin(\phi t * \alpha)$

else

$Xt = 0$

6. Calculate a and c

$a' = 2 * (1 - \cos \alpha) * Xt$

$c' = 2 * (1 - \cos \alpha) * Xh$

7. Calculate F1, F2

Look up F11...F23 in table

$F1 = F11 + d * F12 + z * F13$

$F2 = F21 + d * F22 + z * F23$

Table 1: Values for F11...F23

range of ε		25° circumsolar region					
from	**to**	**F11**	**F12**	**F13**	**F21**	**F22**	**F23**
1.000	1.056	-0.011	0.748	-0.080	-0.048	0.073	-0.024
1.056	1.253	-0.038	1.115	-0.109	-0.023	0.106	-0.037
1.253	1.586	0.166	0.909	-0.179	0.062	-0.021	-0.050
1.586	2.134	0.419	0.646	-0.262	0.140	-0.167	-0.042
2.134	3.230	0.710	0.025	-0.290	0.243	-0.511	-0.004
3.230	5.980	0.857	-0.370	-0.279	0.267	-0.792	0.076
5.980	10.080	0.734	-0.073	-0.228	0.231	-1.180	0.199
10.080		0.421	-0.661	0.097	0.119	-2.125	0.446

8. Calculate diffuse component

$D_t = D_h * \{ 0.5 [1 + \cos \beta] * [1 - F1] + F1 * [a'/c'] + F2 * \sin \beta \}$

This calculation procedure can be repeated for each hour of sunlight during the day and the results summed to obtain a figure representing the diffuse radiation received on a tilted surface during one day.

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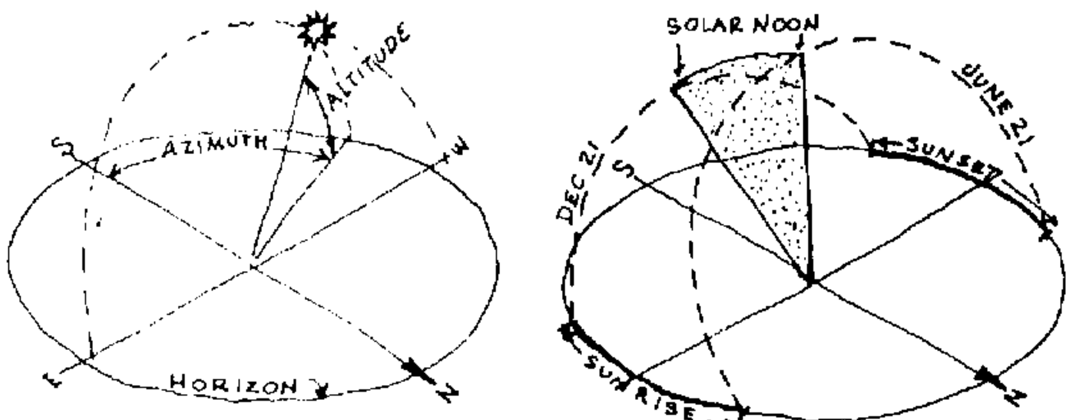
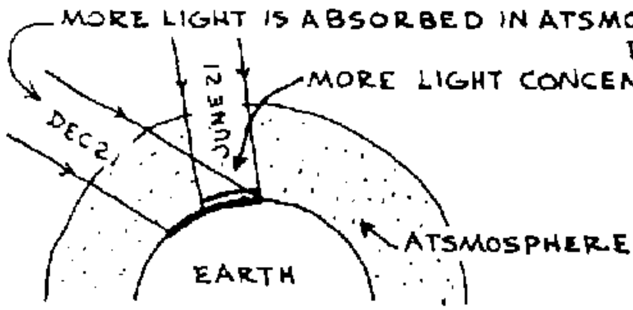
52: **Owner-built Home / Owner-built Homestead. Kern. Schribner Press NY USA 1972 / 1975 / 1977 0-684-14223-6 / 0-684-14926-5**

A heliodon is a simulated-sun device. When using it, one must make a cardboard, scale model of the proposed garden or house in plan form, that is, at first omitting the outside walls and roofs of any structures. Then, as various summer or winter solar angles are set on the heliodon, the designer's addition of walls and roofs and specific plantings will cast shadows on one's model, determining window sizes, ceiling heights, plant groupings, and plant spacings for eventual construction or placement.

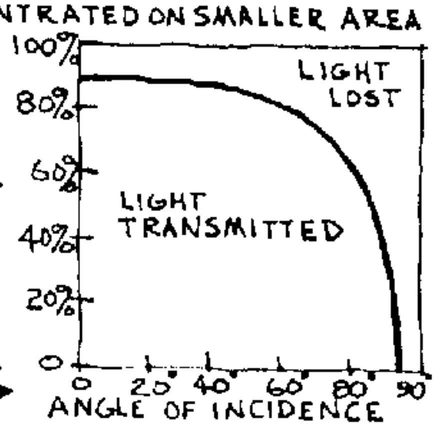
Soon after beginning to work with a heliodon, one discovers that east and west building openings or garden aspects are vulnerable to



SUN PATH AT SEASONS FOR SPECIFIC LATITUDE



SEASONAL EFFECT OF SUNS RAYS

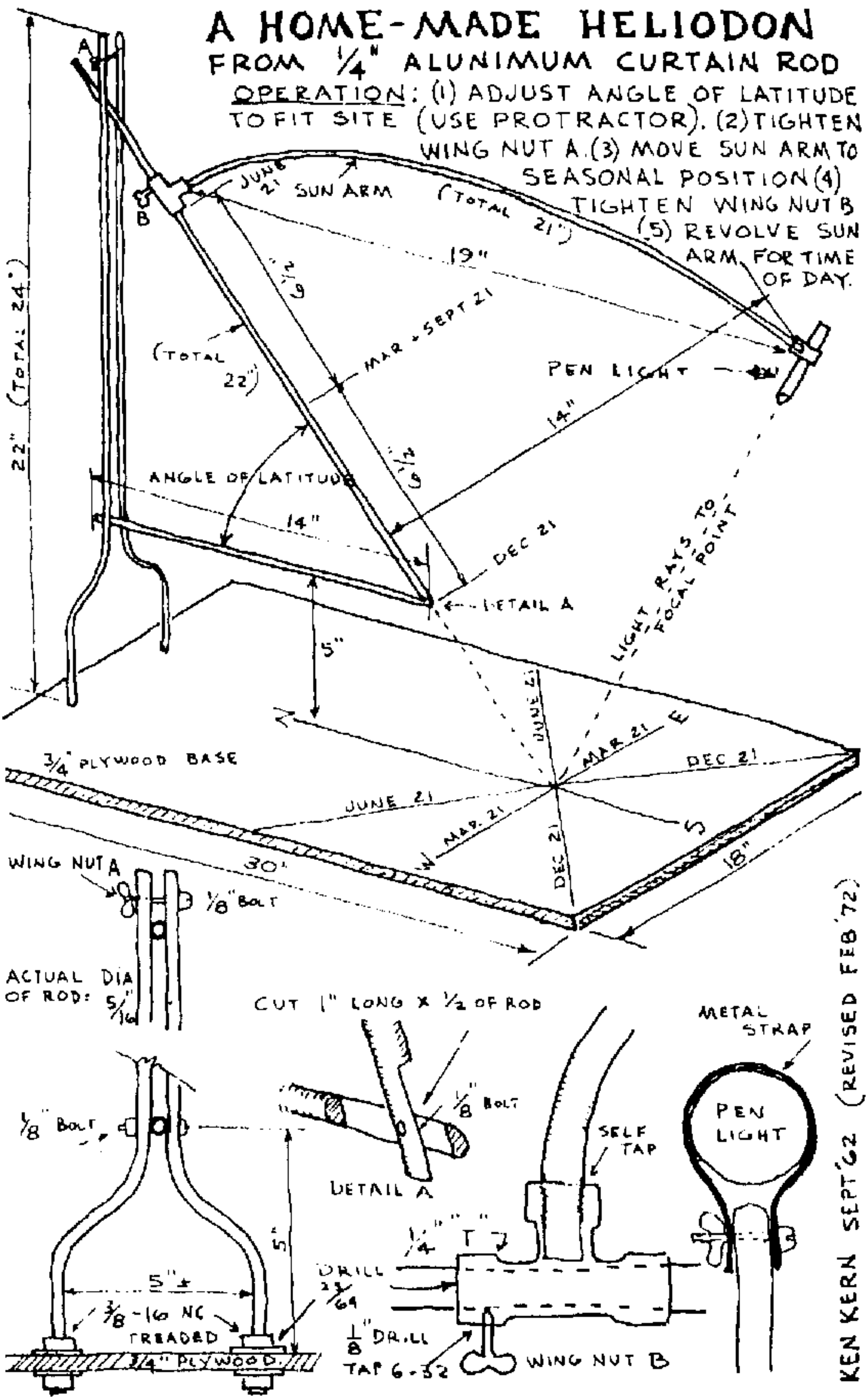


AMOUNT OF LIGHT TRANSMITTED OR REFLECTED FROM GLASS →

A HOME-MADE HELIODON

FROM ¼" ALUNIMUM CURTAIN ROD

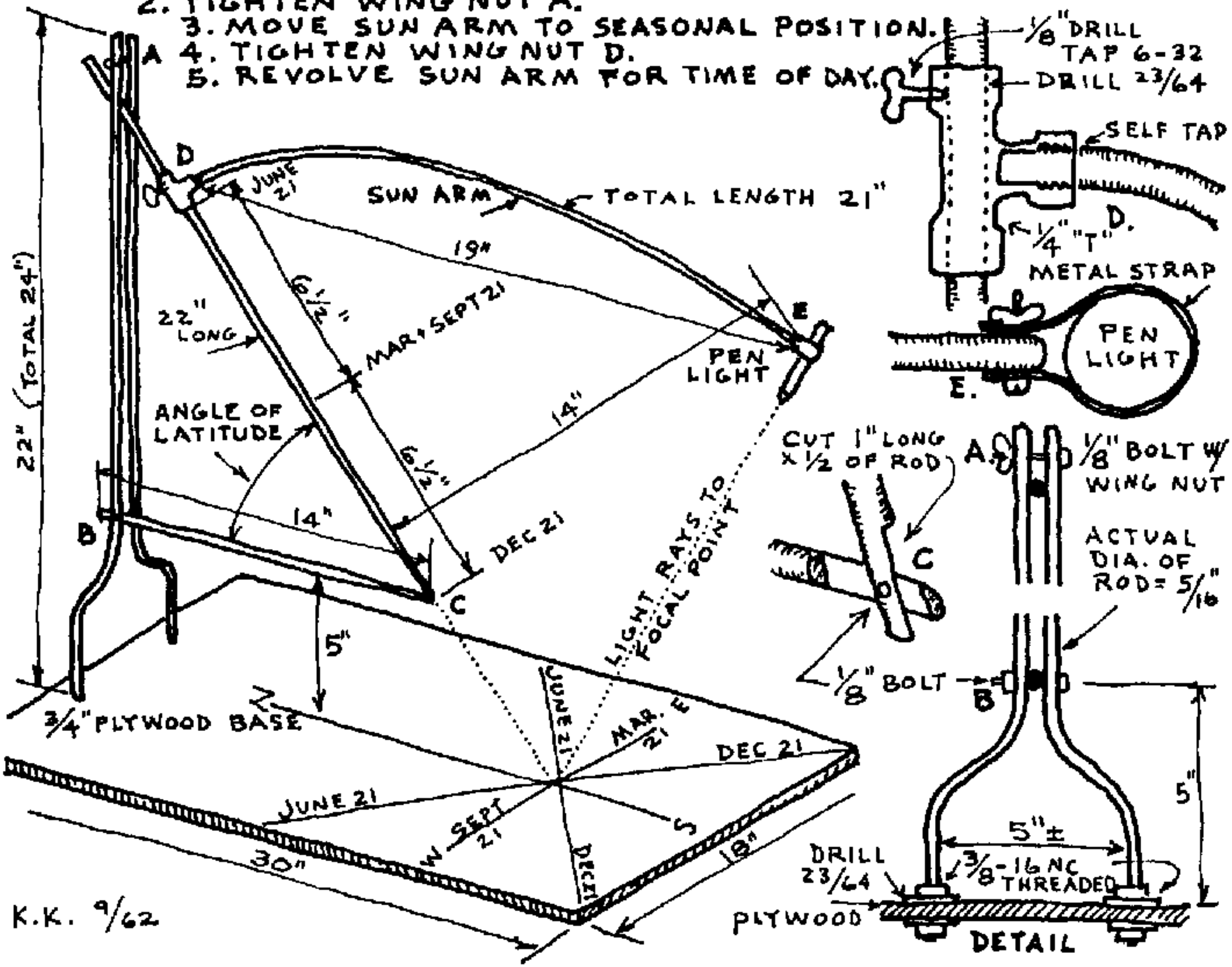
OPERATION: (1) ADJUST ANGLE OF LATITUDE TO FIT SITE (USE PROTRACTOR). (2) TIGHTEN WING NUT A. (3) MOVE SUN ARM TO SEASONAL POSITION (4) TIGHTEN WING NUT B (5) REVOLVE SUN ARM FOR TIME OF DAY.

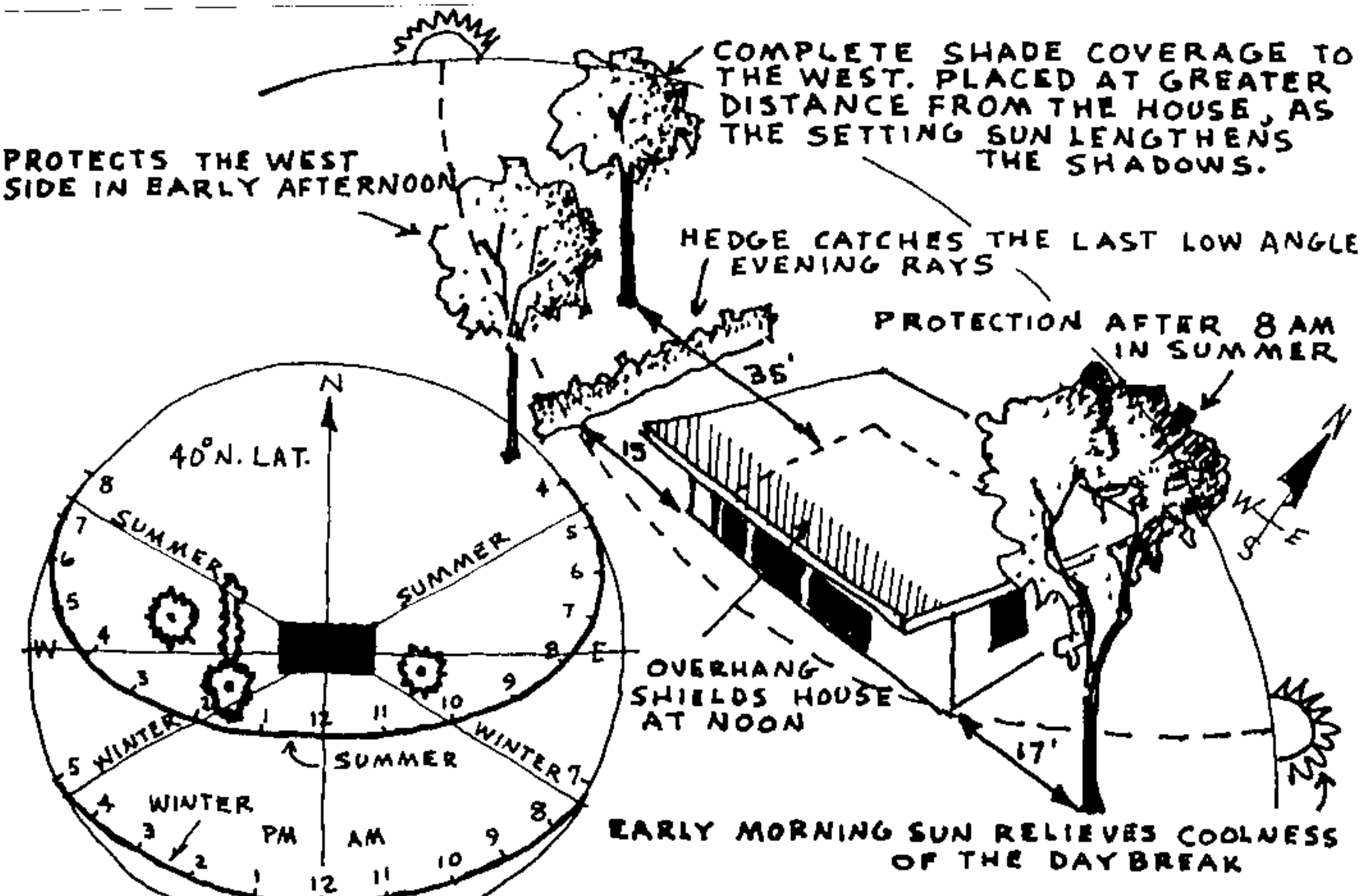


KEN KERN SEPT '62 (REVISED FEB '72)

9.2 HOME-MADE HELIODON FROM 5/16" CURTAIN ROD

1. ADJUST ANGLE OF LATITUDE WITH PROTRACTOR.
2. TIGHTEN WING NUT A.
3. MOVE SUN ARM TO SEASONAL POSITION.
4. TIGHTEN WING NUT D.
5. REVOLVE SUN ARM FOR TIME OF DAY.





9.3 PLANT LOCATIONS

summer solar-heat radiation. In late June, the sun is at its zenith and the day is at its longest length of time. The horizontal sweep of the summer sun is 242°, about twice that of its sweep in the winter. One might readily realize from model and heliodon manipulation that certain east and west openings and aspects will be impossible to protect from summer-sun heat by conventional means. Illogically, something like a 20-foot roof overhang might be indicated for shading an exposed area! It will, therefore, instantly and graphically become obvious that the judicious planting of a few particular kinds of trees and shrubs in combination with the building of complementary, external shading devices or garden structures will achieve the desired results.

Table III.2. Sun's rising and setting

Latitude	40°N.		30°N.		20°N.		10°N.		Equator		10°S.		20°S.		30°S.		40°S.	
	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m.	rises h. m.	sets h. m	rises h. m.	sets h. m.
Jan. 1	7 23	4 43	6 57	5 9	6 36	5 30	6 18	5 48	6 1	6 5	5 44	6 22	5 25	6 41	5 4	7 2	4 36	7 30
„ 16	7 22	4 58	6 59	5 21	6 40	5 49	6 23	5 57	6 8	6 12	5 52	6 28	5 35	6 45	5 16	7 4	4 52	7 28
Feb. 1	7 11	5 17	6 53	5 35	6 38	5 50	6 24	6 4	6 13	6 16	5 58	6 29	5 45	6 43	5 30	6 58	5 11	7 17
„ 16	6 54	5 34	6 40	5 48	6 30	5 58	6 21	6 7	6 12	6 16	6 2	6 26	5 53	6 35	5 42	6 46	5 28	7 0
Mar. 1	6 36	5 49	6 28	5 57	6 22	6 4	6 16	6 9	6 10	6 14	6 5	6 20	5 59	6 26	5 52	6 33	5 44	6 43
„ 16	6 13	6 5	6 11	6 7	6 10	6 8	6 8	6 10	6 7	6 11	6 5	6 13	6 4	6 14	6 2	6 16	6 0	6 18
April 1	5 47	6 21	5 52	6 16	5 56	6 12	5 59	6 9	6 2	6 6	6 5	6 3	6 8	6 0	6 12	5 56	6 16	5 52
„ 16	5 23	6 37	5 34	6 26	5 43	6 17	5 51	6 9	5 58	6 2	6 5	5 55	6 12	5 48	6 21	5 39	6 31	5 29
May 1	5 2	6 52	5 19	6 35	5 32	6 22	5 44	6 10	5 55	5 59	6 6	5 48	6 17	5 37	6 30	5 24	6 46	5 8
„ 16	4 46	7 6	5 8	6 44	5 25	6 27	5 40	6 12	5 54	5 58	6 8	5 44	6 22	5 30	6 39	5 13	7 0	4 52
June 1	4 36	7 20	5 1	6 55	5 21	6 35	5 39	6 17	5 55	6 0	6 12	5 44	6 29	5 26	6 49	5 6	7 14	4 42
„ 16	4 32	7 28	5 0	7 0	5 21	6 39	5 41	6 19	5 58	6 2	6 15	5 45	6 34	5 26	6 55	5 5	7 22	4 38
July 1	4 35	7 31	5 3	7 3	5 25	6 41	5 44	6 22	6 1	6 5	6 18	5 48	6 36	5 30	6 58	5 8	7 24	4 42
„ 16	4 46	7 26	5 10	7 1	5 30	6 41	5 47	6 24	6 4	6 8	6 19	5 52	6 36	5 35	6 56	5 16	7 20	4 52
Aug. 1	4 59	7 13	5 20	6 52	5 36	6 36	5 51	6 21	6 4	6 8	6 17	5 55	6 31	5 41	6 47	5 25	7 8	5 4
„ 16	5 13	6 55	5 28	6 40	5 41	6 27	5 52	6 16	6 2	6 6	6 12	5 56	6 23	5 45	6 35	5 32	6 49	5 19
Sept. 1	5 28	6 32	5 38	6 22	5 45	6 15	5 51	6 9	5 58	6 2	6 4	5 54	6 10	5 50	6 17	5 43	6 26	5 34
„ 16	5 42	6 8	5 46	6 4	5 48	6 2	5 51	5 59	5 53	5 57	5 55	5 55	5 57	5 53	6 0	5 50	6 2	5 48
Oct. 1	5 57	5 43	5 55	5 45	5 52	5 48	5 50	5 50	5 48	5 52	5 46	5 54	5 43	5 57	5 41	5 59	5 37	6 3
„ 16	6 13	5 19	6 4	5 28	5 56	5 36	5 50	5 42	5 44	5 48	5 37	5 55	5 31	6 1	5 23	6 9	5 14	6 18
Nov. 1	6 30	4 58	6 15	5 13	6 3	5 25	5 52	5 36	5 42	5 46	5 32	5 56	5 21	6 7	5 8	6 20	4 52	6 36
„ 16	6 48	4 42	6 27	5 3	6 11	5 19	5 56	5 34	5 43	5 47	5 29	6 1	5 14	6 16	4 58	6 32	4 37	6 53
Dec. 1	7 4	4 34	6 39	4 59	6 20	5 18	6 3	5 35	5 47	5 51	5 30	6 8	5 13	6 25	4 53	6 45	4 28	7 10
„ 16	7 17	4 34	6 51	5 1	6 29	5 22	6 11	5 41	5 54	5 58	5 37	6 15	5 17	6 34	4 56	6 56	4 28	7 24

This table shows the approximate mean local times of the sun's rising and setting for the latitudes given. The times for intermediate dates and latitudes can be found by interpolation.

Example: Required time of sunset Lat. 4°S. on 1st May. 1st May Equator sun sets 5h.59m. On 1st May 10°S. sun sets 5h.48m. therefore difference for 10° = 11 mins. difference for 1° = 1·1 min. and difference for 4° = 4·4 mins. this amount subtracted from 5·59 (= 5·54 mins.) is the time of sunset on 1st May. (From "Field Service Pocket Book", 1914).

Conversion Tables

1. Conversion Factors

To Convert From	To	Multiply By
Btu	Gram calories	251.9958
Btu	Kilogram calories	.00397
Btu	Cubic centimeters atmospheres	10405.6
Btu	Cubic foot atmospheres	.36747
Btu	Foot pounds	777.649
Btu	Horsepower hours	.0003927
Btu	Kilowatt hours	.00029287
Btu/square foot	Langleys	.271
Btu/hour/square foot/°F	Watts/CM^2/°C	5.6820×10^{4}
Cubic foot atmospheres	Btu	2.721
Cubic feet of water	Gallons	7.4805
Cubic feet of water	Pounds	62.366
Foot pounds	Btu	.001285
Gallons of water	Cubic feet	0.13368
Gallons of water	Pounds	8.3453
Gram calories	Btu	.00397
Horsepower	Foot pounds/hour	1,980,000.
Horsepower	Foot pounds/minute	33,000.
Horsepower	Foot pounds/second	550.
Horsepower	Kilowatts	.7457
Horsepower	Watts	745.7
Horsepower hours	Btu	2546.14

To Convert From	To	Multiply By
Horsepower years	Btu	22,304,186.4
Kilogram calories	Btu	3.97
Kilowatts	Horsepower	1.34102
Kilowatt hours	Btu	3414.43
Langleys	Btu/square foot	3.69
Lumens (at 5,550 Å)	Watts	0.0014706
Months (mean calendar)	Hours	730.1
Pints (U.S., liq)	Cubic centimeters	473.18
Pints	Cubic inches	28.875
Pounds of water	Cubic feet of water	0.01602
Pounds of water	Gallons (U.S., liq)	0.1198
Watts	Btu/hour	3.4144
Watts	Btu/minute	0.05691
Watts	Calories/minute	14.34
Watts	Horsepower	0.001341
Watts/square centimeter	Btu/square feet/hour	3,172.
Watt-hours	Btu	3.4144
Watt-hours	Calories	860.4
Watt-hours	Horsepower hours	0.001341

2. Fahrenheit-Centigrade Conversion Table

The numbers in the center column, in boldface type, refer to the temperature in either Fahrenheit or Centigrade degrees. If it is desired to convert from Fahrenheit to Centigrade degrees, consider the center column as a table of Fahrenheit temperatures and read the corresponding Centigrade temperature in the column at the left. If it is desired to convert from Centigrade to Fahrenheit degrees, consider the center column as a table of Centigrade values, and read the corresponding Fahrenheit temperature on the right.

SOURCE: Clifford Strock and Richard L. Koral, eds., *Handbook of Air Conditioning, Heating, and Ventilating*, 2d ed. (New York: Industrial Press, 1965).

For conversions not covered in the table, the following formulas are used:

$F = 1.8\ C + 32 \qquad C = (F - 32) \div 1.8$

Deg C		Deg F	Deg C		Deg F
–46	**– 50**	– 58	8.9	**48**	118.4
–40	**– 40**	– 40	9.4	**49**	120.2
–34	**– 30**	– 22	10.0	**50**	122.0
–29	**– 20**	– 4	10.6	**51**	123.8
–23	**– 10**	14	11.1	**52**	125.6
–17.8	**0**	32–	11.7	**53**	127.4
–17.2	**1**	33.8	12.2	**54**	129.2
–16.7	**2**	35.6	12.8	**55**	131.0
–16.1	**3**	37.4	13.3	**56**	132.8
–15.6	**4**	39.2	13.9	**57**	134.6
–15.0	**5**	41.0	14.4	**58**	136.4
–14.4	**6**	42.8	15.0	**59**	138.2
–13.9	**7**	44.6	15.6	**60**	140.0
–13.3	**8**	46.4	16.1	**61**	141.8
–12.8	**9**	48.2	16.7	**62**	143.6
–12.2	**10**	50.0	17.2	**63**	145.4
–11.7	**11**	51.8	17.8	**64**	147.2
–11.1	**12**	53.6	18.3	**65**	149.0
–10.6	**13**	55.4	18.9	**66**	150.8
–10.0	**14**	57.2	19.4	**67**	152.6
– 9.4	**15**	59.0	20.0	**68**	154.4
– 8.9	**16**	60.8	20.6	**69**	156.2
– 8.3	**17**	62.6	21.1	**70**	158.0
– 7.8	**18**	64.4	21.7	**71**	159.8
– 7.2	**19**	66.2	22.2	**72**	161.6
– 6.7	**20**	68.0	22.8	**73**	163.4
– 6.1	**21**	69.8	23.3	**74**	165.2
– 5.6	**22**	71.6	23.9	**75**	167.0
– 5.0	**23**	73.4	24.4	**76**	168.8
– 4.4	**24**	75.2	25.0	**77**	170.6
– 3.9	**25**	77.0	25.6	**78**	172.4
– 3.3	**26**	78.8	26.1	**79**	174.2
– 2.8	**27**	80.6	26.7	**80**	176.0
– 2.2	**28**	82.4	27.2	**81**	177.8
– 1.7	**29**	84.2	27.8	**82**	179.6
– 1.1	**30**	86.0	28.3	**83**	181.4
– 0.6	**31**	87.8	28.9	**84**	183.2
0–	**32**	89.6	29.4	**85**	185.0
0.6	**33**	91.4	30.0	**86**	186.8
1.1	**34**	93.2	30.6	**87**	188.6
1.7	**35**	95.0	31.1	**88**	190.4
2.2	**36**	96.8	31.7	**89**	192.2
2.7	**37**	98.6	32.2	**90**	194.0
3.3	**38**	100.4	32.8	**91**	195.8
3.9	**39**	102.2	33.3	**92**	197.6
4.4	**40**	104.0	33.9	**93**	199.4
5.0	**41**	105.8	34.4	**94**	201.2
5.6	**42**	107.6	35.0	**95**	203.0
6.1	**43**	109.4	35.6	**96**	204.8
6.7	**44**	111.2	36.1	**97**	206.6
7.2	**45**	113.0	36.7	**98**	208.4
7.8	**46**	114.8	37.2	**99**	210.2
8.3	**47**	116.6	37.8	**100**	212.0

APPENDIX: Conversion Factors

To convert from:	To:	Multiply by:
Length		
centimeters (cm)	inches	0.394
feet (ft)	centimeters	30.5
inches (in)	centimeters	2.54
kilometers (km)	miles	0.621
meters (m)	feet	3.28
meters (m)	yards	1.094
miles (mi)	kilometers	1.609
millimeters (mm)	inches	0.0394
yards (yd)	meters	0.914
Area		
acres	hectares	0.405
acres	sq. meters	4047
hectares (ha)	acres	2.47
hectares (ha)	sq. meters	10,000
sq. centimeters (cm^2)	sq. inches	0.155
sq. feet (ft^2)	sq. meters	0.0929
sq. inches (in^2)	sq. centimeters	6.45
sq. kilometers (km^2)	sq. miles	0.386
sq. kilometers (km^2)	hectares	100
sq. meters (m^2)	sq. feet	10.76
sq. yards (yd^2)	sq. meters	0.836
Volume		
barrels (petroleum, bbl)	liters	159
cubic centimeters (cm^3)	cubic inches	0.0610
cubic feet (ft^3)	cubic meters	0.0283
cubic inches (in^2)	cubic centimeters	16.39
cubic meters (m^3)	cubic feet	35.3
cubic meters (m^3)	cubic yards	1.308
cubic yards (yd^3)	cubic meters	0.765
gallons (gal) US	liters	3.79
gallons (gal) Imp.	liters	4.545
gallons (gal) Imp.	gallons, US	1.20
Weight		
grams (g)	ounces, avdp.	0.0353
kilograms (kg)	pounds	2.205
ounces avdp. (oz)	grams	28.3
pounds (lb)	kilograms	0.454
tons (long)	pounds	2240
tons (long)	kilograms	1016
tons (metric)	pounds	2205
tons (metric)	kilograms	1000
tons (short)	pounds	2000
tons (short)	kilograms	907

continued

To convert from:	To:	Multiply by:
Pressure		
atmosphere	grams/sq.cm	1033
atmosphere	pounds/sq.in	14.7
pounds/sq.in (psi)	grams/sq.cm	70.3
Energy		
British thermal units (Btu)	kilojoules	1.054
calories (cal)	joules	4.19
ergs	joules	1×10^{-7}
kilojoules (kJ)	Btu	0.948
joules (J)	calories	0.239
kilowatt-hours (kWh)	megajoules	3.6
megajoules (MJ)	kilojoules	1000
gigajoules (GJ)	megajoules	1000
terajoules (TJ)	gigajoules	1000
Energy Density		
Btu/gal	joules/cm^3	0.27
Btu/ft^3	kJ/m^3	36.5
Power		
horsepower (hp)	Btu/min	42.4
horsepower (hp)	horsepower (metric)	1.014
horsepower (hp)	kilowatts	0.746
kilowatts (kW)	horsepower	1.341
watts (W)	Btu/hour	3.41
watts (W)	joules/sec	1
Miscellaneous		
liter petrol	megajoules	35
kilogram oil	megajoules	43.2
barrel oil equivalent	gigajoules	6.1
ton coal equivalent	gigajoules	29.3
ton coal equivalent	barrels oil equivalent	4.8
pounds/acre	kilograms/hectare	1.1

SI units and conversion factors

Basic SI units, prefixes, and most common derived SI units used

Basic SI units

Quantity	*Basic unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampère	A
Temperature	kelvin	K

SI prefixes

Prefix	*Symbol*	*Factor*	*Prefix*	*Symbol*	*Factor*
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	μ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
deca	da	10^{1}	atto	a	10^{-18}

Most common derived SI units

Quantity	*Unit*	*Symbol*
Area	square metre	m^2
Volume (contents)	cubic metre	m^3
Speed	metre per second	m/s
Acceleration	metre per second, squared	m/s^2
Frequency	hertz	Hz (= s^{-1})
Pressure	pascal	Pa (= N/m^2)
Volume flow	cubic metre per second	m^3/s
Mass flow	kilogram per second	kg/s
Density (specific mass)	kilogram per cubic metre	kg/m^3
Force	newton	N (= $kg.m/s^2$)
Energy/heat/work	joule	J (= N.m)*
Power/energy flow	watt	W (J/s)
Energy flux	watt per square metre	W/m^2
Calorific value (heat of combustion)	joule per kilogram	J/kg
Specific heat capacity	joule per kilogram kelvin	J/kg K
Voltage	volt	V (= W/A)

* NB The joule can also be written in the form watt second (1J = 1W.s)

Conversion of non-SI units to SI units

Although academic scientists and engineers may be strict in their use of SI units for their calculations, a number of non-SI units are still in everyday use. For example, engines are still sold by cc (cubic centimetres) and hp (horse power), and water-pumping windmill manufacturers often quote in terms of cubic feet of the same type of equipment there is not always consistency. In order to be able to compare different manufacturers' products, therefore, it is important to be able convert the different data to a common unit. The following tables give some useful conversion factors for many of the common non-SI units.

Conversion factors

Length

Unit (symbol)	millimetre (mm)	metre (m)	kilometre (km)	inch (in.)	foot (ft)	mile (m.)
	1	0.001	10^{-6}	0.0394	0.0033	5.4×10^{-7}
	1000	1	0.001	39.4	3.28	5.4×10^{-4}
	10^{6}	1000	1	39360	3280	0.5392
	25.4	0.025	2.5×10^{-5}	1	0.083	1.4×10^{-5}
	305	0.305	3.0×10^{-4}	12	1	1.9×10^{-4}
	1.6×10^{6}	1609	1.609	63360	5280	1

Area

Unit (symbol)	square metre (m^2)	hectare (ha)	square kilometre (km^2)	square foot (ft^2)	acre –	square mile (sq. m.)
	1	10^{-4}	10^{-6}	10.76	2.5×10^{-4}	3.9×10^{-7}
	10000	1	0.01	1.1×10^{5}	2.471	3.9×10^{-3}
	10^{6}	100	1	1.1×10^{7}	247.1	0.386
	0.0929	9.3×10^{-6}	9.3×10^{-8}	1	2.3×10^{-5}	3.6×10^{-8}
	4047	0.4047	4×10^{-3}	43560	1	1.6×10^{-3}
	2.6×10^{6}	259	2.590	2.8×10^{7}	640	1

Volume

Unit (symbol)	litre (l)*	cubic metre (m^3)	cubic inch (in^3)	US gallon (gal)	Imperial gallon (gal)	cubic foot (ft^3)
	1	10^{-3}	61.02	0.264	0.220	0.0353
	1000	1	6102	264	220	35.31
	0.0164	1.6×10^{-5}	1	4.3×10^{-3}	3.6×10^{-3}	5.8×10^{-4}
	3.785	3.8×10^{-3}	231.1	1	0.833	0.134
	4.546	4.5×10^{-3}	277.4	1.201	1	0.160
	28.32	0.0283	1728	7.47	6.23	1

* L in some countries

Mass

Unit (symbol)	gram (g)	kilogram (kg)	tonne (t)	pound (lb)	ton –
	1	0.001	10^{-6}	2.2×10^{-3}	9.8×10^{-7}
	1000	1	0.001	2.205	9.8×10^{-4}
	10^{6}	1000	1	2205	0.984
	453.6	0.4536	4.5×10^{-4}	1	4.5×10^{-4}
	10^{6}	1016	1.016	2240	1

Velocity

Unit (symbol)	metres per second (m/s)	kilometres per hour (km/h)	feet per second (ft/s)	miles per hour (mph)	knots (kt)
	1	3.60	3.28	2.237	1.942
	0.278	1	0.912	0.621	0.539
	0.305	1.097	1	0.682	0.592
	0.447	1.609	1.467	1	0.868
	0.566	1.853	1.689	1.152	1

Frequency

Unit (symbol)	hertz (Hz)	revolutions per minute (rpm)	radians per second (rad/s)
	1	60	6.283
	0.0167	1	0.1047
	0.159	9.549	1

Conversion factors

Flow rate

Unit (symbol)	litres per minute (l/min)	cubic metres per second (m³/s)	Imperial gallons per minute (gal(Imp)/min)	cubic feet per second (ft³/s)
	1	1.7×10^{-5}	0.220	5.9×10^{-4}
	60000	1	13206	35.315
	4.546	7.6×10^{-5}	1	2.7×10^{-3}
	1699	0.0283	373.7	1

Force

Unit (symbol)	newton (N)	kilonewton (kN)	kilogram force (kgf)	tonne force (t)	pound force (lbf)	ton force –
	1	0.001	0.102	1×10^{-4}	0.225	1×10^{-4}
	1000	1	102	0.102	225	0.100
	9.807	0.010	1	0.001	2.205	9.8×10^{-4}
	9807	9.807	1000	1	2205	0.984
	4.448	0.004	0.5436	4.5×10^{-4}	1	4.5×10^{-4}
	9964	9.964	1016	1.1016	2240	1

Torque

Unit (symbol)	newton-metre (Nm)	kilonewton-metre (kNm)	foot-pound (ft.lb)
	1	0.001	0.738
	1000	1	738
	1.365	1.4×10^{-3}	1

Work/heat/energy (smaller quantities)

Unit (symbol)	calorie (cal)	joule (J)	watt-hour (Wh)	British Thermal Unit (BTU)	footpound force (ft.lbf)	horsepower-hour (hp.h)
	1	4.182	1.2×10^{-3}	3.9×10^{-3}	3.088	1.6×10^{-6}
	0.239	1	2.8×10^{-4}	9.4×10^{-4}	0.7376	3.7×10^{-7}
	860.4	3600	1	3.414	2655	1.3×10^{-3}
	252	1055	2.93	1	778	3.9×10^{-4}
	0.324	1.356	3.8×10^{-4}	1.3×10^{-3}	1	5.0×10^{-7}
	6.4×10^{5}	2.6×10^{6}	745.7	2546	2.0×10^{6}	1

Work/heat/energy (larger quantities)

Unit (symbol)	kilocalorie (kcal)	megajoule (MJ)	kilowatt hour (kWh)	British Thermal Unit (BTU)	horsepower-hour (hp.h)
	1	4.2×10^{-3}	1.2×10^{-3}	3.968	1.6×10^{-3}
	239	1	0.2887	947.8	0.3725
	860.4	3.600	1	3414	1.341
	0.252	1.1×10^{-3}	2.9×10^{-4}	1	3.9×10^{-4}
	641.6	2.685	0.7457	2546	1

Conversion factors

Power

Unit (symbol)	watt (W or J/s)	kilowatt (kW)	metric horse-power (CV)	foot-pound per second (ft.lbf/s)	horse-power (hp)	British Thermal Units per minute (BTU/min)
	1	0.001	1.4×10^{-3}	0.7376	1.3×10^{-3}	0.0569
	1000	1	1.360	737.6	1.341	56.9
	735	0.735	1	558	1.014	41.8
	1.356	1.4×10^{-3}	1.8×10^{-3}	1	1.8×10^{-3}	0.077
	746	0.746	0.9860	550	1	42.44
	17.57	0.0176	0.0239	12.96	0.0236	1

Power flux

Unit (symbol)	watts per square metre (W/m^2)	kilowatts per square metre (kW/m^2)	horsepower per square foot (hp/ft^2)
	1	0.001	1.2×10^{-4}
	1000	1	0.1246
	8023	8.023	1

Calorific value (heat of combustion)

Unit (symbol)	calories per gram (cal/g)	megajoules per kilogram (MJ/kg)	British thermal units per pound (BTU/lb)
	1	4.2×10^{-3}	1.8
	239	1	430
	0.556	2.3×10^{-3}	1

Density (specific mass) and (net) calorific value (heat of combustion) of fuels

	Density (kg/m^3)	Calorific value (MJ/kg)
LPG	560	45.3
Gasoline (petrol)	720	44.0
Kerosene	806	43.1
Diesel oil	850	42.7
Fuel oil	961	40.1
Wood, oven-dried	varies	16–20
Natural gas	—	$103m^3$ at 1013 mbar, 0°C = 39.36×10^9 J

NB These values are approximate since the fuels vary in composition and this affects both the density and calorific value.

Replacement values

When trying to compare different fuel options, energy planners often use replacement values, which indicate in a specific situation how much fuel it would take to replace another one. For example, the tonne coal equivalent (tce) would be used to say how much coal it would take to replace a given quanity of oil or natural gas. The table below gives some of the most common equivalence values.

Fuel	Unit	Tonnes of coal equivalent (tce)	Tonnes of oil equivalent (toe)	Barrels of oil equivalent (boe)	GJ*
Coal	tonne	1.00	0.70	5.05	29.3**
Firewood (air-dried)	tonne	0.46	0.32	2.34	13.6
Kerosene	tonne	1.47	1.03	7.43	43.1
Natural gas	$1000m^3$	1.19	0.83	6.00	34.8
Gasoline (petrol)	barrel***	0.18	0.12	0.90	5.2
Gasoil/diesel	barrel***	0.20	0.14	1.00	5.7

* GJ/tonne is numerically equivalent to MJ/kg
** The energy content of 1 tce and 1 toe varies. The values used here are the European Community norms:
1 tce = 29.31×10^9 J and 1 toe = 41.868×10^9 J
*** 1 barrel of oil = 42 US gallons = $0.158987m^3$

Conversion factors

Power equivalents

	Mtoe/yr	*Mbd*	*Mtce/yr*	*GW_{th}*	*PJ/yr*
Mtoe/yr	1	0.02	1.55	1.43	45
Mbd	50	1	77	71	2235
Mtce/yr	0.65	0.013	1	0.92	29
GW_{th}	0.70	0.014	1.09	1	32
PJ/yr	0.02	4.5×10^{-4}	0.034	0.031	1

Mtoe/yr = Million tonnes of oil per year
Mbd = Million barrels of oil per day
Mtce/yr = Million tonnes of coal equivalent per year
GW_{th} = Gigawatts thermal (see page 203 for further information)
PJ/yr = Petrajoules per year

APPENDIX B

CURRENT CARRYING CAPACITY OF COPPER WIRE

The ratings in the following tabulations are those permitted by the National Electrical Code for flexible cords and for interior wiring of houses, hotels, office buildings, industrial plants, and other buildings.

The values are for copper wire. For aluminum wire the allowable carrying capacities shall be taken as 84% of those given in the table for the respective sizes of copper wire with the same kind of covering.

Size A.W.G.	Area Circular (mils)	Diameter of Solid Wires (mils)	Rubber Insulation (amperes)	Varnished Cambric Insulation (amperes)	Other Insulations and Bare Conductors (amperes)
24	404	20.1	–	–	1.5
22	642	25.3	–	–	2.5
20	1,022	32.0	–	–	4
18	1,624	40.3	3*	–	6**
16	2,583	50.8	6*	–	10**
14	4,107	64.1	15	18	20
12	6,530	80.8	20	25	30
10	10,380	101.9	25	30	35
8	16,510	128.5	35	40	50
6	26,250	162.0	50	60	70
5	33,100	181.9	55	65	80
4	41,740	204.3	70	85	90
3	52,630	229.4	80	95	100
2	66,370	257.6	90	110	125

Note: 1 mil = 0.001 inch.

*The allowable carrying capacities of No. 18 and 16 are 5 and 7 amperes, respectively, when in flexible cords.

**The allowable carrying capacities of No. 18 and 16 are 10 and 15 amperes, respectively, when in cords for portable heaters. Types AFS, AFSI, HC, HPD, and HSJ.

APPENDIX C

CONVERSION FACTORS

To Change	Into	Multiply by
BTU	cal	252
BTU	joules	1,055
BTU	kcal	0.252
BTU	kWh	2.93×10^{-4}
BTU ft^{-2}	langleys ($cal\ cm^{-2}$)	0.271
cal	BTU	3.97×10^{-5}
cal	ft-lb	3.09
cal	joules	4.184
cal	kcal	0.001
cal min^{-1}	watts	0.0698
cm	inches	0.394
cc or cm^3	$in.^3$	0.0610
ft^3	liters	28.3
$in.^3$	cc or cm^3	16.4
ft	m	0.305
ft-lb	cal	0.324
ft-lb	joules	1.36
ft-lb	kg-m	0.138
ft-lb	kWh	3.77×10^{-7}
gal	liters	3.79
hp	kW	0.745
inches	cm	2.54
joules	BTU	9.48×10^{-4}
joules	cal	0.239
joules	ft-lb	0.738
kcal	BTU	3.97
kcal	cal	1,000
kcal min^{-1}	kW	0.0698
kg-m	ft-lb	7.23
kg	lb	2.20
kW	hp	1.34
kWh	BTU	3,413

kWh	ft-lb	2.66×10^6
kW	kcal min^{-1}	14.3
langleys (cal cm^2)	BTU ft^{-2}	3.69
langleys min^{-1} (cal cm^{-2} min^{-1})	watts cm^{-2}	0.0698
liters	gal	0.264
liters	qt	1.06
m	ft	3.28
lb	kg	0.454
qt	liters	0.946
cm^2	ft^2	0.00108
cm^2	in.^{2}	0.155
ft^2	m^2	0.0929
m^2	ft^2	10.8
watts cm^{-2}	langleys min^{-1} (cal cm^2)	14.3

Conversions: length

Use of the table: the number of inches to be converted, which is made up by the number of inches at the head of a column and the fraction at the side of a line, is converted to the number in the position where line and column meet.
For example, 1 1/64 in = 1 in + 1/64 in = 25.797 mm

Inches and fractions of an inch to Millimetres 1 in = 25.4 mm

in → ↓	0	1	2	3	4	5	6	7	8	9	10	11	← in ↓
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	254.000	279.400	0
1/64	0.397	25.797	51.197	76.597	101.997	127.397	152.797	178.197	203.597	228.997	254.397	279.797	1/64
1/32	0.794	26.194	51.594	76.994	102.394	127.794	153.194	178.594	203.994	229.394	254.794	280.194	1/32
3/64	1.191	26.591	51.991	77.391	102.791	128.191	153.591	178.991	204.391	229.791	255.191	280.591	3/64
1/16	1.588	26.988	52.388	77.788	103.188	128.588	153.988	179.388	204.788	230.188	255.588	280.988	1/16
5/64	1.984	27.384	52.784	78.184	103.584	128.984	154.384	179.784	205.184	230.584	255.984	281.384	5/64
3/32	2.381	27.781	53.181	78.581	103.981	129.381	154.781	180.181	205.581	230.981	256.381	281.781	3/32
7/64	2.778	28.178	53.578	78.978	104.378	129.778	155.178	180.578	205.978	231.378	256.778	282.178	7/64
1/8	3.175	28.575	53.975	79.375	104.775	130.175	155.575	180.975	206.375	231.775	257.175	282.575	1/8
9/64	3.572	28.972	54.372	79.772	105.172	130.572	155.972	181.372	206.772	232.172	257.572	282.972	9/64
5/32	3.969	29.369	54.769	80.169	105.569	130.969	156.369	181.769	207.169	232.569	257.969	283.369	5/32
11/64	4.366	29.766	55.166	80.566	105.966	131.366	156.766	182.166	207.566	232.966	258.366	283.766	11/64
3/16	4.762	30.162	55.562	80.962	106.362	131.762	157.162	182.562	207.962	233.362	258.762	284.162	3/16
13/64	5.159	30.559	55.959	81.359	106.759	132.159	157.559	182.959	208.359	233.759	259.159	284.559	13/64
7/32	5.556	30.956	56.356	81.756	107.156	132.556	157.956	183.356	208.756	234.156	259.556	284.956	7/32
15/64	5.953	31.353	56.753	82.153	107.553	132.953	158.353	183.753	209.153	234.553	259.953	285.353	15/64
1/4	6.350	31.750	57.150	82.550	107.950	133.350	158.750	184.150	209.550	234.950	260.350	285.750	1/4
17/64	6.747	32.147	57.547	82.947	108.347	133.747	159.147	184.547	209.947	235.347	260.747	286.147	17/64
9/32	7.144	32.544	57.944	83.344	108.744	134.144	159.544	184.944	210.344	235.744	261.144	286.544	9/32
19/64	7.541	32.941	58.341	83.741	109.141	134.541	159.941	185.341	210.741	236.141	261.541	286.941	19/64
5/16	7.938	33.338	58.738	84.138	109.538	134.938	160.338	185.738	211.138	236.538	261.938	287.338	5/16
21/64	8.334	33.734	59.134	84.534	109.934	135.334	160.734	186.134	211.534	236.934	262.334	287.734	21/64
11/32	8.731	34.131	59.531	84.931	110.331	135.731	161.131	186.531	211.931	237.331	262.731	288.131	11/32
23/64	9.128	34.528	59.928	85.328	110.728	136.128	161.528	186.928	212.328	237.728	263.128	288.528	23/64
3/8	9.525	34.925	60.325	85.725	111.125	136.525	161.925	187.325	212.725	238.125	263.525	288.925	3/8
25/64	9.922	35.322	60.722	86.122	111.522	136.922	162.322	187.722	213.122	238.522	263.922	289.322	25/64
13/32	10.319	35.719	61.119	86.519	111.919	137.319	162.719	188.119	213.519	238.919	264.319	289.719	13/32
27/64	10.716	36.116	61.516	86.916	112.316	137.716	163.116	188.516	213.916	239.316	264.716	290.116	27/64
7/16	11.112	36.512	61.912	87.312	112.712	138.112	163.512	188.912	214.312	239.712	265.112	290.512	7/16
29/64	11.509	36.909	62.309	87.709	113.109	138.509	163.909	189.309	214.709	240.109	265.509	290.909	29/64
15/32	11.906	37.306	62.706	88.106	113.506	138.906	164.306	189.706	215.106	240.506	265.906	291.306	15/32
31/64	12.303	37.703	63.103	88.503	113.903	139.303	164.703	190.103	215.503	240.903	266.303	291.703	31/64
1/2	12.700	38.100	63.500	88.900	114.300	139.700	165.100	190.500	215.900	241.300	266.700	292.100	1/2
33/64	13.097	38.497	63.897	89.297	114.697	140.097	165.497	190.897	216.297	241.697	267.097	292.497	33/64
17/32	13.494	38.894	64.294	89.694	115.094	140.494	165.894	191.294	216.694	242.094	267.494	292.894	17/32
35/64	13.891	39.291	64.691	90.091	115.491	140.891	166.291	191.691	217.091	242.491	267.891	293.291	35/64
9/16	14.288	39.688	65.088	90.488	115.888	141.288	166.688	192.088	217.488	242.888	268.288	293.688	9/16
37/64	14.684	40.084	65.484	90.884	116.284	141.684	167.084	192.484	217.884	243.284	268.684	294.084	37/64
19/32	15.081	40.481	65.881	91.281	116.681	142.081	167.481	192.881	218.281	243.681	269.081	294.481	19/32
39/64	15.478	40.878	66.278	91.678	117.078	142.478	167.878	193.278	218.678	244.078	269.478	294.878	39/64
5/8	15.875	41.275	66.675	92.075	117.475	142.875	168.275	193.675	219.075	244.475	269.875	295.275	5/8
41/64	16.272	41.672	67.072	92.472	117.872	143.272	168.672	194.072	219.472	244.872	270.272	295.672	41/64
21/32	16.669	42.069	67.469	92.869	118.269	143.669	169.069	194.469	219.869	245.269	270.669	296.069	21/32
43/64	17.066	42.466	67.866	93.266	118.666	144.066	169.466	194.866	220.266	245.666	271.066	296.466	43/64
11/16	17.462	42.862	68.262	93.662	119.062	144.462	169.862	195.262	220.662	246.062	271.462	296.862	11/16
45/64	17.859	43.259	68.659	94.059	119.459	144.859	170.259	195.659	221.059	246.459	271.859	297.259	45/64
23/32	18.256	43.656	69.056	94.456	119.856	145.256	170.656	196.056	221.456	246.856	272.256	297.656	23/32
47/64	18.653	44.053	69.453	94.853	120.253	145.653	171.053	196.453	221.853	247.253	272.653	298.053	47/64
3/4	19.050	44.450	69.850	95.250	120.650	146.050	171.450	196.850	222.250	247.650	273.050	298.450	3/4
49/64	19.447	44.847	70.247	95.647	121.047	146.447	171.847	197.247	222.647	248.047	273.447	298.847	49/64
25/32	19.844	45.244	70.644	96.044	121.444	146.844	172.244	197.644	223.044	248.444	273.844	299.244	25/32
51/64	20.241	45.641	71.041	96.441	121.841	147.241	172.641	198.041	223.441	248.841	274.241	299.641	51/64
13/16	20.638	46.038	71.438	96.838	122.238	147.638	173.038	198.438	223.838	249.238	274.638	300.038	13/16
53/64	21.034	46.434	71.834	97.234	122.634	148.034	173.434	198.834	224.234	249.634	275.034	300.434	53/64
27/32	21.431	46.831	72.231	97.631	123.031	148.431	173.831	199.231	224.631	250.031	275.431	300.831	27/32
55/64	21.828	47.228	72.628	98.028	123.428	148.828	174.228	199.628	225.028	250.428	275.828	301.228	55/64
7/8	22.225	47.625	73.025	98.425	123.825	149.225	174.625	200.025	225.425	250.825	276.225	301.625	7/8
57/64	22.622	48.022	73.422	98.822	124.222	149.622	175.022	200.422	225.822	251.222	276.622	302.022	57/64
29/32	23.019	48.419	73.819	99.219	124.619	150.019	175.419	200.819	226.219	251.619	277.019	302.419	29/32
59/64	23.416	48.816	74.216	99.616	125.016	150.416	175.816	201.216	226.616	252.016	277.416	302 816	59/64
15/16	23.812	49.212	74.612	100.012	125.412	150.812	176.212	201.612	227.012	252.412	277.812	303.212	15/16
61/64	24.209	49.609	75.009	100.409	125.809	151.209	176.609	202.009	227.409	252.809	278.209	303.609	61/64
31/32	24.606	50.006	75.406	100.806	126.206	151.606	177.006	202.406	227.806	253.206	278.606	304.006	31/32
63/64	25.003	50.403	75.803	101.203	126.603	152.003	177.403	202.803	228.203	253.603	279.003	304.403	63/64

Use of the tables: the number to be converted, which is made up by adding the unit at the side of a line to the unit at the head of a column, is converted to the number in the position where line and column meet.
For example, 11 in = 10 in + 1 in = 279.400 mm

Inches to Millimetres   1 in = 25.4 mm

Note. This table can also be used for converting milli-inches (mils or 'thou') to micrometres ('microns')

in ↓ / in →	0	1	2	3	4	5	6	7	8	9	← in ↓
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	0
10	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	10
20	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	20
30	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	30
40	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	40
50	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	50
60	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	60
70	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	1955.800	1981.200	2006.600	70
80	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	80
90	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	90
100	2540.000										100

in ↓ / in →	0	10	20	30	40	50	60	70	80	90	← in ↓
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	
0	0.000	254.000	508.000	762.000	1016.000	1270.000	1524.000	1778.000	2032.000	2286.000	0
100	2540.000	2794.000	3048.000	3302.000	3556.000	3810.000	4064.000	4318.000	4572.000	4826.000	100
200	5080.000	5334.000	5588.000	5842.000	6096.000	6350.000	6604.000	6858.000	7112.000	7366.000	200
300	7620.000	7874.000	8128.000	8382.000	8636.000	8890.000	9144.000	9398.000	9652.000	9906.000	300
400	10160.000	10414.000	10668.000	10922.000	11176.000	11430.000	11684.000	11938.000	12192.000	12446.000	400
500	12700.000	12954.000	13208.000	13462.000	13716.000	13970.000	14224.000	14478.000	14732.000	14986.000	500
600	15240.000	15494.000	15748.000	16002.000	16256.000	16510.000	16764.000	17018.000	17272.000	17526.000	600
700	17780.000	18034.000	18288.000	18542.000	18796.000	19050.000	19304.000	19558.000	19812.000	20066.000	700
800	20320.000	20574.000	20828.000	21082.000	21336.000	21590.000	21844.000	22098.000	22352.000	22606.000	800
900	22860.000	23114.000	23368.000	23622.000	23876.000	24130.000	24384.000	24638.000	24892.000	25146.000	900
1000	25400.000										1000

Millimetres to Inches   1 mm = 0.039 370 in

Note. This table can also be used for converting micrometres ('microns') to milli-inches (mils or 'thou')

mm ↓ / mm →	0	1	2	3	4	5	6	7	8	9	← mm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	0.039	0.079	0.118	0.157	0.197	0.236	0.276	0.315	0.354	0
10	0.394	0.433	0.472	0.512	0.551	0.591	0.630	0.669	0.709	0.748	10
20	0.787	0.827	0.866	0.906	0.945	0.984	1.024	1.063	1.102	1.142	20
30	1.181	1.220	1.260	1.299	1.339	1.378	1.417	1.457	1.496	1.535	30
40	1.575	1.614	1.654	1.693	1.732	1.772	1.811	1.850	1.890	1.929	40
50	1.969	2.008	2.047	2.087	2.126	2.165	2.205	2.244	2.283	2.323	50
60	2.362	2.402	2.441	2.480	2.520	2.559	2.598	2.638	2.677	2.717	60
70	2.756	2.795	2.835	2.874	2.913	2.953	2.992	3.031	3.071	3.110	70
80	3.150	3.189	3.228	3.268	3.307	3.346	3.386	3.425	3.465	3.504	80
90	3.543	3.583	3.622	3.661	3.701	3.740	3.780	3.819	3.858	3.898	90
100	3.937										100

mm ↓ / mm →	0	10	20	30	40	50	60	70	80	90	← mm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
100	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	100
200	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	200
300	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	300
400	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	400
500	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23 228	500
600	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	600
700	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	700
800	31.496	31.890	32.283	32.677	33.071	33.465	33:858	34.252	34.646	35.039	800
900	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	900
1000	39.370										1000

Conversions: length

Use of the tables: the number to be converted, which is made up by adding the unit at the side of a line to the unit at the head of a column, is converted to the number in the position where line and column meet.
For example, 11 in = 10 in + 1 in = 27.940 cm

Inches to Centimetres 1 in = 2.54 cm

in → ↓	0	1	2	3	4	5	6	7	8	9	← in ↓
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	
0	0.000	2.540	5.080	7.620	10.160	12.700	15.240	17.780	20.320	22.860	0
10	25.400	27.940	30.480	33.020	35.560	38.100	40.640	43.180	45.720	48.260	10
20	50.800	53.340	55.880	58.420	60.960	63.500	66.040	68.580	71.120	73.660	20
30	76.200	78.740	81.280	83.820	86.360	88.900	91.440	93.980	96.520	99.060	30
40	101.600	104.140	106.680	109.220	111.760	114.300	116.840	119.380	121.920	124.460	40
50	127.000	129.540	132.080	134.620	137.160	139.700	142.240	144.780	147.320	149.860	50
60	152.400	154.940	157.480	160.020	162.560	165.100	167.640	170.180	172.720	175.260	60
70	177.800	180.340	182.880	185.420	187.960	190.500	193.040	195.580	198.120	200.660	70
80	203.200	205.740	208.280	210.820	213.360	215.900	218.440	220.980	223.520	226.060	80
90	228.600	231.140	233.680	236.220	238.760	241.300	243.840	246.380	248.920	251.460	90
100	254.000										100

in → ↓	0	10	20	30	40	50	60	70	80	90	← in ↓
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	
0	0.000	25.400	50.800	76.200	101.600	127.000	152.400	177.800	203.200	228.600	0
100	254.000	279.400	304.800	330.200	355.600	381.000	406.400	431.800	457.200	482.600	100
200	508.000	533.400	558.800	584.200	609.600	635.000	660.400	685.800	711.200	736.600	200
300	762.000	787.400	812.800	838.200	863.600	889.000	914.400	939.800	965.200	990.600	300
400	1016.000	1041.400	1066.800	1092.200	1117.600	1143.000	1168.400	1193.800	1219.200	1244.600	400
500	1270.000	1295.400	1320.800	1346.200	1371.600	1397.000	1422.400	1447.800	1473.200	1498.600	500
600	1524.000	1549.400	1574.800	1600.200	1625.600	1651.000	1676.400	1701.800	1727.200	1752.600	600
700	1778.000	1803.400	1828.800	1854.200	1879.600	1905.000	1930.400	195 .800	1981.200	2006.600	700
800	2032.000	2057.400	2082.800	2108.200	2133.600	2159.000	2184.400	2209.800	2235.200	2260.600	800
900	2286.000	2311.400	2336.800	2362.200	2387.600	2413.000	2438.400	2463.800	2489.200	2514.600	900
1000	2540.000										1000

Centimetres to Inches 1 cm = 0.393 701 in

cm → ↓	0	1	2	3	4	5	6	7	8	9	← cm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	0.394	0.787	1.181	1.575	1.969	2.362	2.756	3.150	3.543	0
10	3.937	4.331	4.724	5.118	5.512	5.906	6.299	6.693	7.087	7.480	10
20	7.874	8.268	8.661	9.055	9.449	9.843	10.236	10.630	11.024	11.417	20
30	11.811	12.205	12.598	12.992	13.386	13.780	14.173	14.567	14.961	15.354	30
40	15.748	16.142	16.535	16.929	17.323	17.717	18.110	18.504	18.898	19.291	40
50	19.685	20.079	20.472	20.866	21.260	21.654	22.047	22.441	22.835	23.228	50
60	23.622	24.016	24.409	24.803	25.197	25.591	25.984	26.378	26.772	27.165	60
70	27.559	27.953	28.346	28.740	29.134	29.528	29.921	30.315	30.709	31.102	70
80	31.496	31.890	32.283	32.677	33.071	33.465	33.858	34.252	34.646	35.039	80
90	35.433	35.827	36.220	36.614	37.008	37.402	37.795	38.189	38.583	38.976	90
100	39.370										100

cm → ↓	0	10	20	30	40	50	60	70	80	90	← cm ↓
	in	in	in	in	in	in	in	in	in	in	
0	0.000	3.937	7.874	11.811	15.748	19.685	23.622	27.559	31.496	35.433	0
100	39.370	43.307	47.244	51.181	55.118	59.055	62.992	66.929	70.866	74.803	100
200	78.740	82.677	86.614	90.551	94.488	98.425	102.362	106.299	110.236	114.173	200
300	118.110	122.047	125.984	129.921	133.858	137.795	141.732	145.669	149.606	153.543	300
400	157.480	161.417	165.354	169.291	173.228	177.165	181.102	185.039	188.976	192.913	400
500	196.850	200.787	204.724	208.661	212.598	216.535	220.472	224.409	228.346	232.283	500
600	236.220	240.157	244.094	248.031	251.969	255.906	259.843	263.780	267.717	271.654	600
700	275.591	279.528	283.465	287.402	291.339	295.276	299.213	303.150	307.087	311.024	700
800	314.961	318.898	322.835	326.772	330.709	334.646	338.583	342.520	346.457	350.394	800
900	354.331	358.268	362.205	366.142	370.079	374.016	377.953	381.890	385.827	389.764	900
1000	393.701										1000

Fractions to Decimals

Fraction	Decimal equivalent	Fraction	Decimal equivalent
1/2	0.5	1/32	0.031 25
1/3	0.333 333	1/33	0.030 303
1/4	0.25	1/34	0.029 412
1/5	0.2	1/35	0.028 571
1/6	0.166 667	1/36	0.027 778
1/7	0.142 857	1/37	0.027 027
1/8	0.125	1/38	0.026 316
1/9	0.111 111	1/39	0.025 641
1/10	0.1	1/40	0.025
1/11	0.090 909	1/41	0.024 390
1/12	0.083 333	1/42	0.023 810
1/13	0.076 923	1/43	0.023 256
1/14	0.071 429	1/44	0.022 727
1/15	0.066 667	1/45	0.022 222
1/16	0.062 5	1/46	0.021 739
1/17	0.058 824	1/47	0.021 277
1/18	0.055 556	1/48	0.020 833
1/19	0.052 632	1/49	0.020 408
1/20	0.05	1/50	0.02
1/21	0.047 619	1/51	0.019 608
1/22	0.045 455	1/52	0.019 231
1/23	0.043 478	1/53	0.018 868
1/24	0.041 667	1/54	0.018 519
1/25	0.04	1/55	0.018 182
1/26	0.038 462	1/56	0.017 857
1/27	0.037 037	1/57	0.017 544
1/28	0.035 714	1/58	0.017 241
1/29	0.034 483	1/59	0.016 949
1/30	0.033 333	1/60	0.016 667
1/31	0.032 258		

Note. For the decimal equivalent of other fractions with 1 as numerator, and a number from 0.01 to 100.9 as denominator, see reciprocals, pages 144–147.

Fractions 3rds	6ths	12ths	24ths	Decimal equivalent
			1	0.041 667
		1	2	0.083 333
			3	0.125
	1	2	4	0.166 667
			5	0.208 333
		3	6	0.25
			7	0.291 667
1	2	4	8	0.333 333
			9	0.375
		5	10	0.416 667
			11	0.458 333
	3	6	12	0.5
			13	0.541 667
		7	14	0.583 333
			15	0.625
2	4	8	16	0.666 667
			17	0.708 333
		9	18	0.75
			19	0.791 667
	5	10	20	0.833 333
			21	0.875
		11	22	0.916 667
			23	0.958 333
3	6	12	24	1

Fractions 1/2's	1/4's	8ths	16ths	32nds	64ths	Decimal equivalent (all figures are exact)
					1	0.015 625
				1	2	0.031 25
					3	0.046 875
			1	2	4	0.062 5
					5	0.078 125
				3	6	0.093 75
					7	0.109 375
		1	2	4	8	0.125
					9	0.140 625
				5	10	0.156 25
					11	0.171 875
			3	6	12	0.187 5
					13	0.203 125
				7	14	0.218 75
					15	0.234 375
	1	2	4	8	16	0.25
					17	0.265 625
				9	18	0.281 25
					19	0.296 875
			5	10	20	0.312 5
					21	0.328 125
				11	22	0.343 75
					23	0.359 375
		3	6	12	24	0.375
					25	0.390 625
				13	26	0.406 25
					27	0.421 875
			7	14	28	0.437 5
					29	0.453 125
				15	30	0.468 75
					31	0.484 375
1	2	4	8	16	32	0.5
					33	0.515 625
				17	34	0.531 25
					35	0.546 875
			9	18	36	0.562 5
					37	0.578 125
				19	38	0.593 75
					39	0.609 375
		5	10	20	40	0.625
					41	0.640 625
				21	42	0.656 25
					43	0.671 875
			11	22	44	0.687 5
					45	0.703 125
				23	46	0.718 75
					47	0.734 375
	3	6	12	24	48	0.75
					49	0.765 625
				25	50	0.781 25
					51	0.796 875
			13	26	52	0.812 5
					53	0.828 125
				27	54	0.843 75
					55	0.859 375
		7	14	28	56	0.875
					57	0.890 625
				29	58	0.906 25
					59	0.921 875
			15	30	60	0.937 5
					61	0.953 125
				31	62	0.968 75
					63	0.984 375
2	4	8	16	32	64	1

§ 35. The Parabola. Derivation of the Canonical Equation of the Parabola

101. *A parabola is the locus of points whose distance from a fixed point (called the focus) in the plane is equal to their distance from a fixed straight line (called the directrix* and assumed not to pass through the focus).

It is customary to denote the focus of a parabola by the letter F, and the distance from the focus to the directrix by the letter p. The quantity p is called *the parameter* of a parabola. The curve is shown in Fig. 61 (the details of the drawing are fully explained in the next few articles).

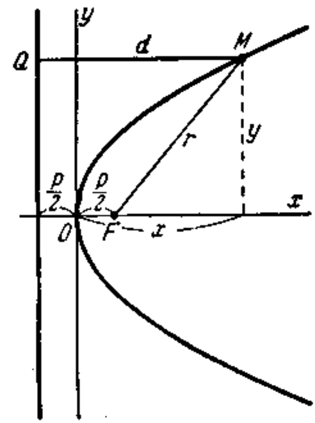


Fig. 61.

Note. In accordance with Art. 100, *a parabola is said to have eccentricity* $\varepsilon = 1$.

102. Let there be given a parabola (we assume that the parameter p is also given). Let us attach to the plane a rectangular cartesian coordinate system, whose axes are specially chosen with respect to the given parabola; namely, let the x-axis be drawn through the focus perpendicular to the directrix, the direction from the directrix to the focus adopted as positive on the x-axis, and the origin placed midway between the focus and the directrix (Fig. 61). We now proceed to derive the equation of the given parabola in this coordinate system.

Take an arbitrary point M in the plane and designate its coordinates as x and y. Let r denote the distance of the point M from the focus ($r = FM$), and d the distance of the point M from the directrix. The point M will lie on the given parabola if, and only if,

$$r = d. \tag{1}$$

In order to obtain the desired equation, it is necessary to express the variables r and d in terms of the current coordinates x, y and to substitute these expressions in (1). Note that the coordinates of the focus F are $\left(\frac{p}{2}, 0\right)$; bearing this in mind and using formula (2) of Art. 18, we find

$$r = \sqrt{\left(x - \frac{p}{2}\right)^2 + y^2}. \tag{2}$$

Denote by Q the foot of the perpendicular dropped from M upon the directrix. The coordinates of the point Q will clearly be $\left(-\frac{p}{2}, y\right)$; hence, by formula (2) of Art. 18, we obtain

$$d = MQ = \sqrt{\left(x+\frac{p}{2}\right)^2 + (y-y)^2} = x + \frac{p}{2} \qquad (3)$$

(on extracting the root, we take $x+\frac{p}{2}$ with its original sign since $x+\frac{p}{2}$ is a positive number; this follows from the fact that the point $M(x, y)$ must lie on that side of the directrix where the focus is situated, that is, we must have $x > -\frac{p}{2}$, whence $x+\frac{p}{2} > 0$). Substituting expressions (2) and (3) for r and d in (1), we find

$$\sqrt{\left(x-\frac{p}{2}\right)^2 + y^2} = x + \frac{p}{2}. \qquad (4)$$

The coordinates of a point $M(x, y)$ satisfy equation (4) if, and only if, the point M lies on the given parabola; accordingly, (4) is the equation of this parabola referred to the chosen coordinate system.

To reduce the equation of the parabola to a simpler form, we square both members of (4), which gives

$$x^2 - px + \frac{p^2}{4} + y^2 = x^2 + px + \frac{p^2}{4}, \qquad (5)$$

or

$$y^2 = 2px. \qquad (6)$$

We have derived equation (6) as a consequence of equation (4). It is easy to show that equation (4) may, in its turn, be derived as a consequence of (6). In fact, equation (5) is readily obtained from (6) by "retracing steps"; next, from (5) we get

$$\sqrt{\left(x-\frac{p}{2}\right)^2 + y^2} = \pm\left(x + \frac{p}{2}\right).$$

It remains to show that, if x, y satisfy equation (6), then the plus sign is here the only sign to choose. But this is clear since, from (6), $x = \frac{y^2}{2p}$ and, consequently, $x \geqslant 0$, so that $x+\frac{p}{2}$ is a positive number. Thus, we have come back to equation (4). Since each of equations (4) and (6) is a consequence of the other, they are equivalent. We hence conclude that *equation* (6) *is the equa-*

tion of the parabola. This equation is called the *canonical* equation of the parabola.

103. The equation $y^2 = 2px$, which represents the parabola in a certain system of rectangular cartesian coordinates is an equation of the second degree; accordingly, *the parabola is a curve of the second order.*

§ 36. Discussion of the Shape of the Parabola

104. Let us analyse the equation

$$y^2 = 2px \qquad (1)$$

in order to form a clear idea of the shape of the parabola and thereby to show the correctness of its representation in Fig. 61.

Since equation (1) contains y only in an even power, the parabola represented by it is symmetrical with respect to the axis Ox. It will therefore be sufficient to investigate only the portion of the parabola which lies in the upper half-plane. This portion is represented by the equation

$$y = +\sqrt{2px}. \qquad (2)$$

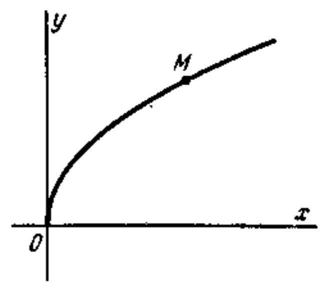


Fig. 62.

For negative values of x, equation (2) gives imaginary values of y. Consequently, no point of the parabola appears to the left of the axis Oy. For $x = 0$, we have $y = 0$. Hence the origin lies on the parabola and is its extreme "left" point. Equation (2) shows that, as x increases from zero, y continually increases. The equation also shows that, as $x \to +\infty$, $y \to +\infty$.

Thus, the variable point $M(x, y)$, which traces the portion of the parabola under consideration, moves to the "right" and "upwards", starting from the origin and receding indefinitely from both the axis Oy (to the "right") and the axis Ox ("upwards"; see Fig. 62).

Note. The following two properties of the parabola are also of importance: (1) the direction of the parabola is perpendicular to the axis Ox in the point $O(0, 0)$; (2) the portion of the parabola in the upper half-plane is convex "upwards". The graph in Fig. 62 has been drawn in accordance with these properties. Their proof will not, however, be given here, since the most natural methods for curve analysis of such kind are those furnished by the calculus.

105. Now that we have established the shape of the portion of the parabola lying in the upper half-plane, the determination of the shape of the entire parabola will present no difficulties; we have merely to reflect this portion of the curve in the axis Ox. The above-discussed Fig. 61 gives a general idea of the entire parabola represented by the equation

$$y^2 = 2px.$$

Usually the axis of symmetry of a parabola is referred to simply as its *axis* (in the case under consideration, the axis of the parabola coincides with the axis Ox). The point where a parabola cuts its axis is called *the vertex of the parabola* (in our case, the vertex is coincident with the origin). The number p, that is, the parameter of a parabola, represents the distance between the focus and the directrix. The geometric meaning of the parameter p may also be described as follows. Take some definite value of the abscissa, say $x = 1$, and find from equation (1) the corresponding values of the ordinate: $y = \pm\sqrt{2p}$. We obtain two points of the parabola, $M_1(1, +\sqrt{2p})$ and $M_2(1, -\sqrt{2p})$, symmetric with respect to the axis; the distance between these points is equal to $2\sqrt{2p}$. Thus, $2\sqrt{2p}$ is the length of the chord perpendicular to the axis and one unit of length distant from the vertex. We see that the length $(=2\sqrt{2p})$ of this chord of the parabola increases with p. Consequently, the parameter p characterises the "spread" of a parabola, provided that this "spread" is measured perpendicular to the axis at a definite distance from the vertex.

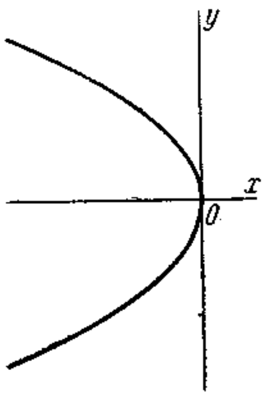


Fig. 63.

106. The equation

$$y^2 = -2px \tag{3}$$

(where p is positive) may be reduced to the equation $y^2 = 2px$ by substituting $-x$ for x, that is, by a transformation of coordinates corresponding to a reversal of the direction of the axis Ox. Hence, the equation $y^2 = -2px$ also represents a parabola whose axis is coincident with the axis Ox and whose vertex coincides with the origin; but this parabola is situated in the left half-plane, as shown in Fig. 63.

107. By analogy with the foregoing, we may assert that each of the equations

$$x^2 = 2py, \quad x^2 = -2py$$

(where $p > 0$) represents a parabola symmetric with respect to the axis Oy, with vertex at the origin (these equations, as well as equations (1) and (3), are referred to as the canonical equations of the parabola). A parabola represented by the equation $x^2 = 2py$ is said to open upwards; a parabola represented by

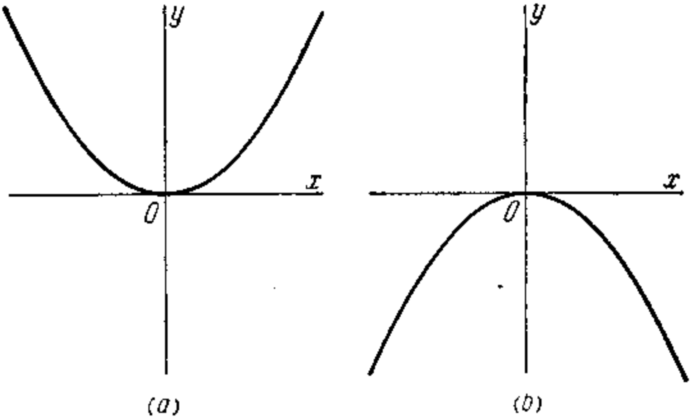


Fig. 64.

the equation $x^2 = -2py$ is said to open downwards (see Fig. 64 *a* and *b*, respectively); the use of these terms is natural and requires no further explanation.

Triangulation is an application of the principles of trigonometry to the calculation of inaccessible lines and angles.

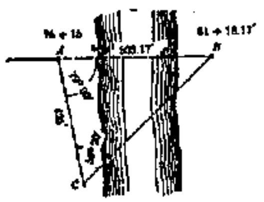


FIG. 1.

A common occasion for its use is illustrated in Fig. 1, where the line of survey crosses a stream too wide and deep for actual measurement. Set two points A and B on line, one on each side of the stream. Estimate roughly the distance $A\,B$. Suppose the estimate is 425 ft. Set another point C, making the distance $A\,C$ equal to the estimated distance $A\,B = 425$ ft. Set the transit at A and measure the angle $B\,A\,C =$ say, $79°\,00'$. Next set up at the point C and measure the angle $A\,C\,B =$ say, $56°\,20'$. The angle $A\,B\,C$ is then determined by subtracting the sum of the angles A and C from 180°; thus, $79°\,00' + 56°\,20' = 135°\,20'$; $180°\,00' - 135°\,20' = 44°\,40' =$ the angle $A\,B\,C$. We now have a side and three angles of a triangle given, to find the other two sides $A\,B$ and $C\,B$. In trigonometry, it is demonstrated that, *in any triangle the sines of the angles are proportional to the lengths of the sides opposite to them*. In other words, $\sin A : \sin B = B\,C : A\,C$; or, $\sin A : \sin C = B\,C : A\,B$, and $\sin B : \sin C = A\,C : A\,B$.

Hence, we have $\sin 44°\,40' : \sin 56°\,20' = 425 :$ side $A\,B$;

$\sin 56°\,20' = .83228$;
$.83228 \times 425 = 353.719$;
$\sin 44°\,40' = .70298$;
$353.719 \div .70298 = 503.17$ ft. $=$ side $A\,B$.

Adding this distance to $76 + 15$, the station of the point A, we have $81 + 18.17$, the station at B.

Another case is the following: Two tangents, $A\,B$ and $C\,D$ (see Fig. 2), which are to be united by a curve, meet at some inaccessible point E. Tangents are the straight portions of a line of railroad. The angle $C\,E\,F$, which the tangents make with each other, and the distances $B\,E$ and $C\,E$ are required. Two points A and B of the tangent $A\,B$, and two points C and D of the tangent $C\,D$, being carefully located, set the transit at B, and backsighting to A, measure the angle $E\,B\,C = 21°\,45'$; set up at C, and, backsighting to D, measure the angle $E\,C\,B = 21°\,25'$. Measure the side $B\,C = 304.2$ ft.

FIG. 2.

Angle $C\,E\,F$ being an exterior angle of triangle $E\,B\,C$ equals sum of $E\,B\,C$ and $E\,C\,B = 21°\,45' + 21°\,25' = 43°\,10'$; angle $B\,E\,C = 180° - C\,E\,F = 136°\,50'$. From trigonometry, we have:

$\sin 136°\,50' : \sin 21°\,45' = 304.2$ ft. $: C\,E$;
$\sin 21°\,45' = .37056$;
$.37056 \times 304.2 = 112.724352$;
$\sin 136°\,50' = .68412$;
side $C\,E = 112.724352 \div .68412 = 164.77$ ft.

Again, we find $B\,E$ by the following proportion:

$\sin 136°\,50' : \sin 21°\,25' = 304.2 :$ side $B\,E$;
$\sin 21°\,25' = .36515$;
$.36515 \times 304.2 = 111.07863$;
$\sin 136°\,50' = .68412$;
side $B\,E = 111.07863 \div .68412 = 162.36$ ft.

A building H, Fig. 3, lies directly in the path of the line $A\,B$, which must be produced beyond H. Set a plug at B, and then turn an angle $D\,B\,C = 60°$. Set a plug at C in the line $B\,C$, at a suitable distance from B, say, 150 ft. Set up at C, and turn an angle $B\,C\,D = 60°$, and set a plug at D, 150 ft. from C. The point D will be in the prolongation of $A\,B$. Then, set up at D, and backsighting to C, turn the angle $C\,D\,D' = 120°$. $D\,D'$ will be the line required, and the distance $B\,D$ will be 150 ft., since $B\,C\,D$ is an equilateral triangle.

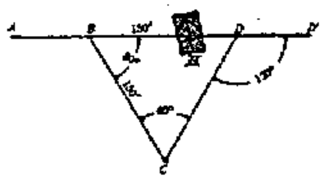


FIG. 3.

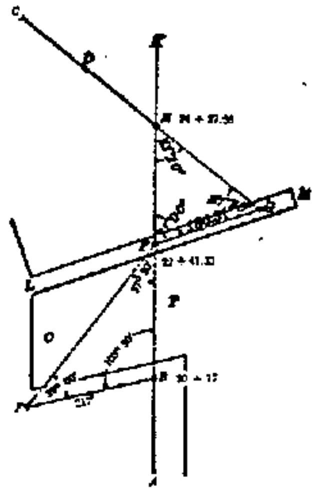


FIG. 4.

$A\,B$ and $C\,D$, Fig. 4, are tangents intersecting at some inaccessible point H. The line $A\,B$ crosses a dock $O\,P$, too wide for direct measurement, and the wharf $L\,M$. F is a point on the line $A\,B$ at the wharf crossing. It is required to find the distance $B\,H$ and the angle $F\,H\,G$. At B, an angle of $103°\,30'$ is turned to the left and the point E set 217' from $B =$ to the estimated distance $B\,F$. Setting up at E, the angle $B\,E\,F$ is found to be $39°\,00'$.

Whence, we find the angle $B\,F\,E = 180° - (103°\,30' + 39°) = 37°\,30'$.

From trigonometry, we have

$\sin 37°\,30' : \sin 39°\,00' = 217$ ft. $:$ side $B\,F$;
$\sin 39°\,00' = .62932$;
$.62932 \times 217 = 136.56244$;
$\sin 37°\,30' = .60876$;
side $B\,F = 136.56244 \div .60876 = 224.33$ ft.

Whence, we find station F to be $20 + 17 + 224.33 = 22 + 41.33$. Set up at F and turn an angle $H\,F\,G = 71°\,00'$ and set up at a point G where the line $C\,D$ prolonged intersects $F\,G$. Measure the angle $F\,G\,H = 57°\,50'$, and the side $F\,G = 180.3$. The angle $F\,H\,G = 180° - (71° + 57°\,50') = 51°\,10'$. From trigonometry we have

$\sin 51°\,10' : \sin 57°\,50' = 180.3 :$ side $F\,H$.

Sin $57°\,50' = .84650$; $.84650 \times 180.3 = 152.62395$; $\sin 51°\,10' = .77897$; side $F\,H = 152.62395 \div .77897 = 195.93$ ft.; whence we find station H to be $24 + 37.26$.

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	ADD 1′	2′	3′	4′	5′
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	18	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332		3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506		3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680		3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854		3	6	9	12	14
5	0·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028		3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201		3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374		3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547		3	6	9	11	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719		3	6	9	11	14
10	0·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891		3	6	9	11	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062		3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	17	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402		3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571		3	6	8	11	14
15	0·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740		3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907		3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074		3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239		3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404		3	5	8	11	14
20	0·3420	3437	3453	3469	3486	3502	3518	3535	3651	3567		3	5	8	11	14
21	·3684	3600	3616	3633	3649	3665	3681	3697	3714	3730		3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891		3	5	8	11	13
23	·3907	3923	3939	3965	3971	3987	4003	4019	4035	4051	16	3	5	8	11	13
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210		3	5	8	11	13
25	0·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368		3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524		3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679		3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833		3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985		3	5	8	10	13
30	0·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	15	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284		2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432		2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577		2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721		2	5	7	10	12
35	0·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864		2	5	7	9	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	14	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143		2	5	7	9	12
38	·6157	6170	6184	5198	6211	6225	6239	6252	6266	6280		2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414		2	4	7	9	11
40	0·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547		2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	13	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807		2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934		2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059		2	4	6	8	10
45	0·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181		2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	12	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420		2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536		2	4	6	8	10
49	0·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649		2	4	6	8	9

O
H

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	ADD 1′ 2′ 3′ 4′ 5′
50°	0·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760		2 4 6 7 9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	11	2 4 5 7 9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976		2 4 5 7 9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080		2 3 5 7 9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	10	2 3 5 7 8
55	0·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281		2 3 5 7 8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377		2 3 5 6 8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471		2 3 5 6 8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	9	2 3 5 6 8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652		1 3 4 6 7
60	0·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738		1 3 4 6 7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821		1 3 4 6 7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	8	1 3 4 5 7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980		1 3 4 6 6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056		1 3 4 5 6
65	0·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128		1 2 4 5 6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	7	1 2 4 6 6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265		1 2 3 4 6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330		1 2 3 4 5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	6	1 2 3 4 5
70	0·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449		1 2 3 4 5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505		1 2 3 4 5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558		1 2 3 3 4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	5	1 2 2 3 4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655		1 2 2 3 4
75	0·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699		1 1 2 3 4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	4	1 1 2 3 3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778		1 1 2 2 3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813		1 1 2 2 3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845		1 1 2 2 3
80	0·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	3	0 1 1 2 2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900		0 1 1 2 2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923		0 1 1 1 2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	2	0 1 1 1 2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960		0 1 1 1 1
85	0·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974		0 0 1 1 1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	1	0 0 1 1 1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993		
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998		See Table
89	0·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000		below.
90	1·0000											

Sines of Angles near 90°

° ′	sine	°	° ′	sine	°
86 48		86·80	87 46		87·7
	0·9985			0·9993	
86 54		86·91	87 56		87·9
	0·9986			0·9994	
87 01		87·02	88 05		88·0
	0·9987			0·9995	
87 08		87·13	88 16		88·2
	0·9988			0·9996	
87 15		87·25	88 29		88·4
	0·9989			0·9997	
87 22		87·37	88 43		88·7
	0·9990			0·9998	
87 30		87·50	89 00		89·0
	0·9991			0·9999	
87 38		87·63	89 25		89·4
	0·9992			1·0000	
87 46		87·78	90 00		90·0

The values in the centre columns represent the sines for all angles lying between the successive ranges shown in the outer columns. Thus sin 87° 20′ is 0·9989. For inverse use, the best angle for a given sine is the one lying midway between the adjacent ranges; if the difference is odd, choose the angle nearer 90°. Thus if sin x = 0·9988, x = 87° 12′.

For tabulated angles read the sine value in the half-line above; e.g., sin 87° 38′ = 0·9991.

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	SUBTRACT 1′	2′	3′	4′	5′
0°	1·000	1·000	1·000	1·000	1·000	1·000	0·9999	0·9999	0·9999	0·9999	·	See table at foot of page.				
1	0·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995						
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987						
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	1	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963		0	0	1	1	1
5	0·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947		0	1	1	1	1
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	2	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905		0	1	1	1	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880		0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	3	0	1	1	2	2
10	0·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820		1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785		1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748		1	1	2	2	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	4	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664		1	1	2	3	4
15	0·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617		1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	5	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516		1	2	3	3	4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461		1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403		1	2	3	4	5
20	0·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	6	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278		1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212		1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	7	1	2	4	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070		1	2	4	5	6
25	0·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996		1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918		1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	8	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8765		1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669		1	3	4	6	7
30	0·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581		1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	9	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396		2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300		2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202		2	3	5	7	8
35	0·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	10	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997		2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891		2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	11	2	4	5	7	9
39	0·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672		2	4	6	7	9

Cosines of Small Angles

° ′	cosine	°
0 00		0·0
	1·0000	
0 34		0·5
	0·9999	
0 59		0·9
	0·9998	
1 16		1·2
	0·9997	
1 30		1·5
	0·9996	
1 43		1·7
	0·9995	
1 54		1·9
	0·9994	
2 03		2·0
	0·9993	
2 13		2·2

° ′	cosine	°
2 13		2·21
	0·9992	
2 21		2·36
	0·9991	
2 29		2·49
	0·9990	
2 37		2·62
	0·9989	
2 44		2·74
	0·9988	
2 51		2·86
	0·9987	
2 58		2·97
	0·9986	
3 05		3·08
	0·9985	
3 11		3·19

This table is similar to that given for sines on page 15; thus

cos 2° 40′ = 0·9989
0·9986 = cos 3° 2′

A
H.

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	SUBTRACT 1′	2′	3′	4′	5′
40°	0·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559		2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443		2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325		2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	12	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083		2	4	6	8	10
45	0·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959		2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833		2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704		2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	13	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441		2	4	7	9	11
50	0·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307		2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170		2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032		2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	14	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750		2	5	7	9	12
55	0·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606		2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461		2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314		2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165		2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	15	3	5	8	10	13
60	0·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863		3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710		3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555		3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399		3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242		3	5	8	11	13
65	0·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083		3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	16	3	5	8	11	13
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762		3	5	8	11	13
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600		3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437		3	5	8	11	14
70	0·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272		3	5	8	11	14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107		3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940		3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773		3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605		3	6	8	11	14
75	0·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436		3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267		3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	17	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925		3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754		3	6	9	11	14
80	0·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582		3	6	9	11	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409		3	6	9	11	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236		3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063		3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889		3	6	9	12	14
85	0·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715		3	6	9	12	14
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541		3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366		3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192		3	6	9	12	15
89	0·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	18	3	6	9	12	15
90	0·0000															

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	ADD 1′	2′	3′	4′	5′
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	18	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332		3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507		3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682		3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857		3	6	9	12	15
5	0·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033		3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210		3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388		3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566		3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745		3	6	9	12	15
10	0·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926		3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107		3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290		3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475		3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661		3	6	9	12	16
15	0·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849		3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	19	3	6	10	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230		3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424		3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620		3	7	10	13	16
20	0·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	20	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020		3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224		3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431		3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	21	4	7	11	14	18
25	0·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856		4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	22	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	6228	6250	5272	5295		4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520		4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	6704	5727	5750	23	4	8	12	15	19
30	0·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985		4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	24	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469		4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	25	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976		4	9	13	17	21
35	0·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	26	4	9	13	17	22
36	·7266	7292	7319	7346	7373	7400	7427	7454	7481	7508	27	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	28	5	9	14	19	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069		5	10	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	29	5	10	15	19	24
40	0·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	30	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	31	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	32	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	33	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	34	6	11	17	23	28
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	36	6	12	18	24	30
46	·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	37	6	12	18	25	31
47	·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	38	6	13	19	25	32
48	·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	40	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708					41	7	14	20	27	34
						1708	1750	1792	1833	1875	42	7	14	21	28	35

O / A .

x	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ	ADD 1′	2′	3′	4′	5′
50°	1·192	196	200	205	209	213	217	222	226	230		1	1	2	3	4
51	·235	239	244	248	253	257	262	266	271	275		1	2	2	3	4
52	·280	285	289	294	299	303	308	313	317	322		1	2	2	3	4
53	·327	332	337	342	347	351	356	361	366	371		1	2	2	3	4
54	·376	381	387	392	397	402	407	412	418	423	5	1	2	3	3	4
55	1·428	433	439	444	450	455	460	466	471	477		1	2	3	4	5
56	·483	488	494	499	505	511	517	522	528	534		1	2	3	4	5
57	·540	546	552	558	564	570	576	582	588	594	6	1	2	3	4	5
58	·600	607	613	619	625	632	638	645	651	658		1	2	3	4	5
59	·664	671	678	684	691	698	704	711	718	725		1	2	3	5	6
60	1·732	739	746	753	760	767	775	782	789	797	7	1	2	4	5	6
61	·804	811	819	827	834	842	849	857	865	873		1	3	4	5	6
62	·881	889	897	905	913	921	929	937	946	954	8	1	3	4	5	7
63	1·963	971	980	988	1·997	2·006	2·014	2·023	2·032	2·041		1	3	4	6	7
64	2·050	059	069	078	087	097	106	116	125	135	9	2	3	5	6	8
65	2·145	154	164	174	184	194	204	215	225	236	10	2	3	5	7	8
66	·246	257	267	278	289	300	311	322	333	344	11	2	4	6	7	9
67	·356	367	379	391	402	414	426	438	450	463	12	2	4	6	8	10
68	·475	488	500	513	526	539	552	565	578	592	13	2	4	6	9	11
69	·605	619	633	646	660	675	689	703	718	733	14	2	5	7	9	12
70	2·747	762	778	793	808	824	840	856	872	888	16	3	5	8	11	13
71	2·904	921	937	954	971	2·989	3·006	3·024	3·042	3·060	17	3	6	9	11	14
72	3·078	096	115	133	152	3·172					19	3	6	9	13	16
						172	191	211	230	251	20	3	7	10	13	17
73	·271	291	312	333	354	376					21	4	7	10	14	18
						376	398	420	442	465	22	4	7	11	15	18
74	·487	511	534	558	582	606					24	4	8	12	16	20
						606	630	655	681	706	26	4	8	13	17	21
75	3·732	758	785	812	839	867					27	4	9	14	18	22
						867	895	923	952	981	29	5	10	14	19	24
76	4·011	041	071	102	134	4·165					31	5	10	16	21	26
						165	198	230	264	297	33	6	11	17	22	28
77	4·331	366	402	437	474	511					36	6	12	18	24	30
						511	548	586	625	665	39	6	13	19	26	32
78	4·705	745	787	829	872	4·915					42	7	14	21	28	35
						4·915	4·959	5·005	5·050	5·097	46	8	15	23	31	38
79	5·145	193	242	292	343	5·396					50	8	17	26	33	42
						396	449	503	558	614	55	9	18	28	37	46
80	5·671	5·730	5·789	5·850	5·912	5·976						10	20	30	41	51
						5·976	6·041	6·107	6·174	6·243		11	23	34	45	56
81	6·314	6·386	6·460	6·535	6·612	6·691						13	25	38	50	63
						6·691	6·772	6·855	6·940	7·026		14	28	42	57	71
82	7·115	7·207	7·300	7·396	7·495	7·596	7·700	7·806	7·916	8·028						
83	8·144	8·264	8·386	8·513	8·643	8·777	8·915	9·058	9·205	9·367						
84	9·514	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20						
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95						
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46						
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27						
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08						
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0						
90	∞															

Differences vary too rapidly for interpolation by P.P.s. See table on page 22.

P.P.s for differences exceeding 14, if not shown on this page, should be taken from the inside end cover of the book. For angles between 72° and 82° P.P.s based on actual differences should be used.