Basic Principles of Passive Solar Design

by: Fred Hopman

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BASIC PRINCIPLES OF PASSIVE SOLAR BUILDING DESIGN

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PREFACE

Traditionally Nepalis have designed and built their houses using some of the principles which are now being developed anew to capture and use the sun's energy to make the houses warmer. Sherpa houses, for example, have double sized windows, a big one to admit the sun's heat on warm days and a smaller one for less heat loss in cold weather. Roofs are insulated with straw, tiles, and stone plates and often they are extended over the windows to keep the sun out in summer.

The new designs and materials used in modern buildings often overlook the formerly used techniques. Concrete walls, cement plastering, flat roofs, big windows all around the building, etc., often bring disadvantages. Roofs leak; in winter it may be too hot on one side of the house in the daytime and freezing cold at night. In summer it is often just too hot to stay in the rooms on the south side.

The recently developing concepts of designing for efficient house heating with solar energy emphasize integrated planning so that all parts of the house contribute to the heating process. The functions of the three principle components of house heating are to admit heat during the warm part of the day, retain and store the heat, and to release it at night. For admitting heat large windows or solar collectors are oriented to the south, small or no windows on the other sides. Retention requires good insulation and adequate masses of heat absorbing materials in which to store the heat. These storage masses (eg. interior brick walls, interior water tanks, etc.) automatically release their heat as the rooms cool off at night.

Solar heating systems may be either "active" or "passive". Active systems use fans and pumps to move the heat about. Passive systems rely on natural thermo-syphoning and the so-called greenhouse effect. Since the passive systems use no forms of energy other than sun power, they are more appropriate for developing countries. This pamphlet describes passive systems only.

This paper is a reduced issue of a report by Mr. Fred Hopman who will publish a complete manual in the autumn of 1978. Here are presented only general principles and information about how the various solar heating systems work, as suggestions of things that might be useful in Nepal. Actual building takes further information and expertise. Several individuals asked for printed information when Mr. Hopman gave his lectures and slide shows during his visit to Nepal in February, 1978. With his cooperation this brochure is presented to fulfil those requests.

Kathmandu, April, 1978

Andreas Bachmann

S A T A

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INTRODUCTION

Solar energy has come to public attention in recent years as it is understood that the picture of fossil fuel consumption is limited. It is apparent that the present energy equation is not balanced. Using up energy reserves is an untenable situation, and the imbalance is reflected in our diseased biosphere. To be in balance, man cannot rely on energy that is not self-renewing. Alternate energy sources, aside from being self-renewing, have the advantages of being non-polluting, free (after the initial investment), and independent of a politically controlled energy source such as the electric grid or oil. This self-sufficiency has important implications as the modern world comes to understand the eruptive danger of energy dependence.

Furthermore, it is becoming evident that depleting forests for fuel has irreversible consequences such as soil erosion, destruction of the plant and animal ecology that depends on the forest, and far-reaching changes in the climate from a cooler,moister to a hotter, drier one as the humidity and evaporative cooling effect of the forest is eliminated. Another major consequence is the destruction of a resource which, if properly managed could provide an indefinite source of fuel, food and beauty.

Since it takes thousands of years for a forest to develop a rich, stable humus layer, it is unfortunate when it is lost to soil erosion in one or two generations of misuse.

There are many examples around the world of this chain of events. Most of the Middle East, Iran, Afghanistan and Pakistan, for instance, were heavily forested only a few hundred years ago and had adequate rainfall, but are now predominantly desert or arid. With present populations and technology (chain saws, etc.) the destruction can be much more rapid.

Environmental destruction is an accidental by-product of, and in direct proportion to, industrialization. This need not be so, and the third-world countries are in a unique position to avoid the hard-learned mistakes encountered in developing with fossil fuels and to take advantage of the recently initiated alternate energy technologies. Many of the needs now supplied by conventional energy can be supplied instead by solar energy on an economically competetive basis. Even if this were not the case, it would be wise to develop solar energy on a major scale in view of the limitsand limitations of fossil fuels.

Solar Energy for House Heating

From the earliest development of solar technology it was understood that to heat a house adequately one must perform these functions; collect the sun's heat, store it, and release it in a useful way. This prompted the development of solar collectors, heat storage units and radiators or hot air controls as separate units. Since the collectors were usually on the roof, and the heat storage units in the house below, a fan or pump was required to motivate the circulation of the heat-transporting fluid. Thus these systems became unduly complex, expensive, unsightly and dependent on the energy grid to operate.

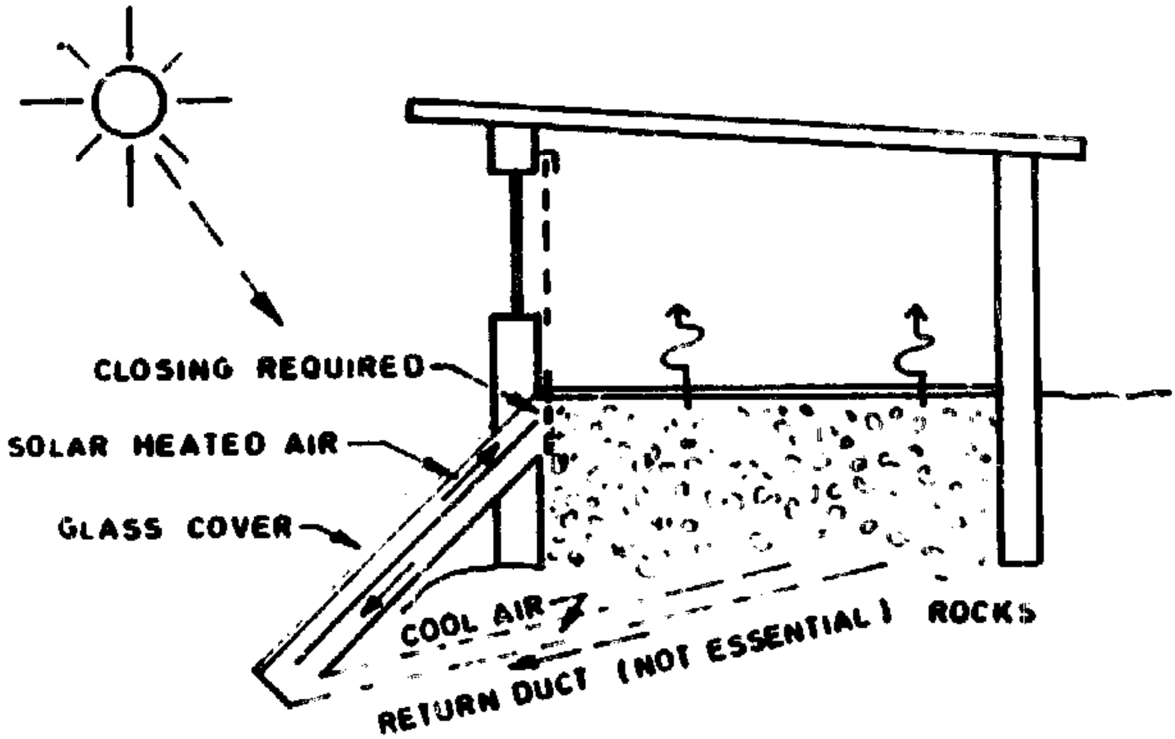
A more sophisticated and far cheaper solution presented itself as the nature of heat and its relationship to building materials was better understood. The three functions of collecting, storing and using the sun's heat were integrated into, and were indistinguishable from the very structure of the house. Since such a system requires no further devices or power to operate, it is termed "passive".

Solar energy has been defined as a "soft" technology, as opposed to, for instance, "hard" nuclear technology. Passive solar heating is at the soft end of solar technology. Another way of putting it is: passive solar technology is the type most directly coupled to the sun and is least damaging to the environment, because it takes the principle of using renewable energy to its logical extreme.

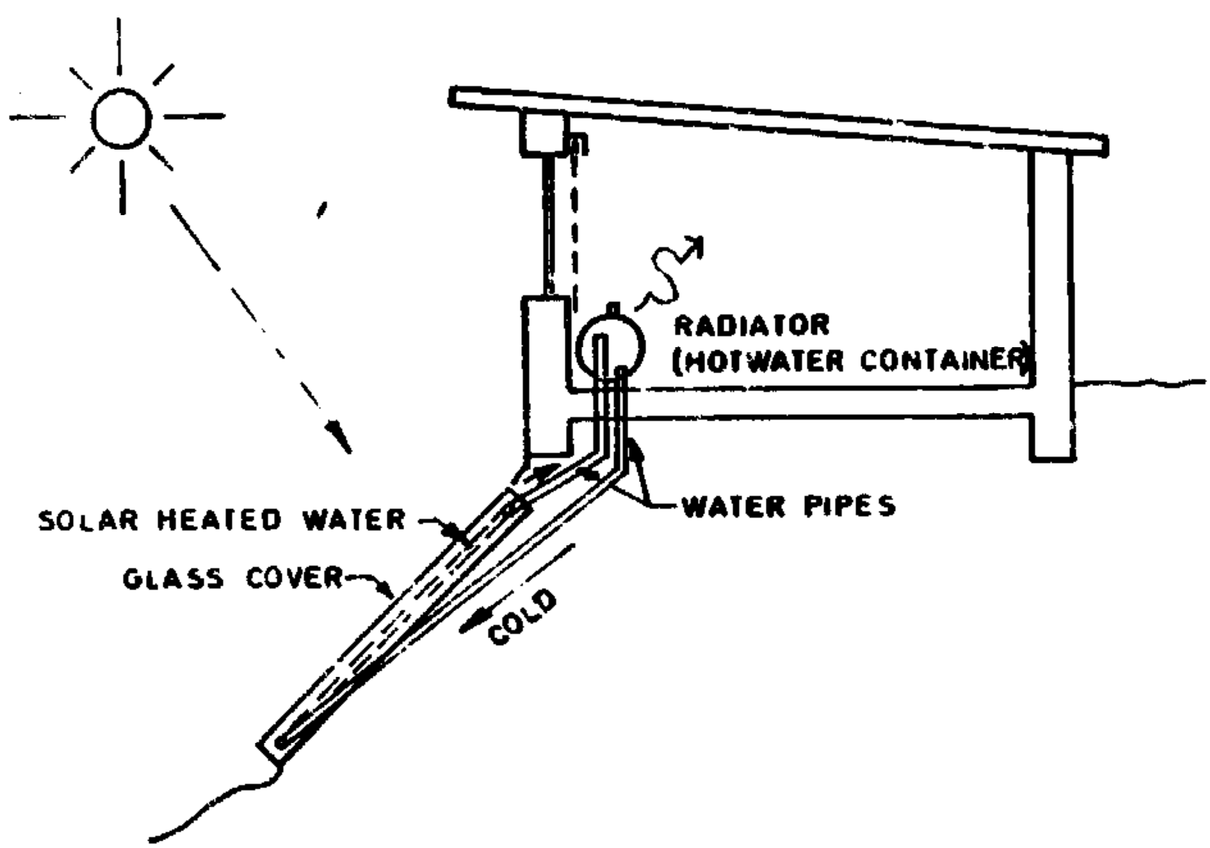
Active and Passive Solar Systems

An "active" solar system is defined as one that relies to some extent on conventional energy to operate. This implies that the added conventional energy is needed to induce the elements in the system to perform in a way that is counter to their

AIR LOOP ROCK STORAGE SYSTEM

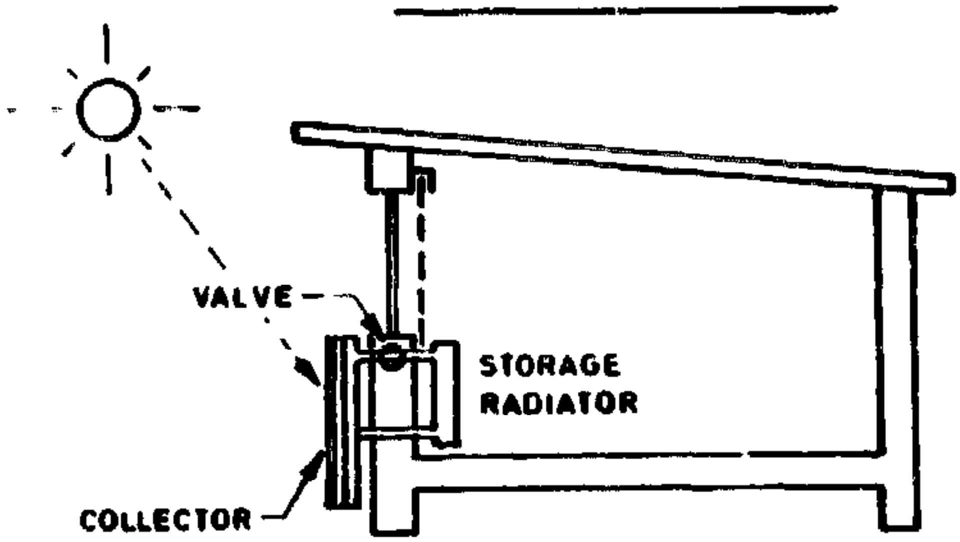


WATER LOOP HEATING



natural propensities, such as to make hot air flow downward and cold air upward. Active systems are not appreciably different in efficiency to passive ones, and are almost always more complex, more expensive and more subject to breakdown because of moving parts and power failure. The justification for active systems of the past is that passive technology was not yet understood. And the main importance of active systems at present is for retrofitting many of the existing structures that may not be able to incorporate passive principles. There seems to be little justification at present for designing a new structure with an active system, unless exposure is a problem.

THERMIC DIODE



A passive system is defined as one which operates entirely on the renewable energy available in the immediate environment. Aside from the manufacture of the original equipment, which in most cases will require at least some non-renewable energy (until our alternate energy technology catches up), the passive systems are in balance. They do not use up resources. In most cases the systems can be constructed of environmentally "clean" materials such as glass, adobe (earth), rock, water and iron. The operation of passive systems takes advantage of the natural characteristic of materials, such as the convective flow of air and water, the absorbtivity of dark colours and dense materials, heat-storing properties of dense materials and water, and the poor heat conductivity of insulating materials. Understanding these properties allows the designer to arrange them in such a fashion that they perform according to the heating and cooling requirements of the house, given the sun as a heat source and the night sky as a heat sink.

Examples (American Building Standards)

As an indication of the success of passive solar heating design, consider the following:

A passive solar home in Atascadero, California which employs a roof pond with movable insulation, has been 100 % heated and cooled since 1973 with a reported initial incremental cost of less than $ 3200.

A 2100 ft^2 home in Princeton, New Jersey, which utilizes a Trombe wall for solar collection and storage has been occupied for two winters with the solar heating system reducing by 76 % the space-heating requirements for the first winter and by 85 % the second winter.

A 10,000 ft^2 warehouse/office structure with 8300 ft^2 of direct gain and drum-wall heated space built in Pecos, New Mexico, at a reported cost of \$ 13/ft^2 has been heated and lighted for almost an entire year with a cumulative heating electric bill of only \$ 80.

A 2300 ft^2 home near Santa Fe, New Mexico, which utilizes a solar greenhouse for heat collection has been heated through its first winter with electric heating bills consistently running less than \$ 20 per month.

A 1955 ft^2 home in Los Alamos, New Mexico, which utilizes a Trombe wall and direct solar gain for heating has been 60 % heated through its first winter, with initial incremental costs for solar heating amounting to only 10 % of the cost of the entire house.

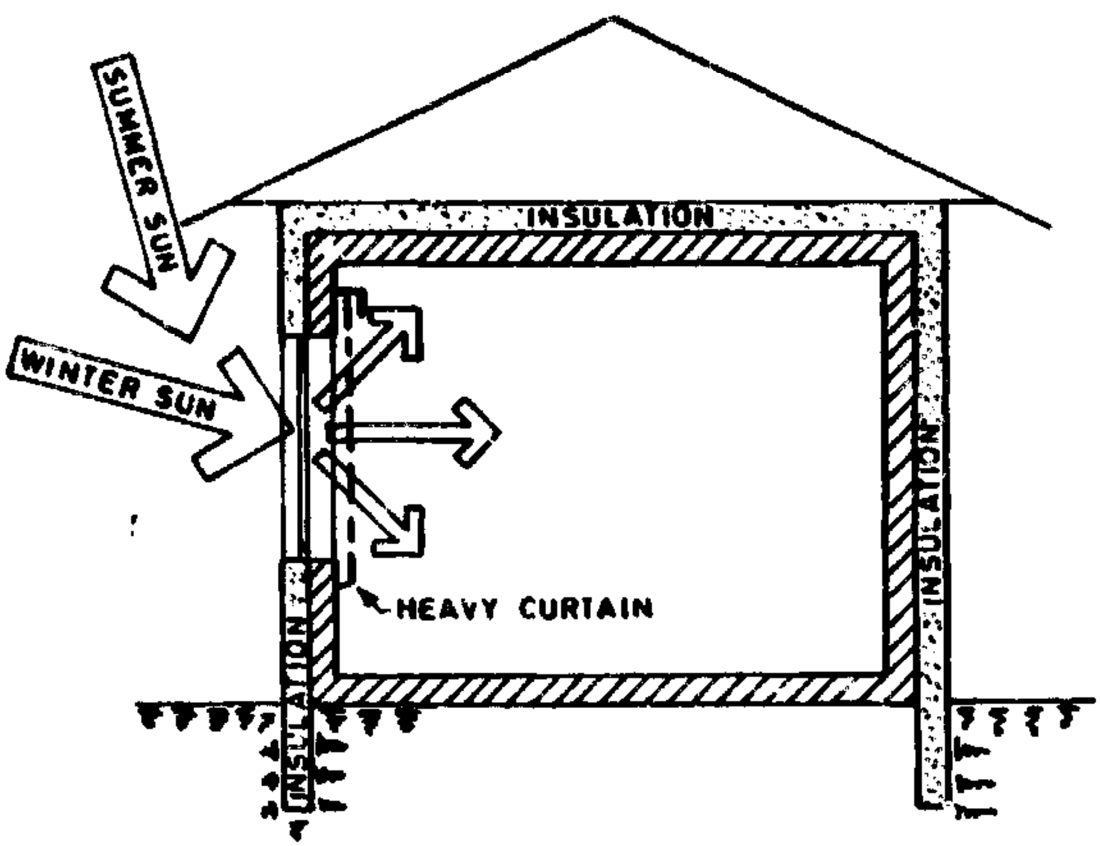
<u>Note</u>: Of necessity, most of the houses tested and described here are several years old. Not all the principles of passive solar heating that are understood now were incorporated in each of these buildingd. Better performance can be expected in future for less additional expense.

SHORT DESCRIPTION OF SEVERAL PASSIVE SOLAR SYSTEMS

Direct Gain

The south side of the house is provided with as much window area as needed according to calculations based on the total heat needed to keep the house warm and the solar energy available. The windows are glazed with two layers of glass or plastic textured on the inside surface of the inner pane to diffuse the light to

DIRECT GAIN



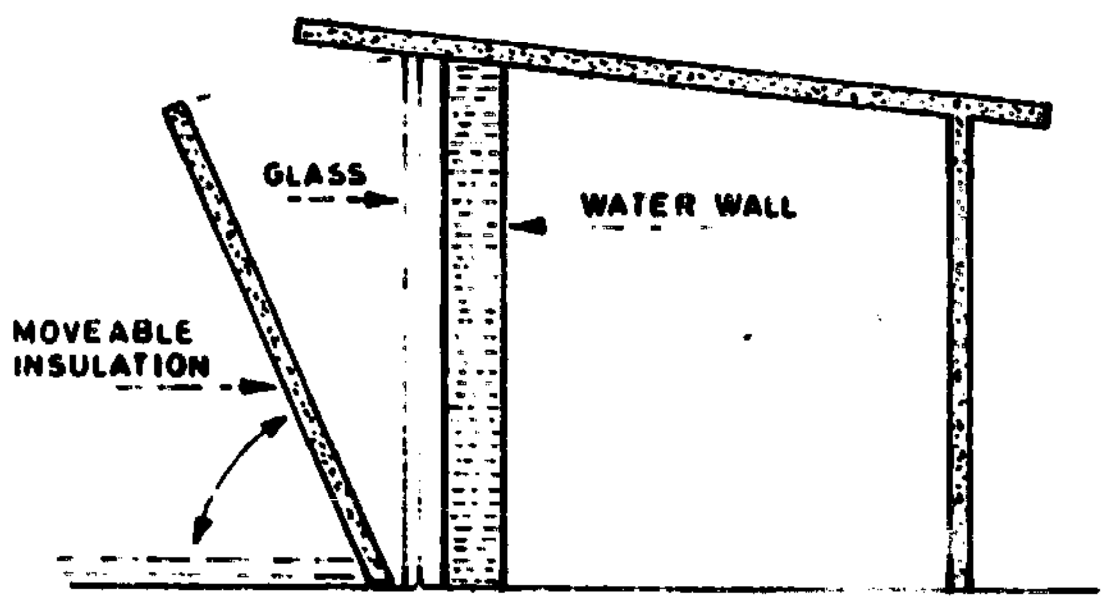
interior surfaces. This diffuse radiation is absorbed by the thermal mass surfaces (concrete, brick, rock, water in containers) which make up walls, partitions, floor and ceiling. Thermal mass surfaces are ideally a dark color, while other surfaces are preferably light so that they do not overheat interior air. A vapor barrier and ample insulation is placed exterior to the mass wall. This prevents the stored heat in the mass walls from escaping except to room interiors. Computer simulations show this system to be able to collect 60 - 70 % of available solar energy. Several houses have been built with this system, some of which are 100 % solar heated in the cold (7000 degree days) climate of northern New Mexico (ample sun). A correctly calculated overhand blocks out summer sun. Reflectors can increase input. Night insulation (curtains, insulated shutters or self-closing and opening louvres) may be necessary in extreme climates. One can readily see that the added cost of the solar aspects of such a building are negligable. It can be calculated that in America the cost of the entire building could be made up over 50 - 70 years, simply from the energy savings, at present energy costs.

In terms of trade-offs, smaller collector windows, but more insulation on the rest of the house is preferable to the other way around, since large windows are such a heat drain at night, or require night insulation.

Water Wall

The water wall is used the same way as the self-insulating water wall (see below) except that it requires moveable insulation--at night for the heating mode, during the day for the cooling mode. The water wall absorbs 60 - 70 % of available radiation.

WATER WALL

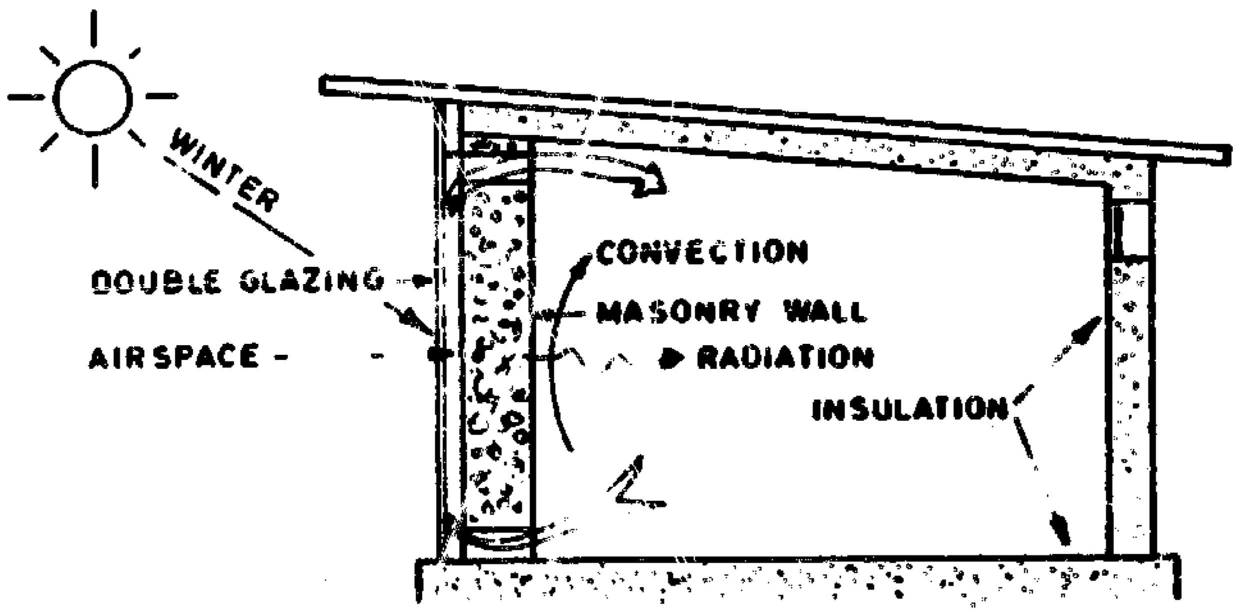


Trombe Wall or Thermal Mass Wall

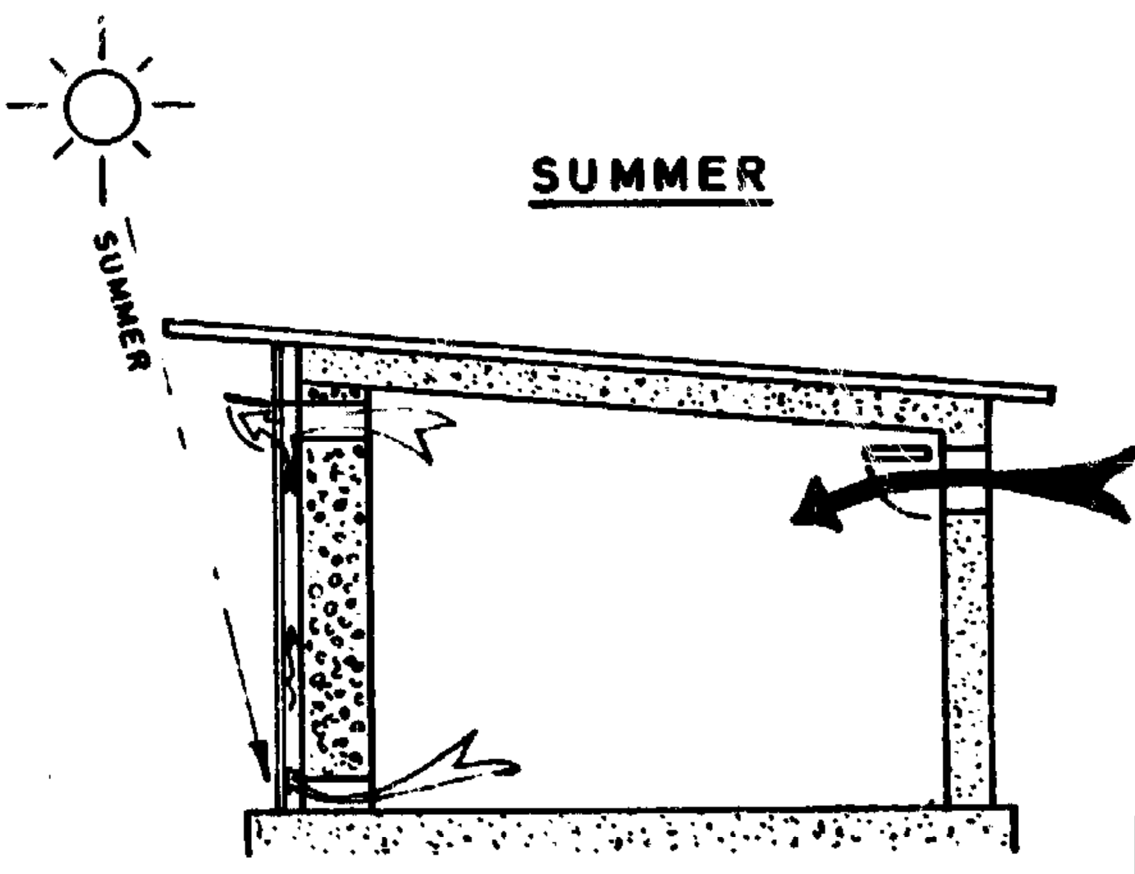
Here the south side of the house is made of a solid wall, painted black on the outside and covered with double glazing. There are two ways that the heat enters the building. Firstly the thermal mass of the wall absorbs the sun's heat all day and radiates it to the interior at night (the delay of the heat wave travelling through the wall and reaching the inner surface depends on the thickness of the

TROMBE WALL OR THERMAL MASS WALL

WINTER



SUMMER



wall and the thermal conductivity of the material).

Secondly, if openings are made through the wall at floor and ceiling level, the heated air between the wall and the exterior glass can convect into the room, being replaced below by cooler air from the room.

The thermal mass wall can also be used in conjunction with direct gain or a solar greenhouse. It is 35 - 45 % efficient.

Existing houses that have good sun exposure on south mass walls can be readily adapted to this system. Generally added insulation is necessary on the other walls.

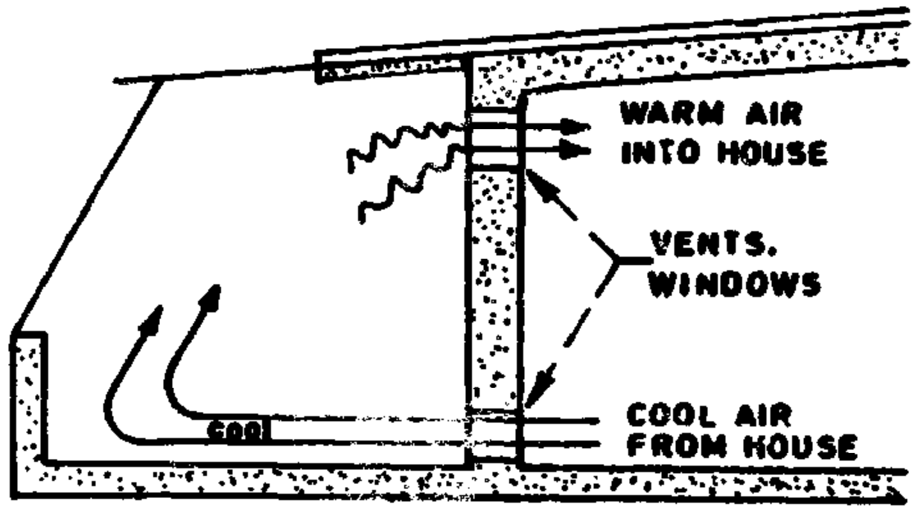
Solar Greenhouse

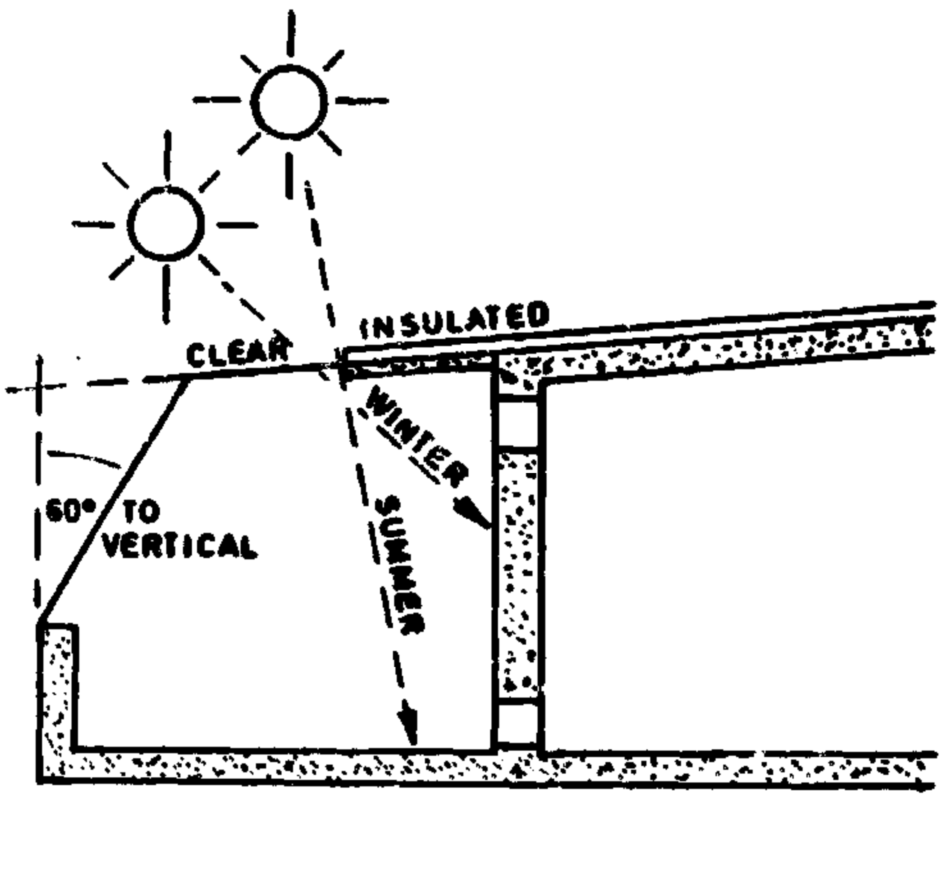
A greenhouse is built on to the south wall of a house and through convection transmits excess heat into the house during the day, while heat stored in the mass wall, which can be a self-insulating water wall or a water wall, radiates to the interior as well. With the self-insulating water wall, one can determine the amount of stored heat that radiates to the interior or back to the greenhouse at night.

This system provides an added sunny space to live in and can provide a place to raise vegetables and flowers as well.

Sun angles have to be considered to prevent over heating of the greenhouse in summer. Large vents are helpful.

SOLAR GREENHOUSE





Roof Ponds

In a roofpond system, the thermal mass in the form of bags of water, is located above the ceiling and has access above to solar radiation and the night sky. Moveable, insulation is required to make the system operational. The system is very good for cooling, since it faces the night sky, but does not have an ideal angle for collection of heat. This drawback can be avoided with reflectors.

Self Insulating Water Wall

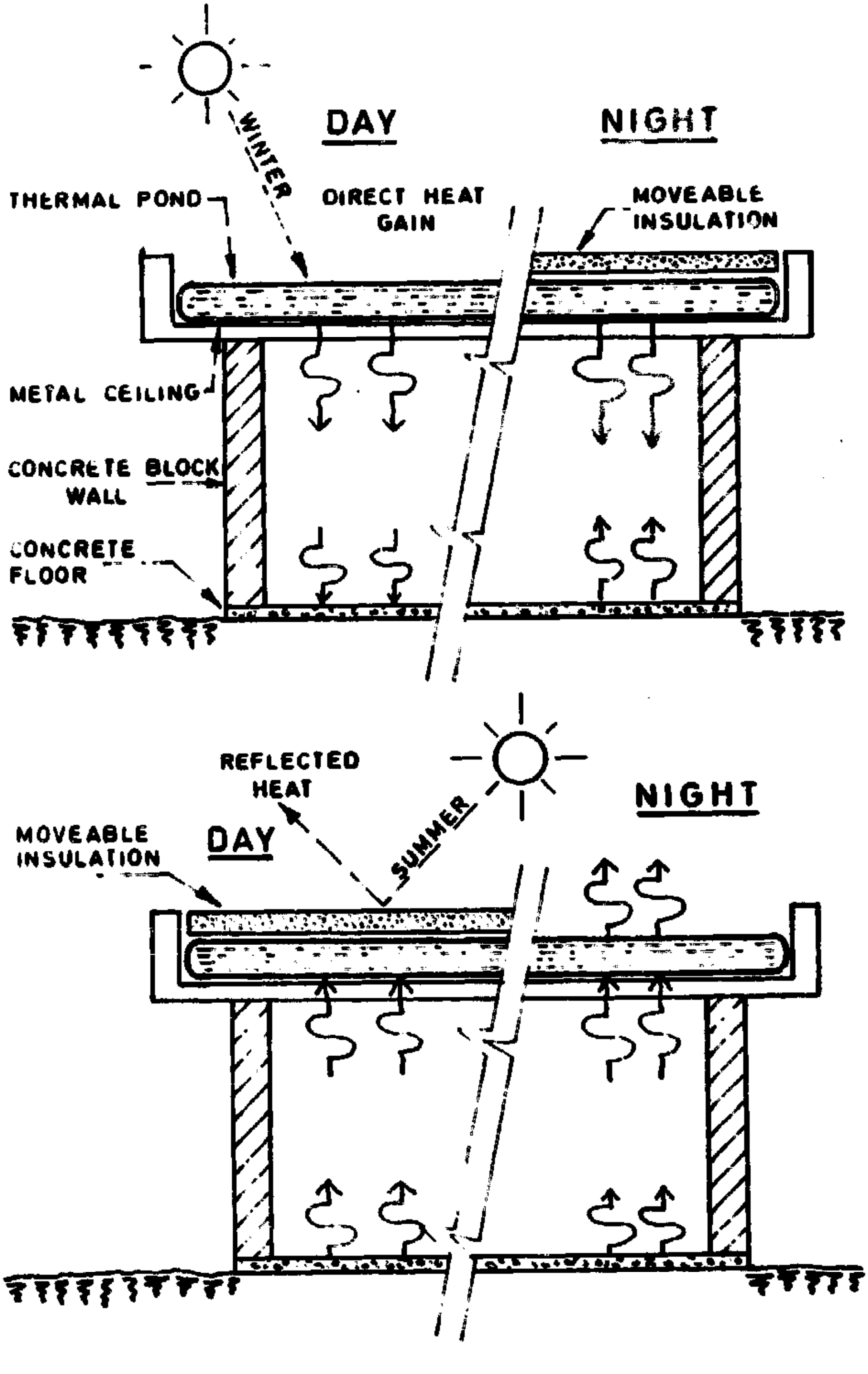
A self insulating water wall, invented and developed by the author, may have advantages when used in conjunction with the direct gain system in some situations.

This system can be used for heating as well as cooling and has the advantage of built-in insulation. The system depends on water-filled tanks that have a sheet of insulation inside close to the south face of the tank.

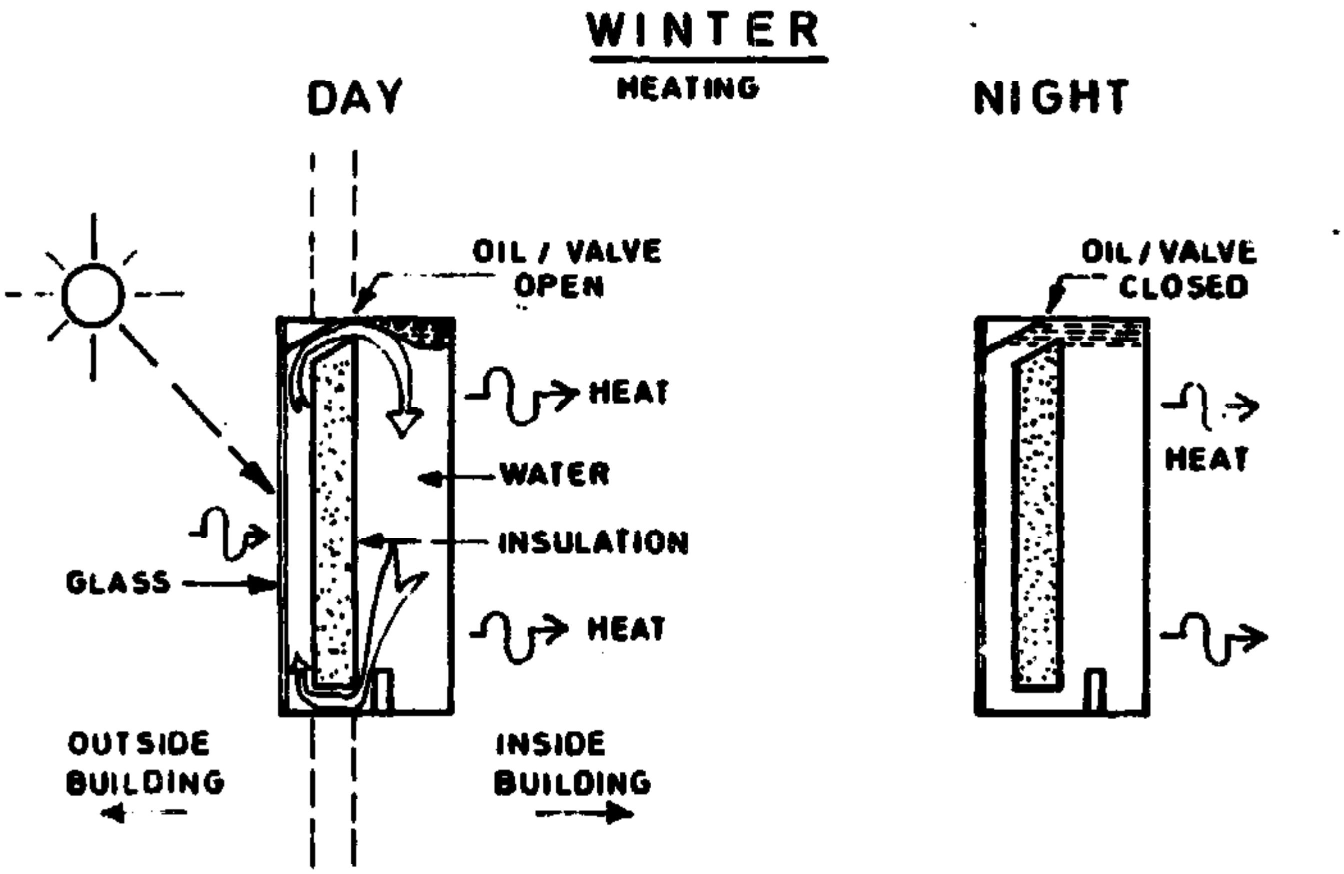
Heating mode: Water that is heated through the surface of the tank convects over the insulation to a large storage compartment and is replaced by colder water entering below the insulation from the storage compartment. Since reverse convection is prevented by a valve at night, the insulation can prevent heat loss from the main (heat storage) compartment.

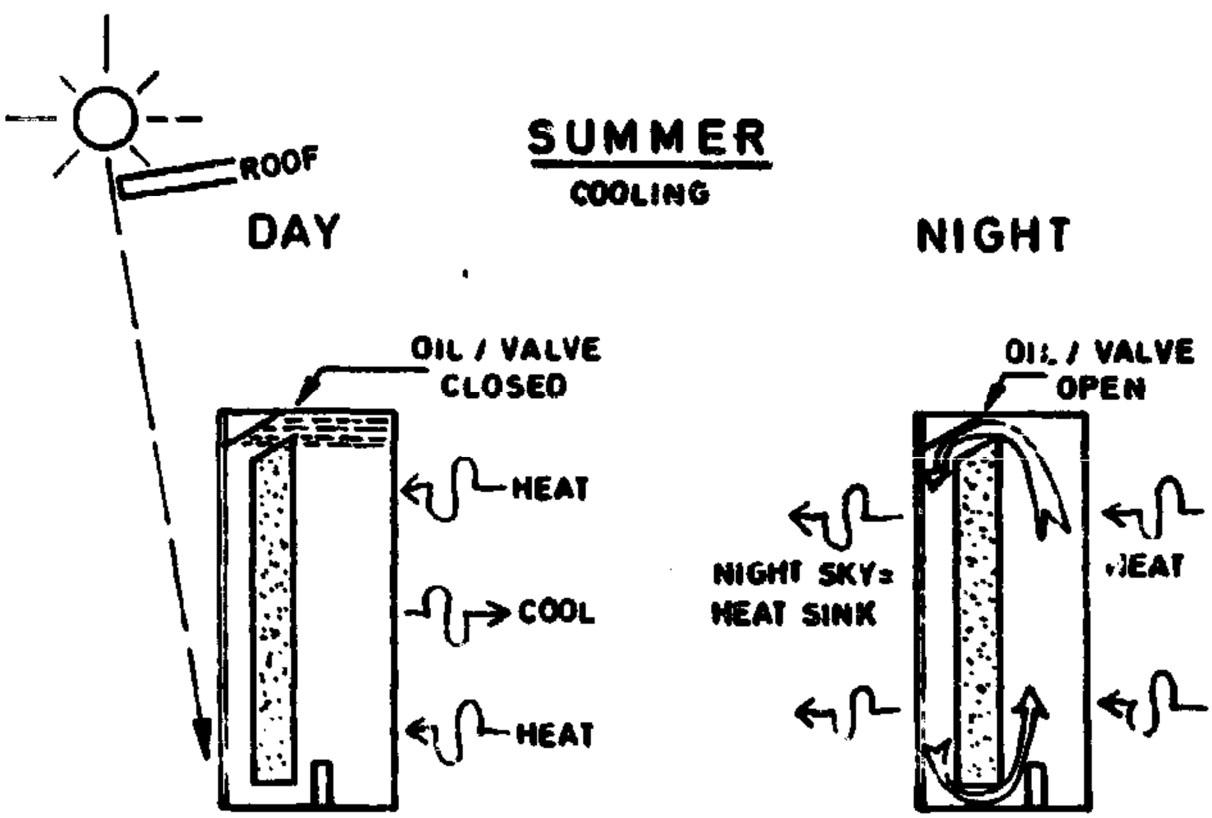
Cooling Mode: The valve can be manually reversed, so that convection can not take

ROOF PONDS


DAY
NIGHT
WINTER
THERMAL POND
DIRECT HEAT GAIN
MOVEABLE INSULATION
METAL CEILING
CONCRETE BLOCK WALL
CONCRETE FLOOR
REFLECTED HEAT
SUMMER
NIGHT
MOVEABLE INSULATION
DAY

THE SELF-INSULATING WATER WALL





place during the day but is allowed during the night. Then the warmer water convects from the main compartment over the insulation, radiates the heat to the night environment and returns cooled below the insulation to the main compartment. The cooled water then acts as a heat sink for the building during the day.

The convection in either selected mode is passive, and the day-night valving action is also passive. These modules are best used in conjunction with direct gain and/or a solar greenhouse. The absorbing efficiency is between 55 and 65 % of available radiation, and very little heat is lost at night.

If used with direct gain, then the south side of the house is made up of self-insulating water wall modules and windows. The inner surface of the modules radiates heat to the interior and the rate of radiation can be controlled by a curtain. The same considerations of overhang, as mentioned above apply to this system. This system is suitable for retrofitting existing houses.

The phenomenal advantage of these systems is only now becoming apparent, partly because the interaction of heat and materials was not self-evident and required considerable research, and partly because the systems have not been widely publicised since there is no hardware to sell and nobody has a vested interest in their promotion.

SUMMARY OF PASSIVE SOLAR PRINCIPLES

Orientation: The ideal is a location that gets no shading during the winter months when the sun is low.

Another consideration is protection from prevailing wind. If the local climate has prevailing morning or afternoon cloudiness the house is oriented slightly more to the west or to the east respectively.

Design: The house has east-west alongation to expose a large surface to the south. The harsher the climate or the poorer the insulation the larger the south face (absorbing face) has to be in proportion to the internal volume (i.e. the narrower the house is N-S).

North Wall: Small window area, good insulation, thermal mass inside.

East and West Walls: Small to medium window area, good insulation, thermal mass inside.

South Wall: One can calculate the size of collector area required for a structure from the collector efficiency and the heat load of the structure. The "heat load" or or heat loss is a function of the size of the structure, the insulating properties and the climate. A rough idea of collector efficiencies can be had from the above discussion of passive systems. The peculiarities of each system should be taken into account and combinations such as direct gain or greenhouse with a self-insulating water wall are desirable. To increase the overall efficiency of all the above, except the self-insulating water wall, night insulation must be added. External reflectors increase the incoming radiation.

Ceiling: Well insulated, preferably thermal mass inside.

Roof: Overhang to south that allows winter sun in, but cuts out summer sun. Preferable is an adjustable overhang (eg. hinged) since for the same sun angle, one needs more solar input in the spring than in the fall. Horizontal louvres with adjustable angles can also be used for shading. They should be mounted outside the glass for minimum heat intake.

Foundation: Should be insulated on the outside about 100 cm. vertically below ground level, and have a vapor barrier between it, and the mass wall above it.

Insulation and Airproofing: Double airlock entrance, preferably away from prevalent wind, but not on south side.

All insulation is placed on the exterior of the walls. Construction should be as air proof as possible; windows and doors are weather stripped, flu's have dampers, fireplaces are closed off. Curtains, thermal shutters or night insulation against the windows is helpful. Care must be used to avoid edge leakage or convection behind these.

Thermal Mass: The building should have sufficient thermal storage potential (rock, water, concrete, brick) to store heat according to the expected % of the heating to be achieved by solar heating (For temperate climate a rough guess is that 24 hours heat storage will result in 60 - 70 % solar heating, given adequate insulation).

The most cost-effective system, as indicated above, uses only windows to the south (diffusing glass). All interior walls, floor (and ceiling) are made of material with good thermal mass. A thickness of 10 - 15 cm for most materials is sufficient although more does not give an appreciable advantage or disadvantage. Water is more than twice as effective as concrete at storing heat. It mixes in its container, so it is very efficient at absorbing, retaining and releasing heat as well. Partition walls are still effective at twice the thickness mentioned above (20 - 30 cm) since they absorb and release heat from both sides.

Thermal mass is preferably painted a dark (absorbing) color, but the greater the surface of thermal mass inside, the less dark it needs to be. Note: With a large amount of sun shining in, dark surfaces are not objectionable. Objects without thermal mass are preferably of light colors so they reflect the incoming radiation rather than converting it to heat which would be given off to interior air, causing possible overheating.

Glazing: Can be either glass or plastic. If one intends to use interior walls, ceiling and floor for heat storage, the glass or plastic should diffuse the light (textured surfaces). Double glass is used throughout the house (2 - 4 cm space is ideal). If extremely clear glass is used (low iron content), triple glazing becomes economical on the south side, since one can then dispense with moveable insulation at night.

All windows and doors should be recessed from external walls to decrease heat loss from wind.

WHAT ARE THE RETROFIT POSSIBILITIES ?

If the orientation of a house is adequate, and the south wall of the house has sufficient exposure, the following considerations are made: Is the thermal envelope sufficient ? This depends on the severity of the climate, and the percent of heating that is to be achieved by solar energy.

Is there sufficient thermal mass ? If the existing house is made of stone, brick, cement or other dense material and is not insulated inside, it probably has sufficient heat storage capacity if insulation is attached outside. If the house is made predominantly of insulating materials (wood, cinderblack or insulated stud walls) then thermal mass must be introduced to the extent that heat is to be stored for night-time use.

Note: Often existing houses have good potential for solar heating when the sun is shining but may not have sufficient southern exposure or too great a heat load to warrant storing the heat. One efficient way of introducing thermal mass into an existing building is to replace the south wall with self-insulating water wall modules that are glazed on the outside.

For plant lovers, or where added space is needed, an add-on greenhouse is ideal and quite effective as a solar heater.

OTHER CONSIDERATIONS

Sunlight: has a radiation spectrum that is made up of invisible, high-frequency, ultraviolet radiation, visible radiation and invisible, lower-frequency infra-red, or heat radiation.

When sunlight strikes a white surface (say whitewash) 90 % or more of the radiation is reflected back as diffuse radiation (white roof in hot climate).

When sunlight strikes a mirror or specular surface the radiation is reflected at the same angle as the angle of incidence. Highly reflective surfaces can reflect upto 95 % of the incoming sunlight, thereby becoming valuable to increase input into any solar device.

When sunlight strikes a black surface, the higher frequency radiation (light) is converted to lower-frequency radiation (heat). An extremely black surface can absorb 85 - 90 % of the sun's radiation, but usually at least 20 % of this is reradiated as heat.

Collector efficiencies of 50 % of available sunlight are average to good. 70 % efficiency is exceptionally good.

Heat is transmitted in 3 distinct ways. Understanding of these is valuable for all solar applications:

1. Radiation is a wave-like transmission of heat that is independent of air and gravity. So it travels downward just as well as upward and a long distance as well as a short one, although the intensity is greatly reduced the further it travels, because it spreads out. Radiant heat

virtually does not heat up the air it travels through.

2. Conduction occurs between two substances in contact with one another or inside one substance transmitting the heat from the hotter part or substance to the colder at the mutual interface. Compared to radiation this is a very slow process.

Example 1: Heat travels through 30 cm of concrete in about 10 hours. However, an input of heat at one surface of a 30 cm wall at a high temperature will arrive at the other surface of the wall at only a fraction of that high temperature (about 4 %) as the heat wave has diffused to the material in the wall.

Example 2: If one is dealing with day and night extremes outside, the inside of a 30 cm wall averages these extremes out and fluctuates only about 4 % of the external extremes with about a 10 hour delay.

Example 3: If one does not want more than 5 or 10° C internal temperature variation, then internal thermal mass becomes virtually ineffective if it is more than 10 - 20 cm thick, since the day-night temperature fluctuations in a wall thicker than this, with good insulation outside, are negligable. For long-term heat storage more mass becomes important.

3. Convection occurs in fluids and gasses (air). Heat is transmitted by physical movement of the fluid from one place to the other. The movement is caused by the

fact that the warmer parts of the fluid or gas are lighter and tend to rise while the cooler parts are heavier and tend to sink, thus setting flowing currents in motion. This is important in transmitting heat, for instance from a greenhouse to an adjoining house. To prevent convection, for instance between two layers of glass, they are kept close together (2 - 4 cm). To promote convection in an air system, the greater the temperature differential and the higher the system the better the flow.

To try to heat mass walls of a building by first heating the air, and then the walls by conduction, is ten times less effective than heating the walls directly with radiant heat.

Insulation: Vacuum is a perfect insulator for convection and conduction. Radiation however passes through.

The characteristic of all conventional building insulation as well as warm clothes, bedding, etc. is that the material contains tiny spaces of air that cannot convect the heat away.

Thus sawdust is a better insulator than wood, or fiberglass than glass. Air-entrained (frothed) ~~concrete or plaster~~, vermiculite (expanded mica), pumice, or cemented sawdust, husks, or pulp are some alternative insulation possibilities. A dead air space between two layers of glass is many times better as an insulator than one layer of glass, and two dead air spaces with a sheet of aluminum foil sandwiched between inner and outer masonry layers creates two air spaces and a radiation barrier.

Volume Considerations: Since the surface of a building loses heat from the interior, one tries to reduce the ratio of surface to interior volume as much as possible. In geometry a sphere has the smallest surface area for a given volume. Architecturally a dome closely approximates a sphere. The further one deviates from compactness, say towards a star shaped floor plan, the greater the surface area to volume. Another consideration is size: the larger the house the smaller the surface to volume ratio. One way of considering it is to take many small houses and put them together to make one large one. All former external walls that have now become internal walls (room dividers) need not be heated.

Weather stripping and Vapour barriers: It is important to seal off air leaks in a building. A convective "chimney effect" takes place in a warm house in a cold environment. Cold air characteristically enters in the lower half of a building and hot air escapes in the upper half. An average house has a complete air exchange every ten minutes, while one air exchange every 40 minutes is quite adequate. Weather stripping of felt, foam rubber or cloth is advisable around all windows and doors. Fiberglass is suggested when two materials of dissimilar coefficients of expansion meet in construction (bricks against wood). A vapour barrier is suggested in walls, and should be interior to the insulation. If it were placed exterior to the insulation, moisture from the room would condense when the dewpoint was reached, some distance into the insulation. This would reduce the insulation efficiency and could cause moisture damage. A good method of sealing interior mass walls is with a layer of plaster, concrete or mud.

SUMMARY

In general it can be said that even though these principles appear to be self-evident once they are known, it has taken this long to understand them because of their holistic nature. The passive systems are directly coupled to the sun and the three functions of collection, storage and distribution of heat are carefully integrated into the architectural whole.

Required is an understanding of the characteristics of the materials used and the physics of sunlight and heat transfer. The new systems are termed "passive" because they are effortless: they take advantage of the natural propensities of heat and materials to achieve the desired results without the need for added conventional energy.

This paper is a short introduction to passive system design. The author offers his services as solar consultant for a more thorough consideration of particular questions or designs.

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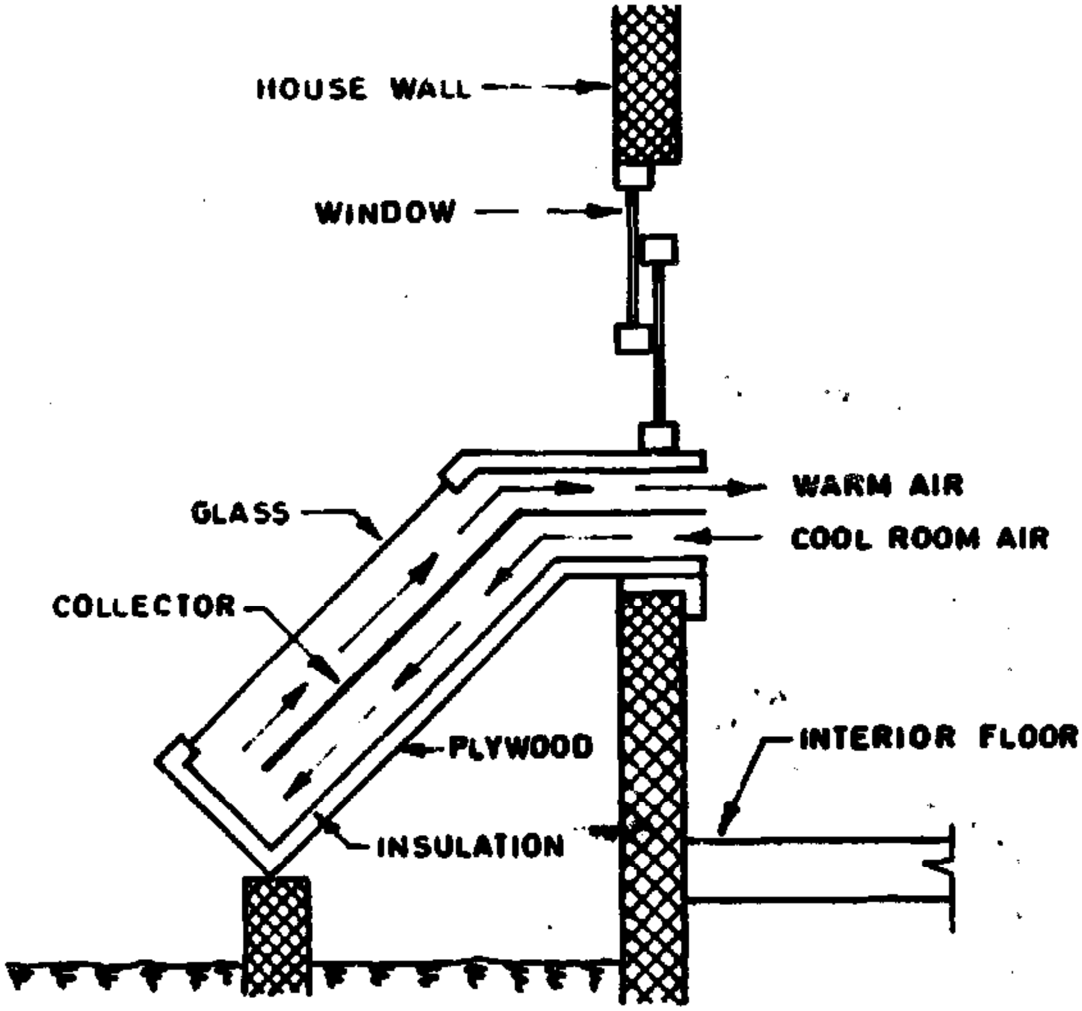
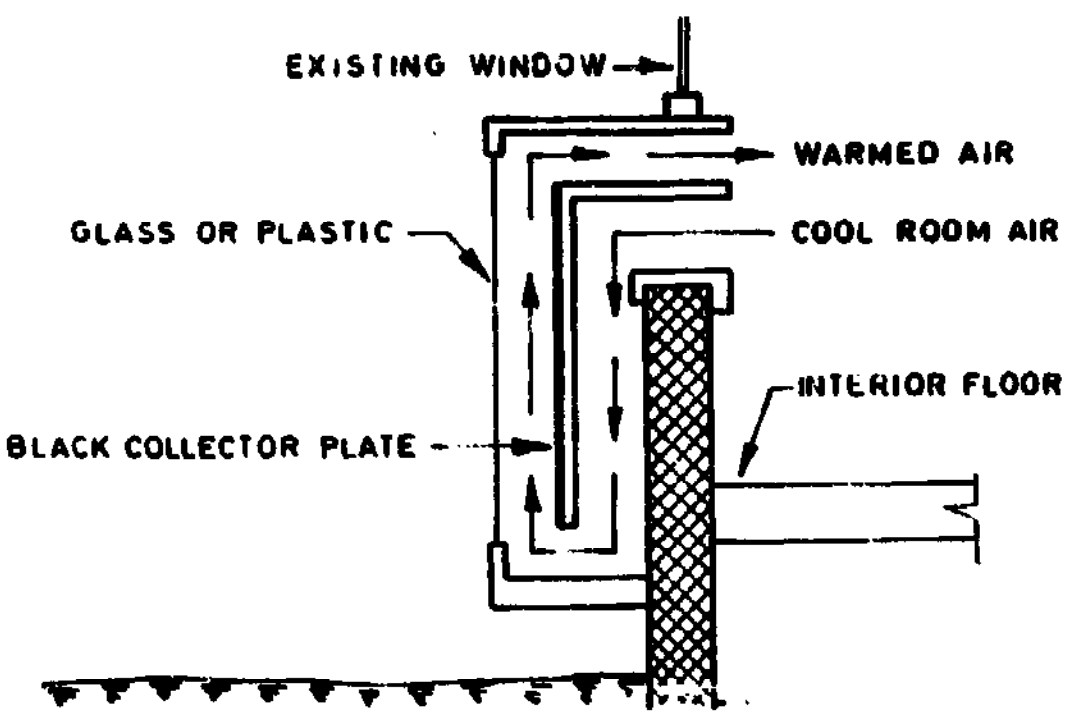
window box solar collectors



a variation



Some places resp. organisations working with Solar Energy in Nepal:

S A T A
Swiss Association for Technical Assistance
Jawalakhel
P.O. Box 113
Kathmandu / Nepal

B Y S
Balaju Yantra Shala
Plumbing Division
Balaju Industrial District
P.O. Box 209
Kathmandu / Nepal

R E C A S T
Research Center for Applied Science and Technology
Tribhuvan University
Kirtipur
Kathmandu / Nepal