

Capturing Heat Two

*Fuel Efficient Cooking Stoves with Chimneys,
A Pizza Oven, and Simple Water Heaters:
How to Design and Build them*



*Praise for the
Capturing Heat series:
"An excellent book...
illustrated, easy to follow...
useful for any community."
-Where Women Have No Doctor*

*By Dean Still, Mike Hatfield, Peter Scott
Aprovecho Research Center*

The Capturing Heat Series is dedicated to my supportive and wonderful family. And thanks especially to Kim, my wife, for making it all work. -D.S.

The Capturing Heat Series:

Capturing Heat

Five Earth Friendly Cooking Technologies
and How to Build Them

Capturing Heat Two

Fuel Efficient Cooking Stoves with Chimneys,
A Pizza Oven, and Simple Water Heaters:
How to Design and Build them

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How to Design and Build them***

By Dean Still, Mike Hatfield, Peter Scott

Illustrations by Mike Van, Brian Thomas, Ethan Hughes,
Loki Quinnangelis, Cathy White

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Additional copies of this book are available for \$8 postpaid from Aprovecho. Copies are available for the cost of postage to those working to benefit the poor.

Table of Contents

Aprovecho Research Center: Introduction and Tour	4
The Pizza Oven - an analysis of retained heat baking	10
Cooking Stoves with Chimneys	16
Heating Water	28

The final copies of this program are available for \$8 postpaid from Aprovecho. Copies are available for the cost of postage to those working to benefit the poor.

Heating Water

We have developed five simple and successful ways of heating water over the years. Three of the designs use combusted biomass to warm water. The fourth and fifth are solar water heaters. A combination of wood burning in the winter and direct solar water heating in the summer seems to suit our maritime climate.

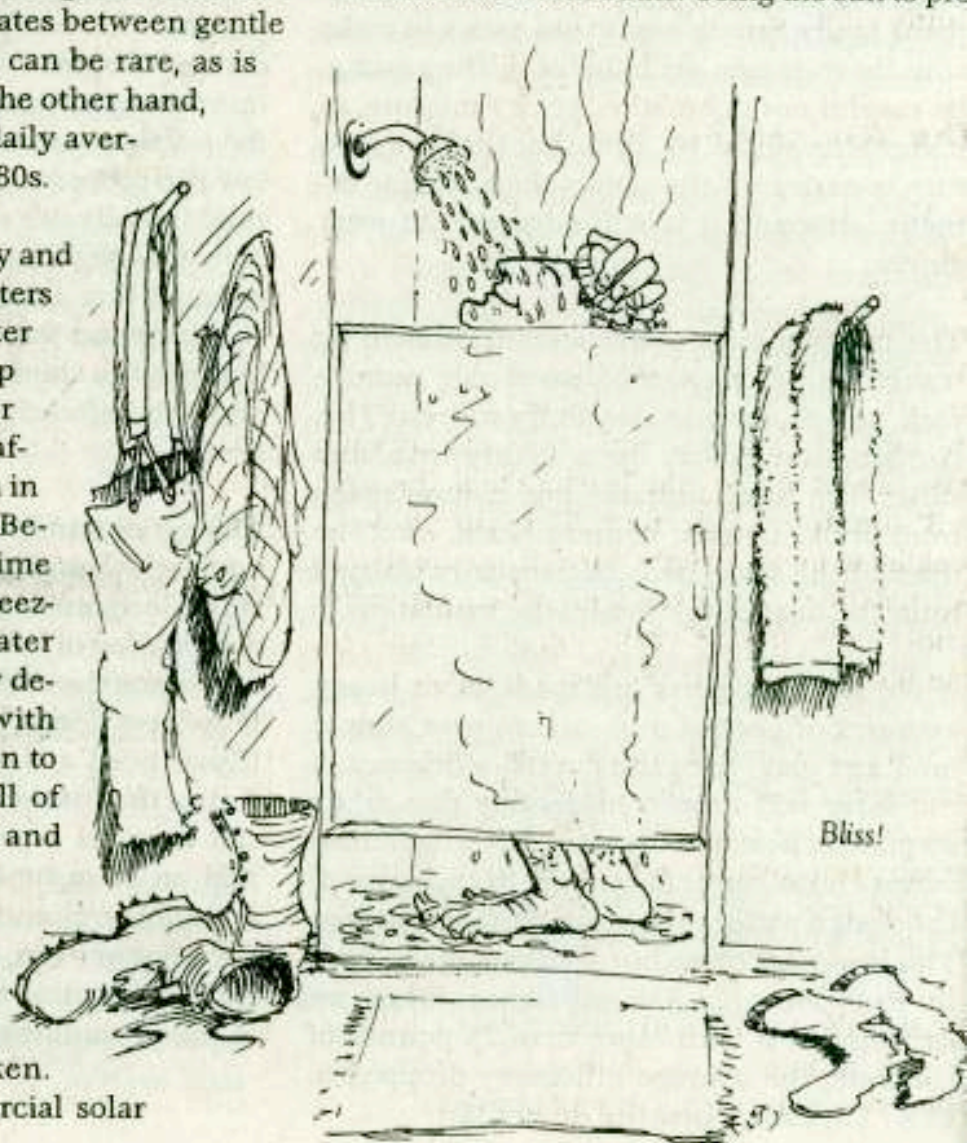
Aprovecho is located in a wonderful part of the planet (44 degrees north latitude) in a long valley nestled between coastal hills and magnificent mountains, about 50 miles inland from the Pacific Ocean. During the winter our weather generally alternates between gentle rain and fog. Sun breaks can be rare, as is snow. Our summers, on the other hand, are dry and warm, with daily average temperatures in the 80s.

In this climate, even fancy and expensive solar water heaters receive very limited winter sunlight. It's sad to look up at thousand-dollar solar water heaters which day after day merely keep clean in the relentless drizzle. Because our winter nighttime temperatures dip below freezing, the solar water heater needs to be a pretty fancy design, one that is filled with anti-freeze or knows when to drain itself. Anything full of water tends to expand and crack.

Water expands as it freezes (most everything else shrinks in size!) and pipes can easily be broken. That's why most commercial solar

water heaters don't directly heat water. Instead, a liquid, like antifreeze, is warmed up in the solar collector, and then the warmth is transferred inside the house to a tank of water. Directly heating water resulted in too many accidentally broken pipes.

Our water-heating efforts evolved at Aprovecho until wood warmed water in the winter and sun did the same in summer. This strategy evolved because wintertime solar water heaters mostly burst while remaining cold in the fog. We were cold and dirty and wanted nice warm baths! Using the sun to pre-



heat water, that was then fully warmed by other means, was not judged worth all the expense and hassle. Stored solar energy, in the form of wood, could be used in the winter, and direct solar energy made lots of water scalding hot all summer long.

If you live in a continually sunny climate, solar-heated bath water is certainly the way to go. It's especially easy to accomplish in places where temperatures do not go below freezing. In Baja California Sur, Mexico, eight inches of water in a dark painted cistern without a glass cover was usually more than 100 degrees F. by late afternoon. An insulated cover provided hot water for the morning's dishes. Try simple solar first if you live in a sunny climate!

The Winiarski Batch Water Heater

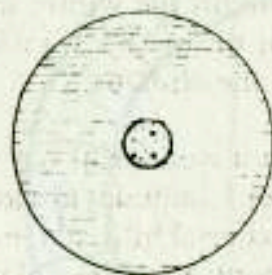
In Mexico, outside of a lot of bathrooms, and for sale at fancy "Alternative Energy" stores in the US, you can find a Mexican-made wood-burning batch water heater. It's called a batch heater because you heat up a tankful of water at a time. The fire is located underneath the tank of water and the flame and hot flue gases shoot up the middle of the tank through a 3"-diameter chimney. The chimney is welded to be watertight. Heat from the flame warms the water in the tank, which is driven under pressure out of the top of the tank, to the nozzle that wets the lucky recipient.

When Larry looked at this design, he immediately realized that by simply changing how the chimney contacted the tank he could greatly improve the efficiency of heat transfer and heat the water using much less fuel. What do you think Larry did?

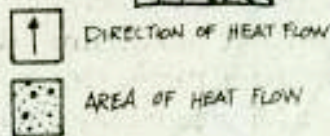
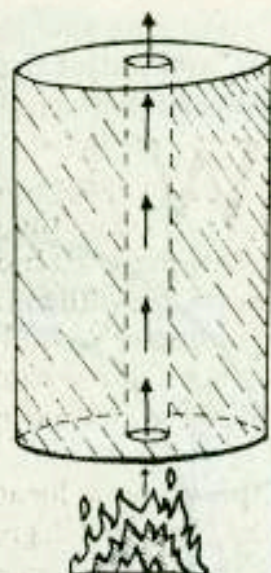
Please take a minute to contemplate solutions to this problem. The following illustration shows how the Mexican model works:

Right: Heat Shoots Up the Middle

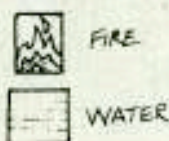
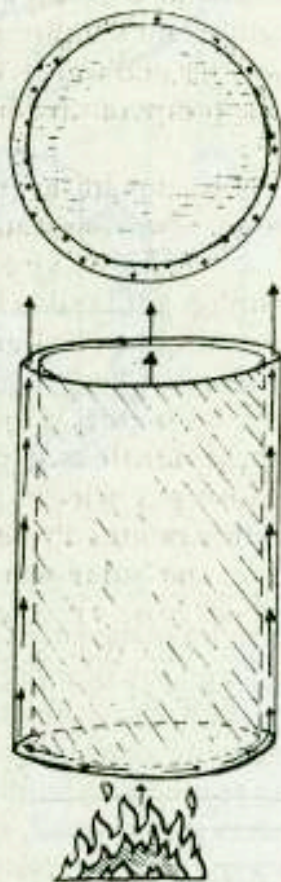
Please feel free to jot down your ideas. (See pages 45-48.) How can we increase heat transfer to the water?



Top View of the Water Heater

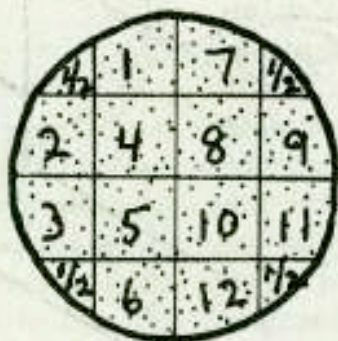
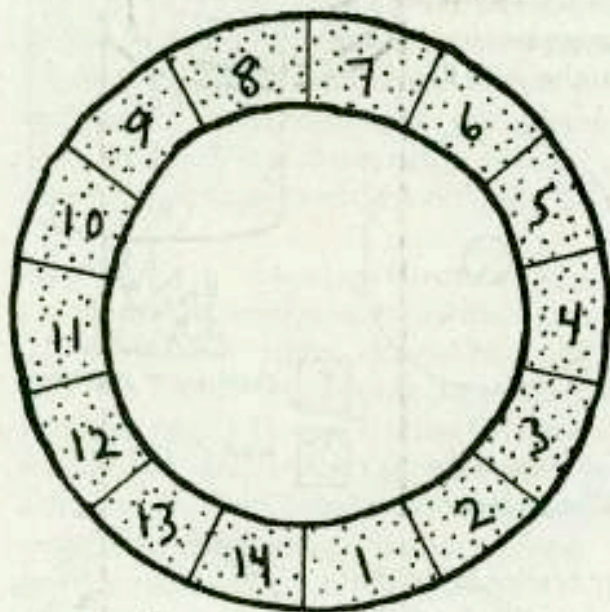


Larry realized that the area exposed to the water inside a 3"-diameter tube was pretty small. For efficient heat transfer you want as much water surface area as possible exposed to the heat created by the fire. To expose the most surface area, Larry put the chimney around the outside of the entire tank instead of inside it. This solution is reminiscent of his bread oven. Heat travels up a narrow gap, rubs against the water tank and efficiently heats up the water!



Right: Increasing the Exposed Surface Area

To make sure that the chimney created the same amount of draft Larry estimated the cross-sectional area inside the tube.



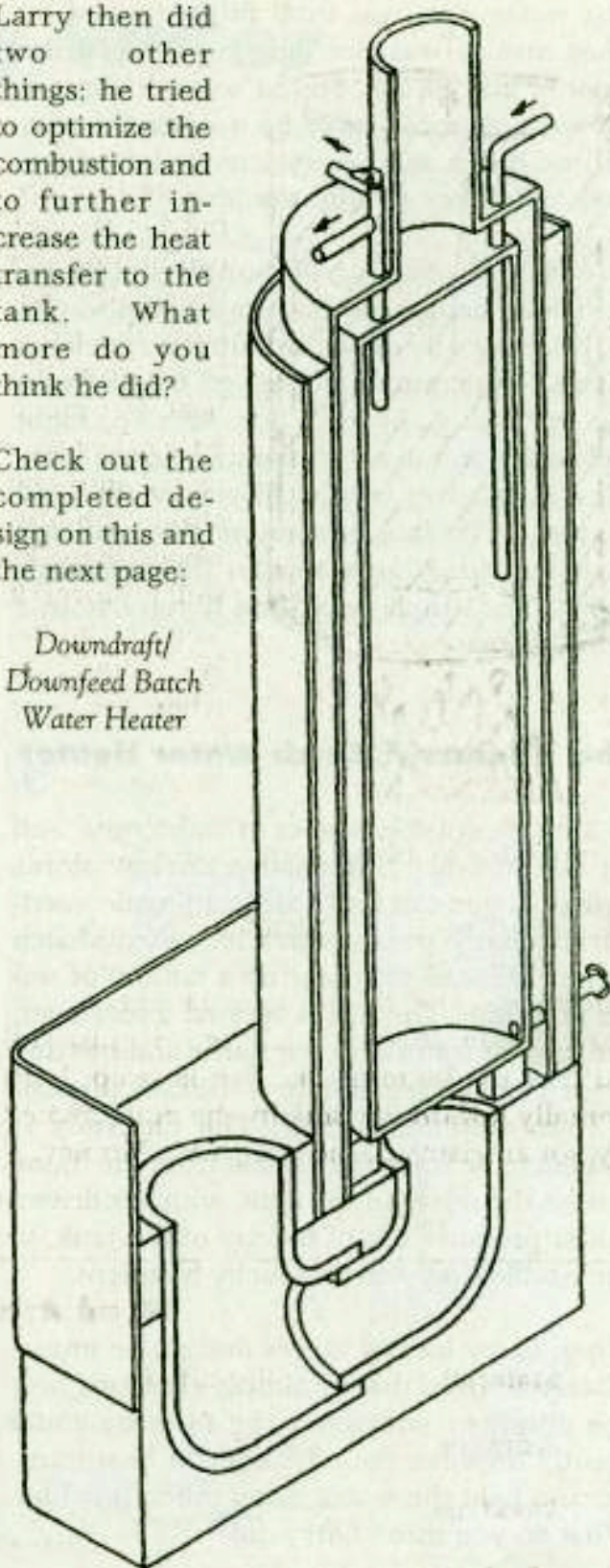
Same Cross-Sectional Area

Then he made sure that the gap between the tank and the new big chimney pipe created a gap with about the same cross-sectional area. Using the same cross-sectional area made the gap (called an annulus) between the two cylinders pretty small, so small that it might get clogged with creosote or ash. So, he compromised and made the gap $3/4$ " and lit an experimental fire underneath the tank with its exterior chimney. It worked great! The draft was swift and the water got hot quickly.

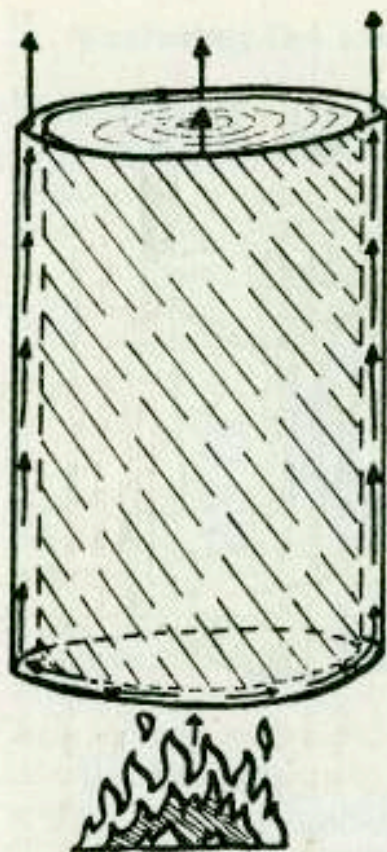
Larry then did two other things: he tried to optimize the combustion and to further increase the heat transfer to the tank. What more do you think he did?

Check out the completed design on this and the next page:

*Downdraft/
Downfeed Batch
Water Heater*



Let's look first at the combustion and feed chamber. There is insulation surrounding the entire fire and fire flow path. The insulation

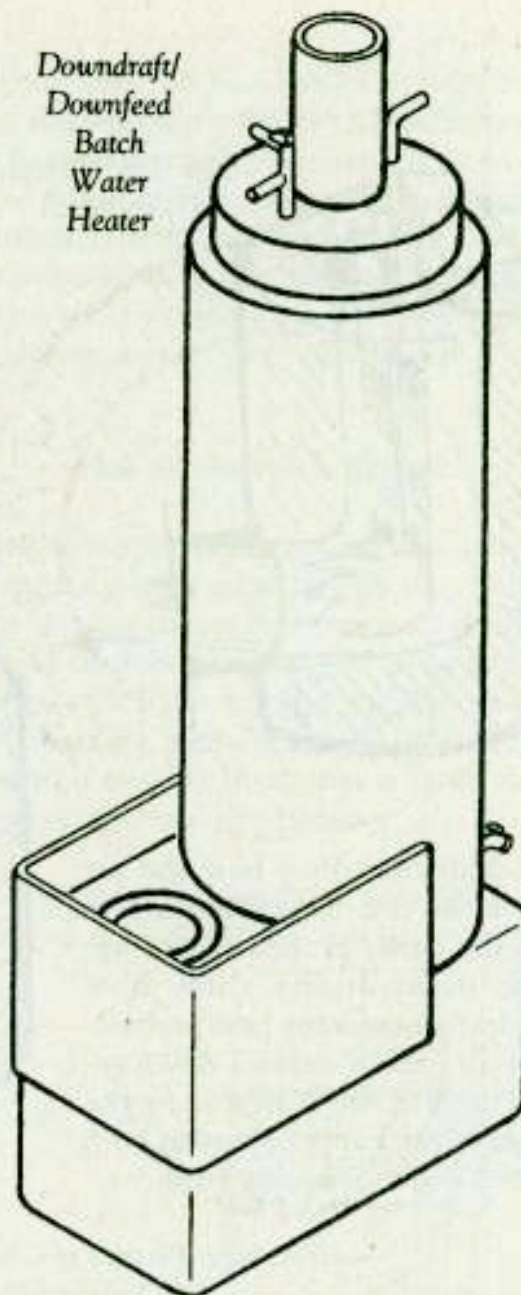


*Downdraft/
Downfeed
Batch Water
Heater*

keeps the fire hot for cleaner combustion and thermally isolates the stove body from the heat. Not much heat is lost uselessly into the stove body. Wood ash works well in stoves; it won't burn and is available wherever there are fires! As you can see below wood ash is

comparable to asbestos and is usually free!

Notice that Larry chooses to use the downdraft/downfeed pattern for feeding the sticks into the combustion chamber. The sticks are presented to the fire vertically and burn at the bottom. The fire is swept horizontally toward the tank by the draft created by hot air rising in the oven and chimney.



*Downdraft/
Downfeed
Batch
Water
Heater*

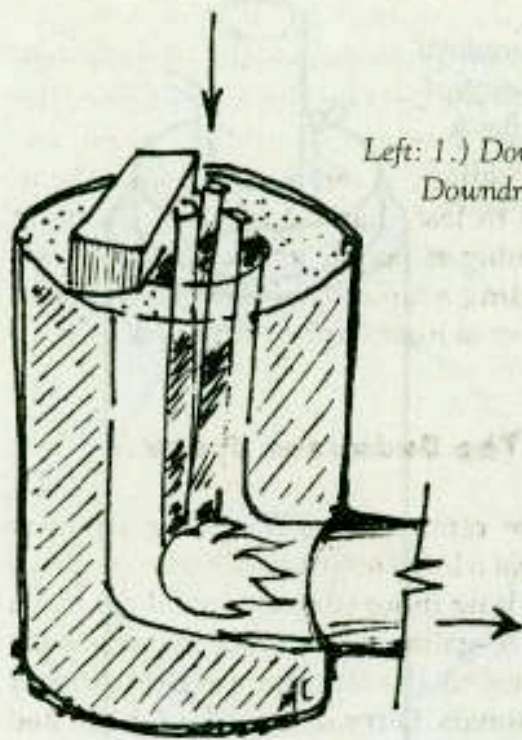
Wood Ash as Insulation

Material	Specific Heat*	Density**	Conductivity***
Asbestos	.20	36	.097
Wood ash	.20	40	.092

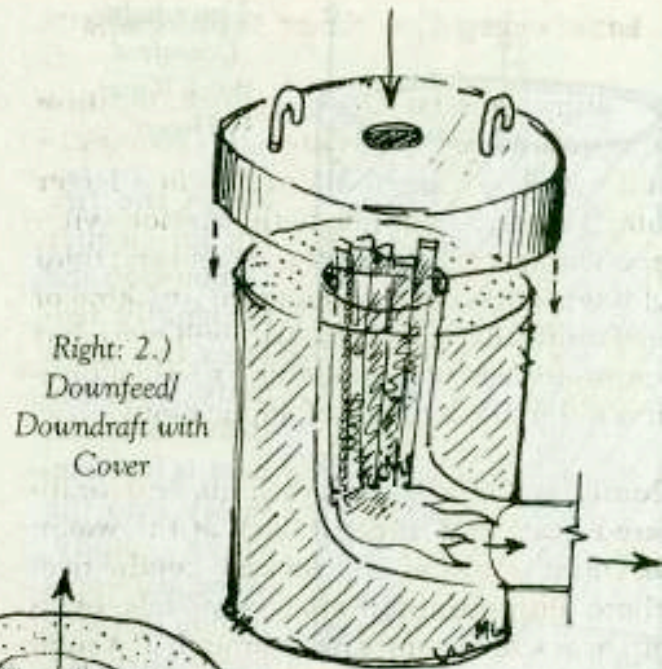
*Btu's to raise 1 lb. 1 degree F.

**lb./cubic feet

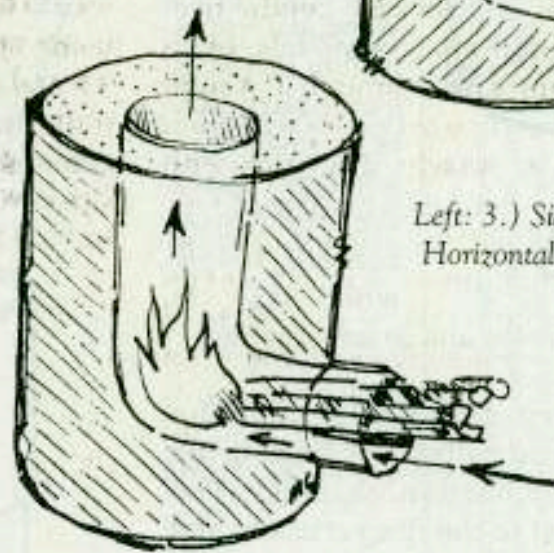
***Btu's per hour per square foot divided by depth (in feet)



Left: 1.) Downfeed/
Downdraft



Right: 2.)
Downfeed/
Downdraft with
Cover

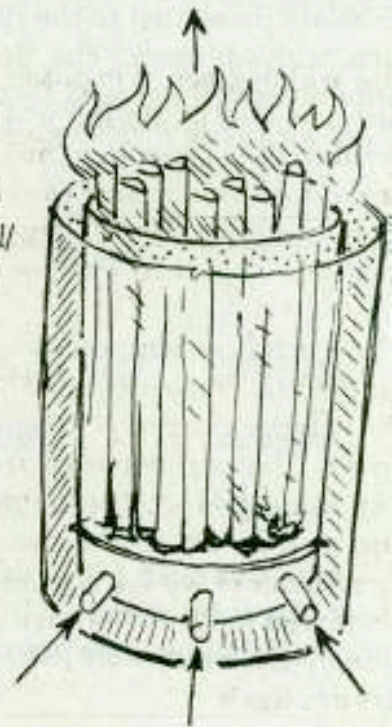


Left: 3.) Sidefeed/
Horizontal Draft

Downdraft describes how the air reaches the fire. This pattern provides the most preheating of air. These illustrations show how downdraft creates the best preheating of air. Air is sucked down towards the fire and is heated on the journey. This happens less in both sidefeed and topburning patterns.

This page: Patterns of Combustion
1.) Downfeed/Downdraft
2.) Downfeed/Downdraft with Cover
3.) Sidefeed/Horizontal Draft
4.) Batch Feed/Updraft

Right: 4.)
Batch Feed/
Updraft



Hot air assists complete combustion. Allowing cold air into the combustion chamber can easily reduce temperatures. In a downdraft design, a brick or a stone blocks too much air from being pulled into the fire and helps the sticks to remain vertical. It's also easy to put a lid over the downdraft fuel magazine, allowing the right amount of air into the fire. You can put a door over the sidefeed entrance as well, but this option is often left unused or removed. (Although downdraft is theoretically preferable, most people like the convenience of sidefeed.)

First a design question for you:

We noticed something odd in our stove tests...

If you are measuring the amount of wood burned and comparing that to the temperature rise in a quantity of water, what is more efficient: heating a full pot of water or a half-full pot of water?

Think about the amount of the pot's surface area in contact with the water before answering.

It turns out that efficiencies rise as more of the pot is filled with water. As well, bigger pots are more efficient than smaller pots. A really big pot, like a big steel drum, has a considerable advantage over a smaller pot. It is inherently more efficient (if you need a lot of hot water or food).

That's why when testing stoves it is necessary to use a standard pot in all tests. Bigger pots are better heat exchangers.

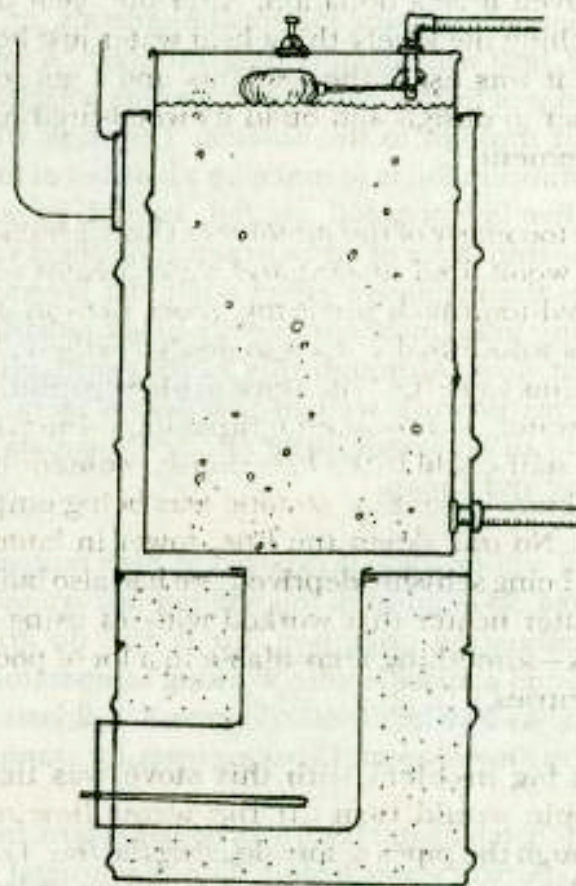
What I love about this design is how cleverly Larry incorporates a sealed skirt around a 33-gallon "pot." To make this 35%-efficient stove, you need to do the following:

Take the resealable lid off of a 55-gallon drum. Place the 33-gallon drum in the middle of the lid and scribe the circle. Cut away the interior of the circle BUT leave 2"-long tabs that will fit tightly against the 55-gallon drum. (See diagram.) If you're careful, the lid will make an almost airtight fit. Stove cement can seal the connection if necessary.

The lid stays with the smaller drum when it is removed from within the larger drum for cleaning. Hot flue gases travel up in the annulus between the two drums and exit out of a 6"-diameter chimney pipe located on the opposite side of the fire.

You will notice that it is possible to locate the firebox dug in the ground. Tiles or stone make the combustion chamber that is back-filled with wood ash or pumice rock or other natural insulators such as perlite or vermiculite. Bricks or stones hold up the 33-gallon drum, which will be quite heavy if filled with water. (One gallon of water weighs about 8.3 pounds.)

Larry does not show it in this sketch, but for greater efficiency one could insulate around the outside of the 55-gallon drum in the same manner as with the bread ovens.



Sudanese Gravity Water Heater

Why not take a minute to think up a few ways to design your own water heater? (See page 45-48.) What pattern would you choose for the combustion chamber? Where should the

Insulating the Heat Flow Path

Insulating the heat flow path includes insulating around the water tank and chimney. A third metal cylinder, obtained from a larger water heater, surrounds both interior cylinders. The space between the second and third cylinder is filled with insulation. Any kind of insulation (that will not burn) will work but it is often easy and compelling to use aluminum foil in these types of applications.

Aluminum foil will block the radiation (or infrared heat) and direct it back at the water. But aluminum foil is also very conductive. Where aluminum foil touches metals, or itself, heat will instantly pass through it. A solid bridge of foil between two cylinders will shoot heat through to the outside. The trick with aluminum foil is to make up a blanket of four or five layers of foil, air, foil, air, foil, air, etc. The thin layer of air between each sheet creates the insulative effect while the layers of shiny foil almost completely block radiation heat flow. Although this sounds difficult it seems to work well in practice. A spiral of foil can be wonderfully effective insulation, easy and cheap.

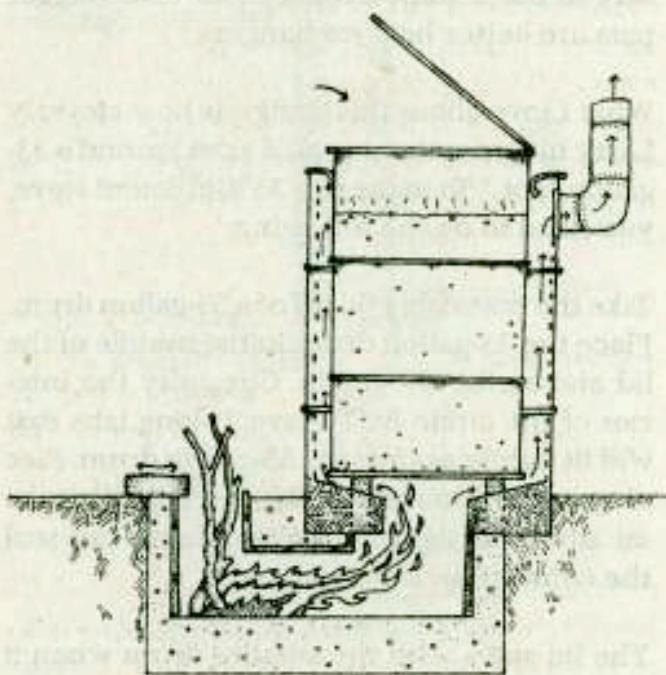
Foil will degrade if exposed to high temperatures. So aluminum foil will not last around a combustion chamber, but it will do great around a space where working temperatures tend to stay below 500 degrees F. Foil lasts almost forever around a baking oven, for example.

The batch heater used a forty-gallon tank from an electric water heater. The sheet metal for the exterior chimney came from its nice white cover. The gap between the two even happened to be 3/4". Perfect! Small bricks hold the tank up above the fire. Of all the wood-fired heaters we have used this is by far the preferred model. It is easy to use and almost free to make in the US, where old water heaters are trash.

At Aprovecho, our best model lasted through many daily showers for five years before the tank burned through. It used little wood, and heated 40 gallons of water up to bathing temperatures in less than 30 minutes. Keeping the fire going as people are bathing makes a never-ending source of hot water available. This design is highly recommended!

The Sudanese Stove

This stove represents perhaps the simplest way to heat a large quantity of water (or food) using nothing more than two steel drums, a 33- and a 55-gallon drum. And, in our tests, it outperformed the regular smaller Rocket cooking stoves. Larry designed it for the Red Cross who needed inexpensive large stoves to feed refugees in the Sudan.



The Sudanese Stove

exit tube be placed—near the top or bottom? I'm sure that your design will be better suited to your life than ours is! What materials around your place could be changed into a stove?

An Instantaneous, On-Demand Wood-Fired Water Heater

We broke down one long winter ago, in the early '90s, and installed a donated Paloma on-demand instantaneous propane-fired water heater. It had cost 600 dollars but was too small for the restaurant's dirty dishes. So we received it as a donation. After one year of watching the lovely thing heat water just before it was used, the students and I got together to design and build its wood-fired replacement.

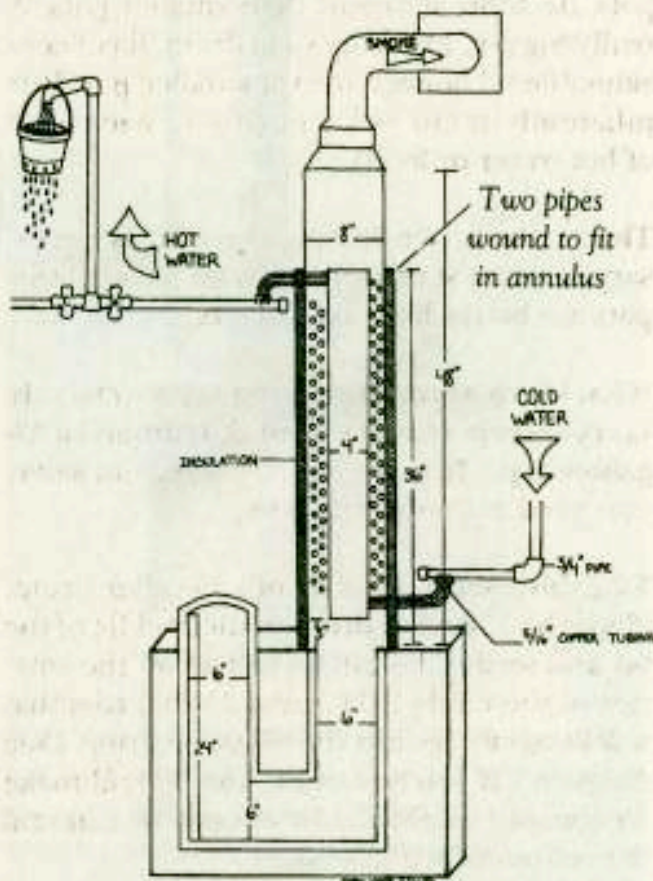
Like too many of the prototypes that we build, this wood-fired on-demand water heater required too much tinkering, more than most of us would really want to do. But, when all systems were "go," the stove made beautifully hot water, at a constant temperature. Interns and staff could bathe luxuriously, content in the knowledge that no tank was being emptied. No one down the line, towel in hand, was being selfishly deprived. We had also built a water heater that worked without using a tank—something unavailable in a lot of poor countries.

The big problem with this stove was that people would turn off the water flowing through the pipes before dousing the fire. The explosions as water turned to steam either blew the safety valve or tore apart plastic pipe. This made for exciting bathing! There's nothing like a good explosion in the shower stall, while you're nude and wet, to clear the mental haze of comfort and naive relaxation.

A Paloma water heater, you see, only lights

the fire after water is running through the pipe. It also will only light the fire, automatically, if more than 1.5 gallons per minute are flowing through the heating chamber. Our little wonder wasn't nearly so smart. Its safe use depended on human wisdom, which is in as short a supply at Aprovecho as elsewhere.

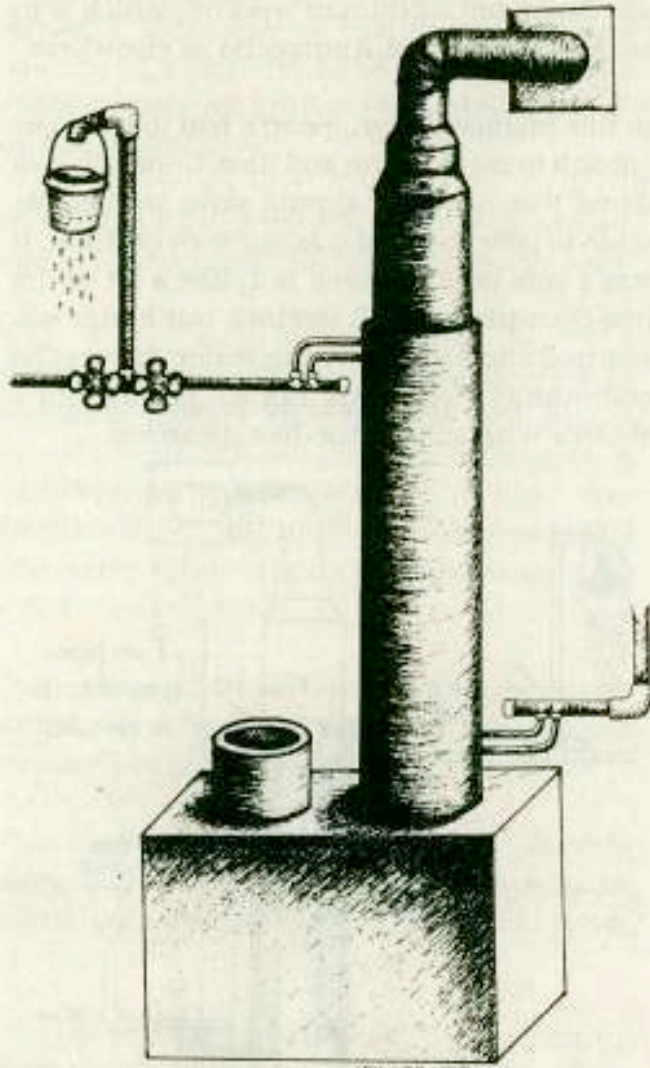
In this manual design, people had to be smart enough to regulate fire and flow. Generally, we found that this very simple stove worked for those of us who loved it as our own creation. It was a cute little monster. But, like a lot of the less-than-perfect A.T. devices, our bomb was scorned and derided by the wider Aprovecho community, who were not so glad to end a shower with submarine-like disasters.



On-Demand Wood Water Heater

The design is included here because there are many places in the world where it is impossible for regular folks to obtain a water tank. If tanks are not to be found, it is possible to

create a lively substitute that you can probably design to be perfectly safe! But our sage advice is that heating a batch of water is probably inherently safer than trying for on-demand service.



Seems Simple Enough

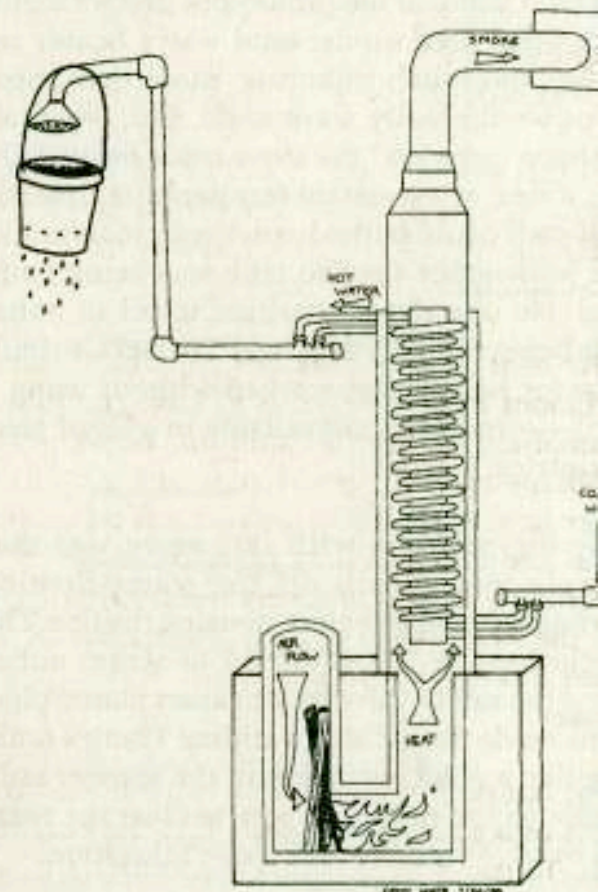
The great attraction of instantaneous designs is the use of pipes or copper tubing. This one had 40' of 1/2" copper tubing. Using a moderate fire, the water temperature rose an average of 65 degrees F. at two gallons per minute flow. Bath water is usually around 105 degrees F., so we needed to add a bit of cold water to the mix for comfort.

As you can see, the copper tube was cut into two 20' lengths and forged into two concen-

tric spirals. We wanted to make the hot flue gases bounce between the pipes so that the heat was "rubbing" the tubing, not flowing past it. What we wanted was something like a closely packed pinball game where the ball (the heat) constantly ricocheted between the cushions (the tubing).

The design neatly divides itself into combustion and heat-exchange categories. The combustion area uses Larry's preferred downdraft/downfeed arrangement. Insulation surrounds the walls of the combustion chamber, which were made from a 8"-diameter steel chimney pipe. Two straight sections and two elbows easily slipped together creating a sleeve that lasted for about two years.

Remember when making downfeed systems that the feed tube should be as low as possible.



Downfeed Pattern in Instantaneous Water Heater

If the feed tube is too high it can function as a chimney and encourage backdrafting. A cover with an air hole cut in it can close off the top of the feed tube. This greatly assists hot burns. Covering most of the big opening gives immediate proof that cold room air cools both combustion and oven temperatures.

The hole in the cover can usually be about 2" in diameter. Keeping unnecessary cold air from the fire is very helpful. Temperatures in the heat exchanger will rise by about 75 degrees F. when the cover is in place. Make sure that the air hole is large enough (visually inspect the fire through the hole) to encourage rapid, fierce combustion.

But be careful when removing the cover. If the feed tube is filled with smoke and the cover is rapidly removed, it's quite possible to ignite the smoke trapped in the feed tube. This explosion can rush up the tube and cover furniture with ash, a dark reminder of the power hidden in uncombusted fuel (smoke)!

For this reason we generally do not have interns completely cover the feed tube. A brick does nicely to hold sticks in a vertical position and regulate the airflow.

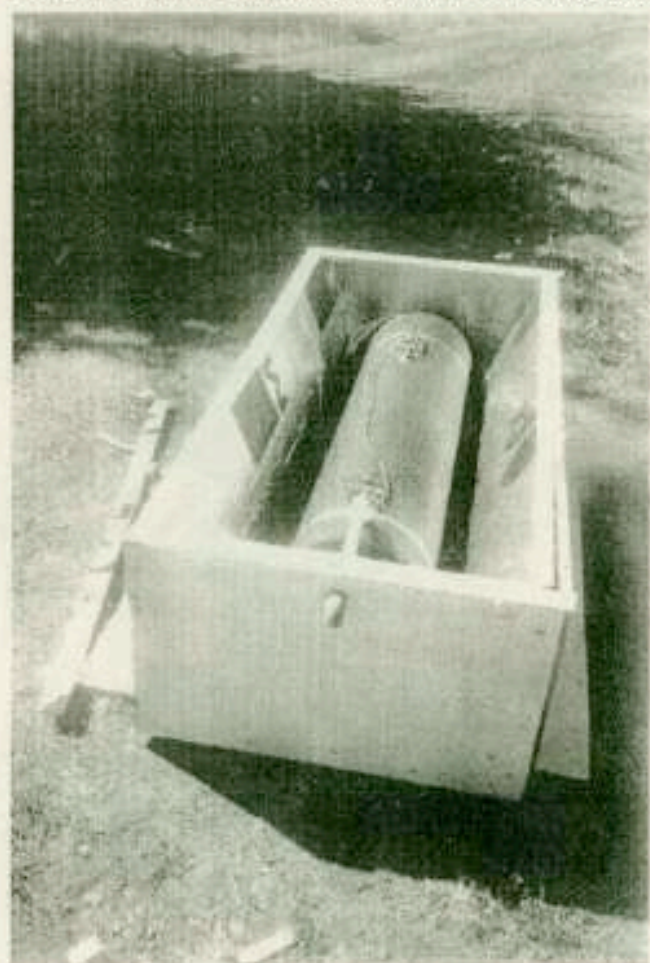
The neat trick in this design, which assists efficient heat transfer, is to have the tubing contained within the annulus, between the 8"-diameter outer stove pipe and a 4"-diameter stove pipe which is closed off on the bottom and top. The only function of the inner chimney pipe is to divert the heat. Without it, the heat would flow up the middle of the flue and much less heat would end up in the water.

The last part of this system is the bucket that acts as a safety reservoir. I like the bucket a lot. To me it symbolizes the simplicity of a good A.T. adaptation.

We were bothered by unexpected spurts of too hot or too cold water raining out of the nozzle. A nameless intern punched holes in the sides of a plastic bucket, three inches up from the bottom of the bucket, and hung it below the shower nozzle. The holes were big enough to drain water faster than it filled the bucket. So, the water had a chance to mix a bit in a small reservoir first before contacting the helpless human below. In this simple way, the water temperature was moderated and bathers became more secure. Love that simple solution!

A Solar Water Heater

I'm not sure how old Aprovecho's batch solar water heater is: I do know that it's more than ten years old, predating my arrival. Since the

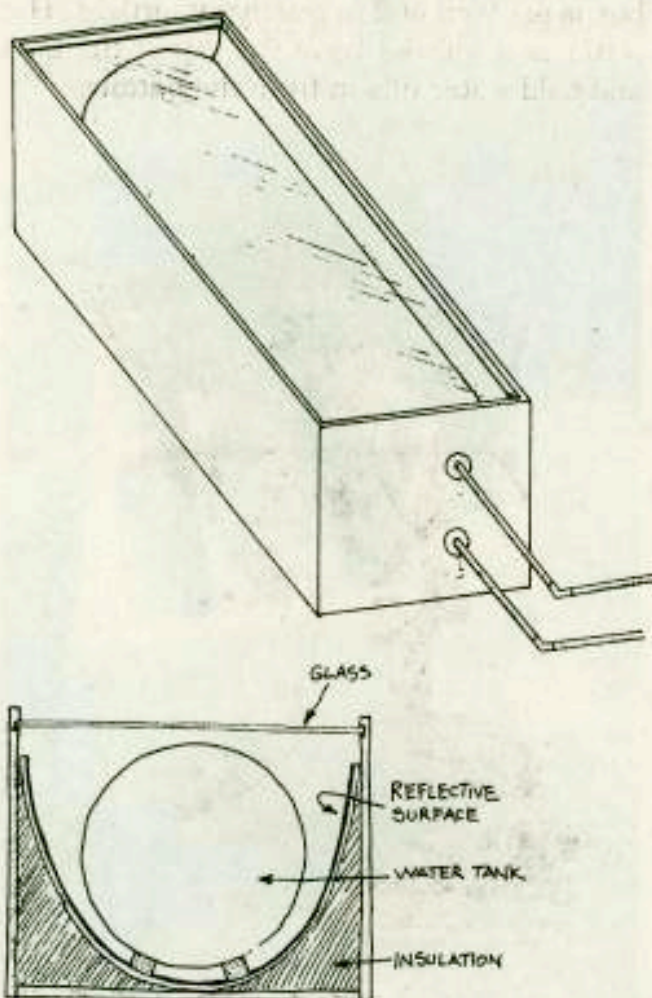


Batch Solar Water Heater

thing probably cost ten bucks to make, I would say that we have received better than fair service.

Heating bath water can be pretty efficient because the water doesn't have to get too hot. On a sunny summer day, the air temperature averages 80 degrees F. or more. Bath water needs to be only around 100 degrees F. The hot water in our batch heater gets to a maximum of 130 degrees F. The slight difference in temperatures (the Delta T) helps to reduce loss through the glass. A solar oven at 300 degrees F. is very much hotter than the outside air and losses are greatly increased.

To create an efficient solar water heater it's better to get more water to 100 degrees F. than



Batch Solar Water Heating Works!

to heat a smaller amount of water up to 130 or 140 degrees. It's best to size the tank so that temperatures do not exceed 100 degrees F. by a great margin. At Aprovecho during our warm summers this translates to a 40-gallon tank. At the end of the day the water is hot enough for comfortable bathing but not so hot that more heat escapes through the glass cover of the solar water heater.

Farrington Daniels must be a very likely candidate for father of appropriate technology if it is accepted that Maria Telkes was mother and E.F. Schumacher the high priest. In his wonderful book, *Direct Use of the Sun's Energy*, Daniels describes how 58% efficiency was obtained when the difference between inlet and outlet temperatures in a solar water heater was 60 degrees F. Efficiency fell to 30% when the difference rose to 100 degrees F. A little difference in the Delta T really affects efficiencies.

There are four design principles that result in a good batch solar water heater:

1.) Large temperature differences (large Delta T) create rapid loss of heat.

That's good in heating stoves but bad in a solar water heater. We want to increase the amount of water in the tank until it gets around 100 degrees F., but not much hotter by day's end. We want a small Delta T.

2.) Reduce losses from the solar water heater in all possible ways.

Insulate inside the box. Use double panes of glass as a transparent cover.

3.) Increase insolation.

Add north and south reflectors to the box. East and west reflectors shade the glass. Position the box so that it is perpendicular to the sun.

Absorptivity Table

(The fraction of sunlight that is absorbed and then emitted as infrared heat.)

White, smooth surface	0.25 to 0.40
Grey to dark grey	0.40 to 0.50
Green, red, and brown	0.50 to 0.70
Dark brown to blue	0.70 to 0.80
Dark blue to black	0.80 to 0.90

Handbook of Air Conditioning and Heating,
1965

average position above the horizon. Also include reflectors inside the box to aim sunlight at the sides of the tank.

4.) *Most importantly, increase as much as possible the ratio of sun-exposed surface area to water volume.*

A cylinder full of water has a poor surface-area-to-volume ratio. A flat rectangular box will heat up water more efficiently. Unfortunately, tanks are easier to find. Shallow boxes are not very hard to make, however!

The batch heater is made with the 40-gallon tank from an old electric water heater. It was stripped of the outer cover and painted flat black. Flat black surfaces will absorb and then emit as infrared heat about 90% of the incoming sunlight. Lighter colors like green and blue absorb only 60% to 70% of sunlight. White paint, especially when shiny, reflects up to 90%, absorbing only 10% of the sun's rays.

Some frog eggs are black on one side and white on the other side. If the egg is cold it rotates to expose the black side to the sun. If

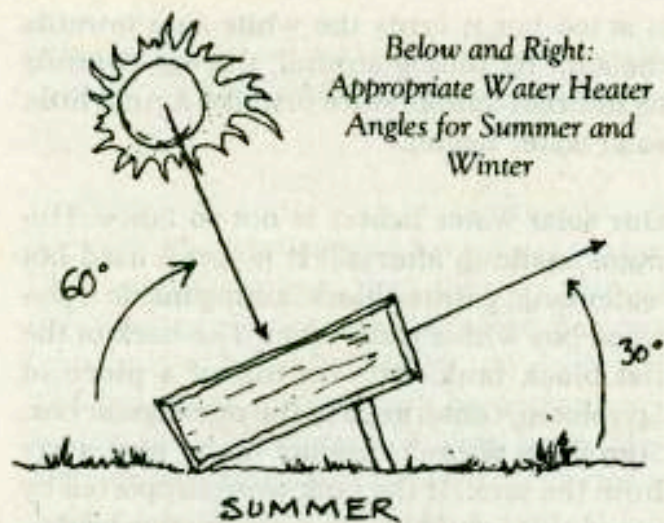
it is too hot it turns the white side towards the sun. By rolling around, the egg controls its internal temperature just like a great little solar water heater.

Our solar water heater is not so fancy. Humans made it, after all! It is just a used hot water tank, painted black, sitting inside a plywood box with a glass cover. The back of the flat black tank rests on top of a piece of Styrofoam, centering it in the rectangular box. Styrofoam doesn't conduct much heat away from the tank. If the tank were supported by metal this would create a conductive bridge, through which heat would be lost.

The shiny sides of the box, made from sheet insulation, are angled so that sunlight hitting the sides is reflected onto the black tank. The box is caulked and is relatively airtight. Hot water is taken out from the top of the tank and cold water fills in from the bottom.



Nature: The Best Design

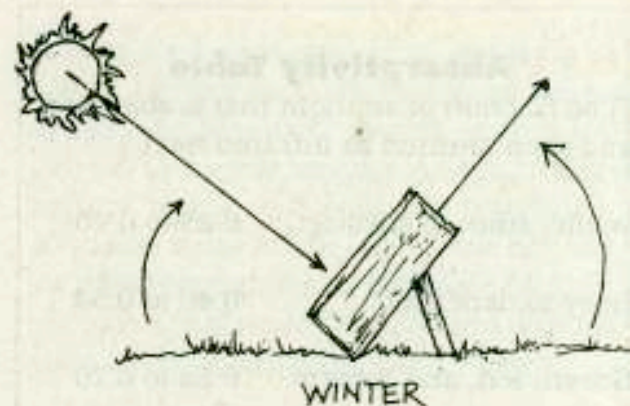


Because we had it around, we settled for one sheet of glass to cover the box. In our climate the water gets hot enough without the added expense of double-paned glass. The air gap between two sheets of glass greatly increases the insulative value of the glass. Remember that a single sheet of glass has almost no resistance (R) to the passage of heat.

An inch of wood is equal to about 1 R. A pane of glass is about .3 R. One-inch-thick sheet insulation is about 7 R. The new, argon-filled windows in the straw bale dormitory at Aprovecho are around 4 R. Packed earth has an R-value of about .25 per inch.

In a cold climate, double panes are necessary. At night, it's very helpful to cover the glass with insulation. The reflectors can be added to the top and bottom of the box so that their shadows never touch the glass. Reflectors on the side of the box cannot be used, because they would block sunlight in the morning and evening. The reflectors increase the square footage of incoming solar energy so the designer can use a bigger tank.

The box and tank are aimed at the average position of the sun. That's easier for us since we are only concerned with summer sun angles. If the water heater is to be used all year long it's necessary to make the box ad-



justable. Our latitude is 44 degrees north. Let's do the simple math to figure out the best angle for our batch solar water heater.

Our latitude, 44 degrees, subtracted from 90 degrees is 46 degrees. 46 degrees plus 23-and-1/2 degrees (which is the earth's declination) is 69-and-1/2 degrees. That's the highest the sun reaches above the horizon in summer time.

44 degrees subtracted from 90 degrees is 46 degrees. 46 degrees minus 23-and-1/2 degrees (again, the earth's declination) is 22-and-1/2 degrees. That's the lowest the sun reaches above the horizon in the dead of winter.

Since we use the solar water heater only in summer, we aimed the box so that its window would be perpendicular to the summer average sun position, which is somewhere around 60 degrees above the horizon. That meant that the box was inclined 30 degrees from the horizontal to intercept the most amount of direct sunlight. (90 degrees, a perpendicular or right angle, minus 60 degrees, the angle of the sun, equals 30 degrees, the inclination of the top of the box.)

Luckily, close is good enough. Glass is very transparent and we don't start losing a lot of energy by reflection until the sunlight is at a sharp angle to the glass. And as long as the box is aimed pretty close to the average daily sun above the horizon, losses are negligible.

You don't start losing appreciable square footage of sunlight until the box is very badly aimed. There's usually less than a 10% drop in efficiency even if the collector is pointed 45 degrees away from true south! (*Environmental Building News*, July/August, 1999.)

The tank is plumbed under pressure. When hot water is withdrawn, cold pressurized water flows into the tank, pushing the hot water onto the bather. In Mexico, lots of people fill black tanks on their roofs in the morning. By evening, they have a tank full of hot water, which makes a shower by gravity.

How much hot water can we make?

The box is 4' by 8'. That makes 32 square feet of intercepted sunlight. The interior reflectors direct almost all of the sunlight to the tank. The 5 hours around noon contain most of the daily input of heat energy. If we have 5 hours of strong sunlight during an average summer day, and if the average number of

Btu's per square foot per hour is 200, then we calculate as follows:

• 5 hours/day x 200 Btu's(square foot)(hour) = 1,000 Btu's/square foot per

day. (This is another good rule of thumb number!)

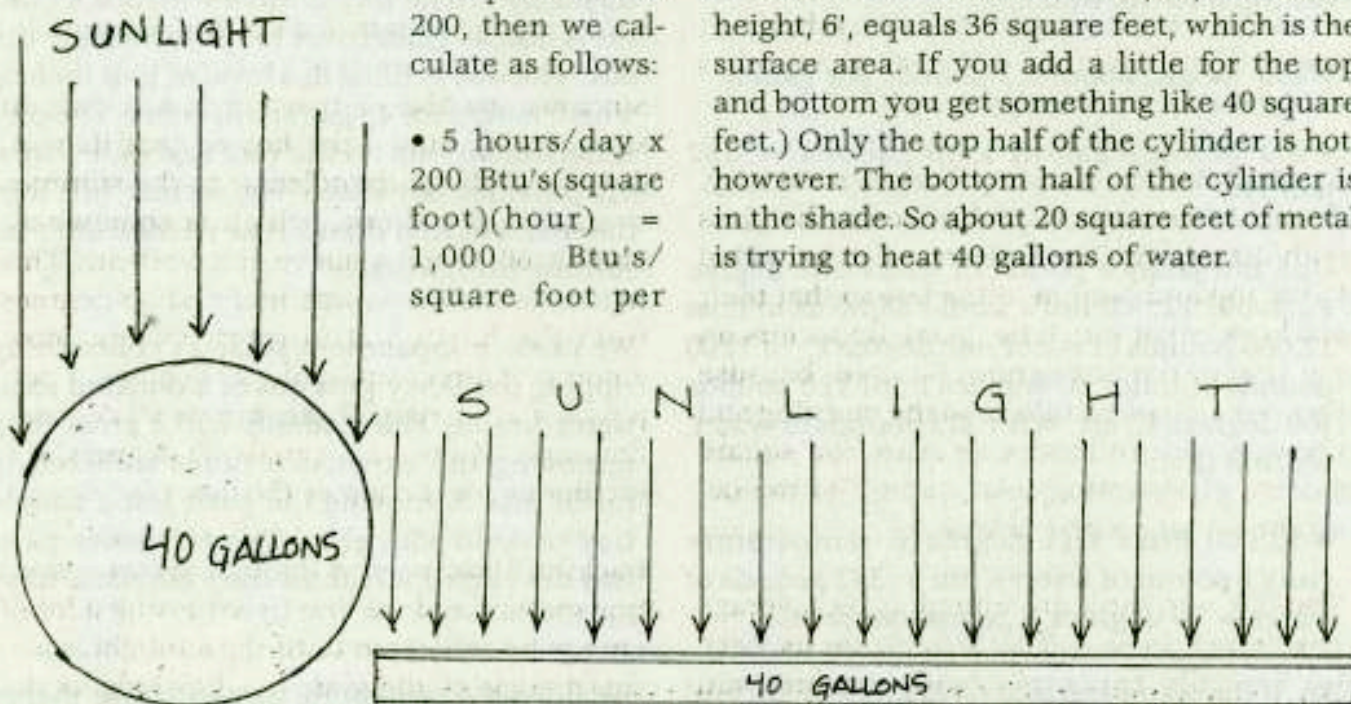
• 1,000 Btu's(square foot)(day) x 32 square feet = 32,000 total Btu's per day.

So something like 32,000 Btu's of energy hit the top and sides of the water tank.

Now, here's the big question: what percentage of the total Btu's actually makes it into the water by day's end?

The Delta T is low so we're not losing heat very rapidly through the glass although the R value is negligible. What hurts this design is that there isn't an optimized amount of hot surface area passing heat to the water. The optimal arrangement would have the most amount of hot metal touching as much of the 40 gallons as possible.

A 6'-long cylinder 2' in diameter has about 40 square feet of surface area. (The diameter, 2', times pi (3.14), equals the circumference, about 6'. The circumference, 6', times the height, 6', equals 36 square feet, which is the surface area. If you add a little for the top and bottom you get something like 40 square feet.) Only the top half of the cylinder is hot, however. The bottom half of the cylinder is in the shade. So about 20 square feet of metal is trying to heat 40 gallons of water.



Same Amount of Water but Greater Exposed Surface Area = Hotter Water

There is about one-half square foot of sun-exposed surface area per gallon in the water tank. A good collector has to have a higher surface-area-to-volume ratio. So due to a limited effectiveness in heat transfer ability, our batch heater will be only moderately efficient.

Great solar water heaters can be 70% efficient. They achieve these incredibly high efficiencies by insulating the glass cover (sometimes even using a vacuum, the best insulator), by optimizing the surface-area-to-water volume ratio, and by keeping water temperatures low. As a rule of thumb a simple cylindrical batch water heater will probably be around 30% to 40% efficient, give or take a bit.

We go back to our equation:

First, we'll assume that something like 40% of 32,000 Btu's make it into our 40 gallons of water.

Since it's best to underestimate performance we'll simplify and round down to 12,000 Btu's getting into the water.

Water weighs about 8.3 pounds per gallon.

- 8.3 pounds/gallon x 40 gallons = 332 pounds.

One Btu heats a pound of water one degree F., so our 12,000 Btu's would allow us to heat 12,000 pounds of water one degree F., or 1200 pounds of water 10 degrees F., or 120 pounds 100 degrees F., etc. With 332 pounds of water, we find that:

- 12,000 Btu's x (1 degree F. temperature rise)/(1 pound of water)/Btu + 332 pounds of water = 36 degrees F. temperature rise.

So, if the water starts at 60 degrees F., we end up around 96 degrees F., which is nice for summer bathing. Maybe four people can wash

both feet and hair every afternoon. If everybody wants to shower everyday at Aprovecho we need to make six of these solar batches to make bigger designs.

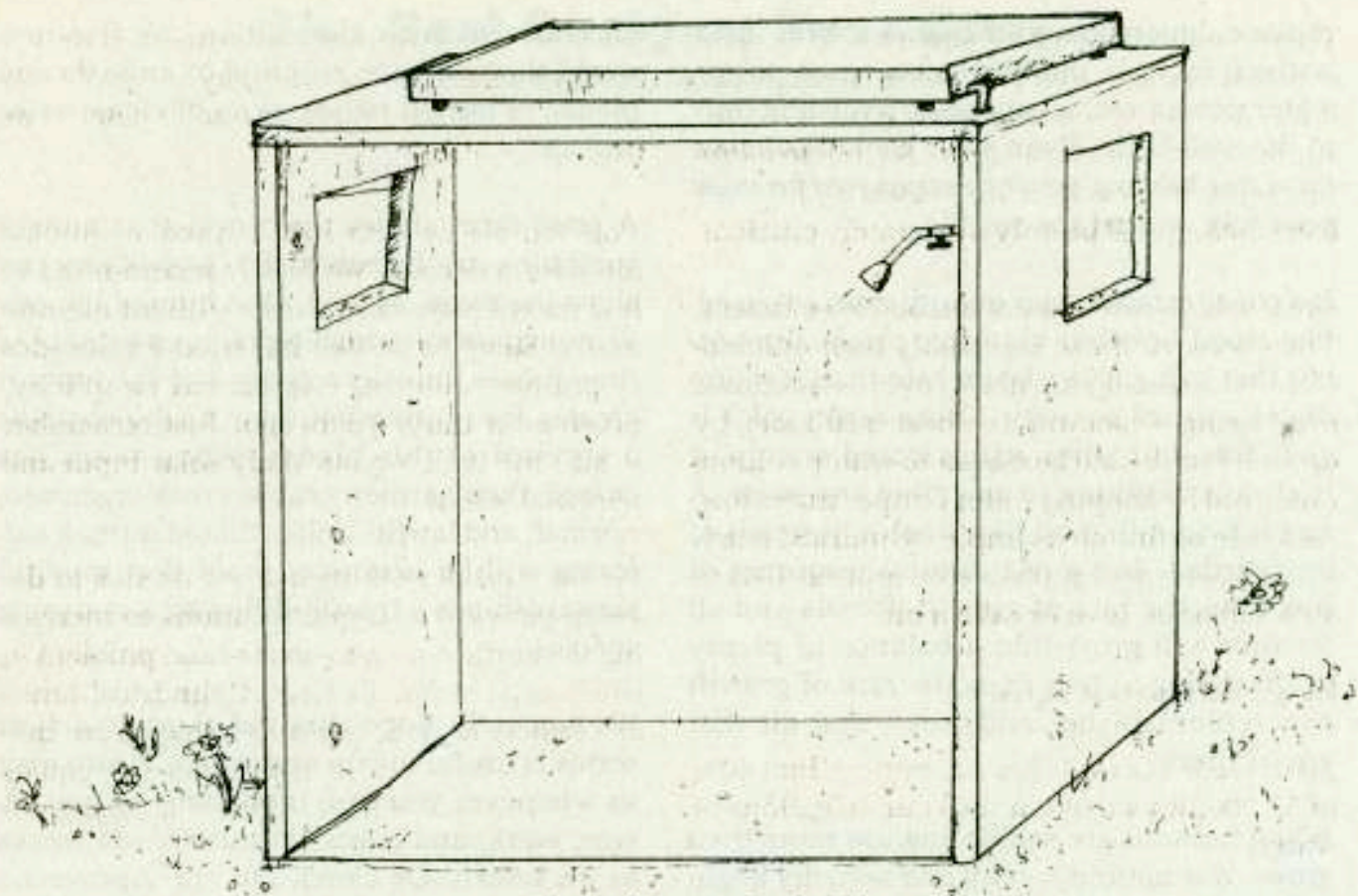
This simple system has worked without hitch for a decade. We highly recommend it. It is inexpensive, and works without maintenance. Steve Baer, who has tried for decades to promote honest, engineered simplicity, invented it thirty years ago. Just remember to size the tank to your daily solar input and personal needs.

Please consider taking a few minutes to develop your own simple solutions to increasing the surface-area-to-water-ratio problem for batch solar water heaters. Cylindrical tanks are easiest to find, but other shapes are better heat exchangers! Greater efficiency equals longer showers! Check out the amazing designs on pages 45-48!

An older design used in rural Japan works very well and consists of a simple wooden tray 3' by 6'. The tray is lined with black plastic. A double glass cover helps to insulate the box. The tray is filled to a level of four inches which makes for 45 gallons of water. The tray is horizontal, sits on the roof and quite capably provides hot water. The farmer fills it in the morning and drains it as needed after returning from work.

We made a Japanese-type solar collector by ripping the fancy guts out of a donated solar water heater. The students had a great time removing the expensive tubes soldered with metal fins. Removing the parts left a simple tray covered with glass. The expensive parts had developed a leak as they almost always do.

We filled the remaining tray with four inches of cold water. This large tray had a greater surface-area-to-volume ratio than our o



Japanese Solar Collector on Roof of Shower Stall

favorite heater made from a tank. When we compared results, the Japanese tray was 51% efficient, compared to the tank at 39%. Even though the tray was flat on the ground, not aimed directly at the sun, it was significantly better. And it pointed out how: Simple works! Batch heaters are great, simple, and can be highly efficient. And sometimes simplicity is much, much better than needless complexity.

And Then

Solar works well if there's a lot of sun, like in our summers. But we can't expect a diffuse energy source to heat water or food or homes on earth very well when clouds obscure its warmth. An architect can talk a blue streak about how well a passive solar house will work in the rain. A salesperson can brag about how hot the newest solar cooker can get. But any-

one can add up a few numbers and pretty accurately predict solar performance.

Hopefully, *Capturing Heat One* and *Two* have provided you with a feeling for the potency of solar energy. Living with direct solar devices quickly shows the power and limitations of direct use of sunlight. Before building a solar cooker or solar water heater, it serves well to do some simple math to see how the design can be expected to perform. If it is sunny, the apparatus will probably work very well if you have optimized the heat transfer! But solar heat is not magical. When it's cloudy or foggy at Aprovecho we usually turn to the concentrated solar energy in biomass.

Biomass is and will be the concentrated solar battery of the poor. If it is available, wood provides natural warmth and even power for industrial applications. Unfortunately, trying to

replace dependence on biomass with alternatives such as photovoltaics, wind power, water power, etc. is an option available only to the well-to-do. Even solar cooking and solar water heating are very expensive for most poor folk around the world.

If a concentrated solar energy source is used, like wood or other biomass, please remember that using it at a faster rate than it reproduces assures scarcity. Using direct solar is guilt free, but when using stored energy, it is always tempting to use more and more. A forest is wealth, and like wealth, it needs to be guarded. If we use natural resources at less than the rate of growth, forests and all fertility will grow into a balance of plenty again. Using at less than the rate of growth can replenish the land, seas, and all that grows there.

When humans are selfish and use more than grows, our natural wealth and security begin to disappear and life becomes harder. We pres-

ently live in such a condition. We live world that we have emptied of animals, plants, of buried riches, even of clean water and air.

A good farm shows the world that human habitation can be beneficial. A good city show the same, as well. One human life demonstrate sustainable practices or not. Time passes, human activity and the harm creates focus attention upon each person a steward of this planet. When harm ceases, then harmony can become organic, normal, and lawful. Self-inflicted human suffering will be historical proof that minimalist stewardship is a trust fulfilled by a mature species.

We sincerely hope that the *Capturing* series is useful to you and yours. Please contact us whenever you can. If possible, stay with us, sign, work, and learn with us for ten weeks as an intern. Or check out the Aprovecho homepage at <http://www.efn.org/~apro>



Larry Winiarski and two friends from Kenya with a Sudanese Water Heater

More Designs

Order Form

Please send me

copies of *Capturing Heat One*, \$7 postpaid

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copies of *Capturing Heat Three*, \$8 postpaid (available in summer 2000).

Enclosed is my \$30 Aprovecho membership contribution.

I would like to make an additional donation to Aprovecho's work: \$_____.

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Aprovecho is a non-profit, membership-supported organization. Dues are \$30 per year and include a newsletter detailing results of current research.

We also offer a ten-week internship program for people who want to learn about organic gardening, sustainable forestry, indigenous skills, and appropriate technology. Sessions begin in March, June, and September in Oregon. Classes (9 am-5 pm Monday through Friday) include lectures, discussion, practical work, and field trips. Please contact Aprovecho for complete information.

Our phone number is (541) 942-8198; fax (541) 942-0302. Please call in advance of your visit. If you would like written information, please send a SASE to Aprovecho Research Center, 80574 Hazelton Rd., Cottage Grove, OR 97424. Or you can check out our website: <http://www.efn.org/~apro>

Aprovecho Research Center

Aprovecho is a center for research, experimentation, and education on alternative technologies that are ecologically sustainable and culturally responsive. Our fields of study include organic gardening, sustainable forestry, indigenous skills, and appropriate technology. The center is located on a beautiful 40 acre land trust near Eugene, Oregon.

Since 1976, Aprovecho Research Center has been involved in developing energy-efficient and non-polluting inventions that reflect current research but which are designed to be made in most any country. The tools are designed to be self-built and self-repaired. The technologies are used at the Research Center. Students and staff are constantly working to improve designs for efficiency, ease of use, and general utility.

Aprovecho is largely supported by its internship program. Three ten-week semesters are offered per year. Classes are both lecture and hands-on, providing the college-aged or older student a chance to live in and learn with a community of teachers dedicated to sustainable living and voluntary simplicity. Please contact us for further information.

Additional copies of this book are available for \$8 postpaid from Aprovecho Research Center, 80574 Hazelton Rd., Cottage Grove, OR 97424, (541) 942-8198. Copies are available for the cost of postage to those working to benefit the poor.