Designing Home Made Wood Burning Heating Stoves

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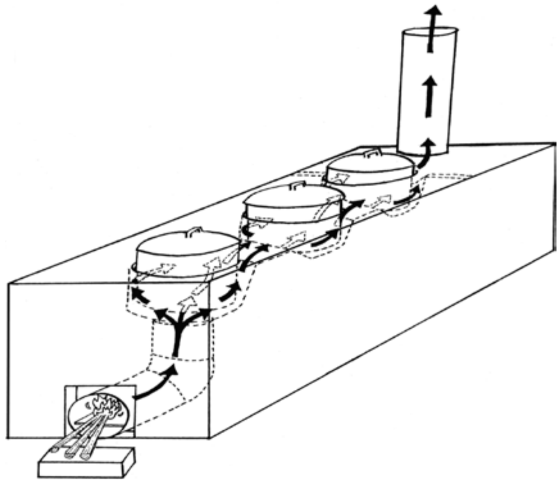


Learning from Cooking Stoves

Aprovecho Research Center has been investigating how to burn wood and biomass since 1976. Most of this work has been with cooking stoves. But a lot of the lessons that were learned experimenting with cooking stoves have been found to be applicable to heating stoves as well. After years of investigation, it became clear that heat transfer to the pot largely determines the fuel efficiency of a cooking stove, especially since high combustion efficiency, transforming a large part of the wood into heat, is relatively easy to achieve.

The Technical Director at Aprovecho is Dr. Larry Winiarski, Mechanical Engineer. Larry is a gifted teacher who has directed our investigations at the research center. The cooking and heating stoves which Aprovecho helps indigenous groups develop around the world are his inventions. Larry's understanding of stove thermodynamics has resulted in a set of ten design principles that can be used to create many types of wood burning space heaters.

Dr. Winiarski pointed out years ago how to improve heating stoves and impressed the Aprovecho staff by building heating stoves that used much less fuel and were clean burning. His experiments showed that the combustion chamber (where the fire burns) is only one part of the successful heating stove. The heat exchanger function, that assists heat transfer to the room, largely determines system efficiency.

A successful combustion chamber achieves nearly complete burns (turning almost 100% of the wood into heat) and doesn't allow smoke, which is un-combusted fuel, to escape. Enough air rushes into an insulated chamber to create a hot fierce fire that burns cleanly. The second job of the good stove is to get as close to 100% of the heat as possible into the room.

Chimney pipes are poor heat exchangers

A cylindrical chimney pipe allows a lot of the heat to escape instead of forcing the heat into the room where it can be of use. The chimney pipe is an inefficient ***heat exchanger***. Hot flue gases rush up the middle of the pipe avoiding the friction of the sides. So, a large portion of the heat created by burning wood is wasted as it escapes up the chimney, and out into the cold air beyond our windows and walls. Testing at Aprovecho has shown that capturing more of the usually lost heat dramatically reduces fuel consumption. Using a good heat exchanger gets families warmer, quicker, using much less fuel!

Clean Burning First!

A good combustion chamber changes wood or other biomass into heat without creating much smoke or creosote (condensed wood tars). Complete combustion of wood results in two byproducts: carbon dioxide and water vapor. Incomplete combustion creates unburned particles that cause pollution, and creosote that fills chimneys and can cause chimney fires if it catches fire.

Complete combustion is the goal of the combustion chamber. But a slow burning heating stove cannot burn wood very cleanly. Nearly complete combustion in a wood burning stove is achieved by doing the following things:

1.) Metering the fuel- cutting wood up into smaller pieces and feeding them at a proper rate into the fire, as they are consumed.

2.) Making a hot fire- Creating a combustion zone where fuel, flame and air are mixed by <u>turbulence</u>, at a high enough <u>temperature</u>, for a long enough <u>time</u> period to completely combust. Combustion temperatures must be hot enough to assist burning all escaping gases released from the wood.

Remember that wood itself does not burn! Wood gets hot and then releases constituent gases that hopefully all burst into flame! A hot fire is a clean fire but a lazy, colder fire pollutes the air which humans need to breathe.

Ignition Temperature (Fahrenheit in Air) of Wood Gases

Hydrogen	750
Carbon Monoxide	1125
Methane	1000

Combustion Engineering, Borman & Ragland, 1998

3.) Preheating the air that enters the combustion area- helps to keep temperatures hot.

4.) Igniting escaping smoke- which is uncombusted fuel, by passing it through flame.

5.) Provide sufficient oxygen- starving the fire slows it, cools it down and produces smoke.

6.) Limit the cold air entering the fire- air is warmed as it passes through a small opening into the combustion chamber. ***Make enough small holes under the door into the combustion chamber so the holes have as much cross sectional area as the chimney exiting the house.*** Position the holes so that primary air is sucked into the coals and up into the combusting wood***. Do not allow the user to block the holes reducing primary air. Blocking the necessary amount of air will create pollution***. The rate of burn in a heating stove should be determined by the amount of fuel in the combustion chamber, not by shutting off air to the fire.

7.) Form a grate out of the firewood- sticks burning close together keep the temperatures high. The pattern should be stick, air, stick, air, with even spaces between the sticks.

8.) Create sufficient draft- use a tall enough chimney or better yet a small fan. An insulated chimney creates a lot more draft than an uninsulated chimney. (Insulating the combustion chamber can elevate temperatures as well.) High velocity jets of hot air entering under the fire, up though the coals, creates mixing which reduces emissions. ***Do not use a damper in the chimney! Design the stove to run efficiently with enough air entering and leaving the stove to burn fuel cleanly.***

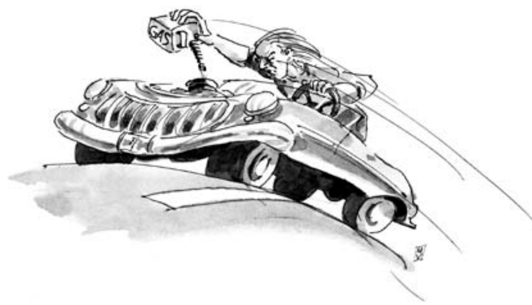
Complete combustion cannot occur when starting a stove because the combustion chamber is too cold. An insulated combustion chamber will heat up quickly and then when burning metered amounts of biomass, make much less smoke. Throwing a big log on the fire, however, always makes smoke. Parts of the log are too cold and are making more gases than can be combusted.

Without enough air wood cannot burn cleanly. The openings into the fire should be as large as the chimney exiting the house. Slowing down the burn by shutting off air to the fire sends horrible plumes of smoke out of the chimney. A stove must have enough air to function efficiently for this reason it is not necessary to provide air inlet controls or a damper in the chimney in the well engineered stove.

Metering the Fuel!

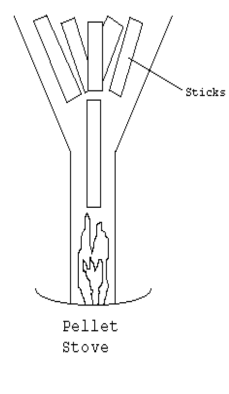
Throwing a big log on the fire is like dumping a gallon of gas down the carburetor of a car all at once… The car may keep running, if it doesn't stall completely. However, smoke will certainly pour out of the exhaust as the car struggles to burn too much fuel.

Fuel needs to be metered to achieve efficient combustion. That's why cars have carburetors that precisely mix just the right amount of air and fuel and spark. The improved heating stove does the same thing burning up the gases without lettingthem escape without combusting.



Pellet Stoves

Pellet stoves don't smoke because just the right amount of fuel is delivered as it is burned up. A fan makes it possible to preheat the air coming into the fire and assures good mixing of gases, air and flame. Pellet stoves never restrict the air entering into the fire. Lots of air is needed for hot clean burning. The amount of heat is regulated by adjusting how much fuel drops per minute into the fire.



In a pellet stove, regulated amounts of fuel drop down into a small crucible replacing the burning fuel at the same rate it is consumed. This small amount of fuel combusts completely. No smoke and few emissions exit out the chimney. In the United States pellet stoves burn so cleanly that they are exempt from environmental regulations!

Metering fuel makes clean burning easy. In a regular wood burning stove, the same thing can be accomplished by burning small sized pieces of dry wood, and watching to make sure that a fierce flame continues to gobble up the fuel. A little observation teaches the operator quickly how to maintain clean burning. Unfortunately, adding fuel at regular intervals is much more demanding that just throwing a log onto the fire and then ignoring the smoke polluting the environment.

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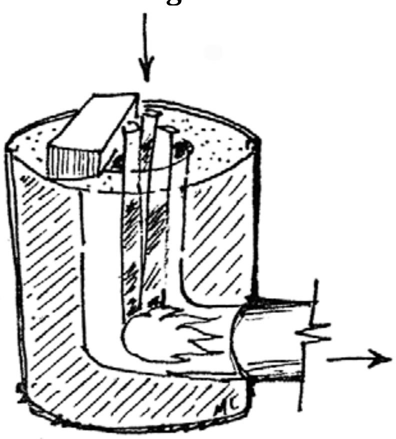
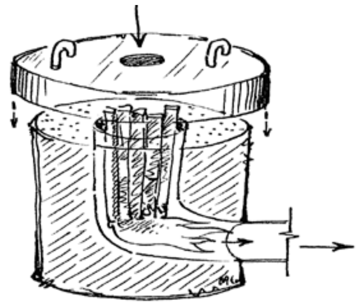
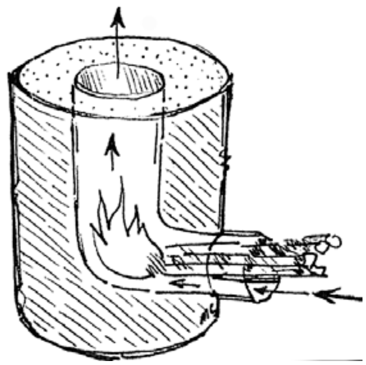
Three Patterns for Combustion Chambers

If smoke passes through flame it ignites. Which one of the following patterns has the greatest potential for clean burning?

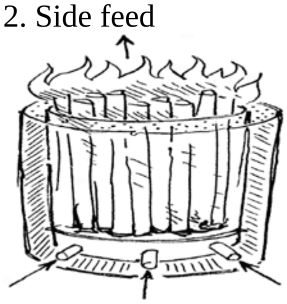




1. Downdraft/downfeed



2. Side feed



3. Top burning

These three illustrations show different clean burning patterns of feeding wood into a combustion chamber. Number 1 shows the pattern that Dr. Winiarski favors: downdraft/downfeed. The wood is burned at the bottom of a vertical stick which falls down as it is consumed. Air is pulled down alongside the sticks and into the fire. The coals fall in front of the flame path and help to create a second environment in which to ignite smoke. A wall of flame is pulled horizontally into an insulated space. Smoke escaping the initial burn will usually ignite in the flame. The downfeed/downdraft stove is clean burning like the pellet stove *because of the metering of fuel into the fire.*

2. Side feed/side draft is how most people in the world feed a fire. The sticks are pushed into the fire as they burn. In this pattern, the fire creates coals that lie underneath the flame which is less helpful for assisting secondary combustion. With care, however, side feed can be an effective option.

3. The third pattern is to pack the wood into the combustion chamber. This is called batch loading. The sticks are vertical and hold each other up.

If you wanted to minimize smoke would you light the fire at the top or bottom of the stack?

If the batch of wood is lit at the bottom any escaping smoke rises up and away from the flame. Lighting the stack at the top, on the other hand, can result in clean burning because smoke is more likely to pass through flame. Masonry heating stoves often use this top burning technique.

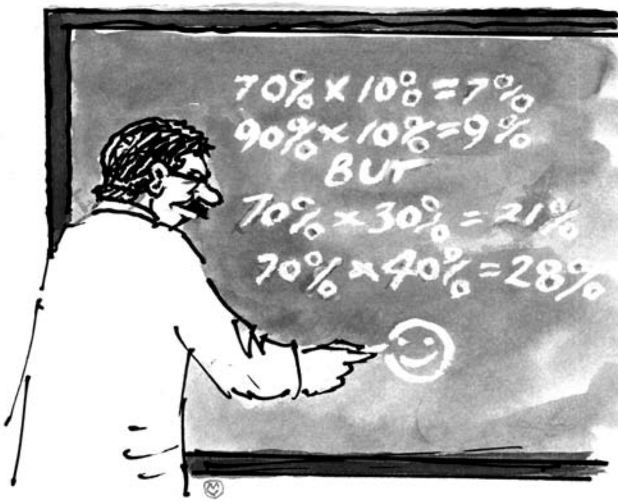
The first decision of the stove designer is to choose one of these three patterns or to combine elements into a variation best suited to the job.

4.) There is, of course, a fourth pattern for a combustion chamber. Enclose logs of woo, held up off the floor by a grate, in a metal enclosure and start the large pieces burning using kindling. Air is supplied through small holes that create high velocity jets that pass up through the charcoal to the burning wood. These holes allow the same amount of air to enter the combustion chamber as leaves it through the heat exchanger and chimney. ***Do not allow the user to block the holes reducing primary air. Cutting down the primary air makes smoke, creating pollution and wasting fuel.*** *Given plenty of air, the logs will burn without tending for a couple of hours, making the stove easy to use. But, providing enough primary air and insulating around the fire will not alter the nature of this arrangement: this is an inevitably smoky pattern. On the other hand, this pattern is so pleasant to operate that even though it is environmentally unfriendly it has to be included as an option.*

Heat Exchangers

There are three types of heat exchangers generally used to capture the heat produced in the combustion chamber. The hot flue gases can: A.) heat **mass** like heavy stone or masonry B.) Have the heat warm **water** which then warms the house or C.) The easiest and least expensive route is to make the hot stove gases efficiently heat cooler **air** inside the room.

Heat exchangers increase heat transfer to the room by making sure that the hot flue gases leaving the room are as cool as possible. Even a smoldering fire turns at least 70% of the wood into heat. But, heat transfer efficiency (heat delivered to the room) can be less than 20% in poorly designed systems. As the cartoon shows below a little improvement in heat transfer equals impressive reductions in wood use.



When analyzing a system, try to improve the least efficient part first. This has the greatest beneficial effect on overall system efficiency!

Choosing Between Air to Air and Air to Mass Heat Exchangers

High mass heat exchangers were created in the days of drafty houses when heating air was a loosing proposition. Old houses had air exchange rates of more than 10 exchanges per hour. All the air in the house was replaced ten times or more every hour! It didn't make sense to heat air that would quickly be out of doors.

Storing in a large thermal mass inside the house that does two things: 1.) allows big hot burns where excess heat is stored instead of immediately over heating the interior.2.) Even when full of stored heat the surface of the heat exchanger remains at a relatively low temperature so that radiant heat is released at a slower rate per hour into the living space. The big warm rock in the living room heats occupants by radiation even when the air is cold. High mass stoves are perfectly suited to the drafty environments for which they were designed.

Drafty Houses Constantly Loose Heat

Today many houses are not so drafty. Tighter houses can have one half an air exchange per hour. Heating air becomes an acceptable option. The hot air has time to warm occupants and interiors. Sealing cracks into the house is the most important first step to holding heat in a house. But, a lot of people still live in drafty houses with a lot of air exchanges per hour. An air to mass stove evolved to heat just such a house. But, it is not necessary to use a massive heat exchanger in tighter, better insulated houses.

The Pluses and Minuses of the Massive Heat Exchanger

Positive

1.) The mass stores heat that can keep the house warm over night.
2.) Gentle radiant heat feels good.
3.) Burning time can be reduced.
4.) The fire can be huge and hot resulting in clean burning. Since the heat is stored, the room doesn't tend to overheat.

Negative

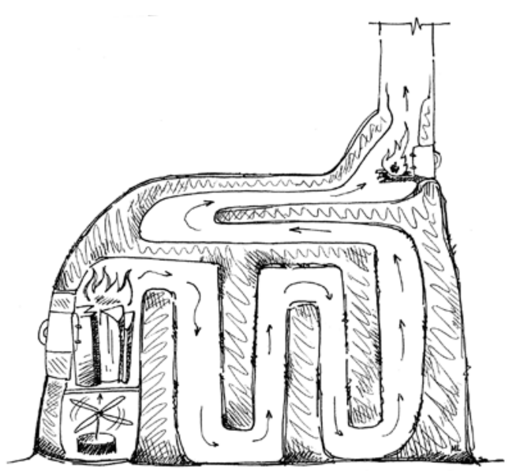
1.) Stored heat is there if you need it or not. If the day suddenly gets warmer the room can overheat.
2.) The mass takes up room. To store sufficient heat the heat exchanger must weigh many tons.
3.) The cold mass will take a long time to heat up and warm the room. Coming home and lighting the stove for warmth will not work with a high mass, slow response heating stove. The stove needs to be kept warm.
4.) Creating the ductwork in stone or brick or adobe can require training and experience.

The Air to Air Heat Exchanger

Positive
1.) Is inexpensive, easy to make
2.) Doesn't weigh very much
3.) Takes up less space
4.) Heats the room quickly
5.) If the weather suddenly warms the heat can be adjusted.

Negative
1.) Doesn't retain heat, is cold after the fire goes out
2.) Discourages big, hot, clean burning fires (which overheat the room). Can encourage small fires that pollute!
3.) Are better suited to less drafty houses

Massive Heat Exchangers Encourage Hot Clean Burning



The great thing about air to mass heat exchangers and air to water systems is that the stove can be fired very hot for a long time without overheating the room. The heat goes into the cool stone or water, instead of immediately into the room air. Big fires are very hot and for that reason produce less harmful emissions. The harmful particles burn up in the hot fire.

When using mass to capture heat after an intense burn the fire can be allowed to go out. An airtight damper and door on the stove stops air from moving up the chimney. The stored heat in the mass radiates into the room replacing heat lost to the outside. Room temperatures stay relatively constant even though the fire is extinguished for prolonged periods of time.

Shutting the flue (sealing off the chimney) after a short burn also helps to decrease the number of air exchanges in the room. As long as air is rising up the chimney it is replaced by cold air that is pulled by the lower pressure in the house through cracks in the doors and window frames. Starting a stove greatly increases the number of air exchanges in a room or house. Using a wood burning stove with a chimney usually has this negative side effect.

However, shutting the flue after a three or four hour burn reduces increased air exchanges. Air to air heating stoves can also reduce or eliminate increased air exchanges by feeding the fire with air supplied from outside the house through a tube in the wall or floor. In this manner air is supplied directly to the fire and is not sucked in through the cracks!

An external supply of air into the combustion chamber is very helpful as it eliminates increased air exchange into the house. Or use big, hot burns that store excess heat in mass so that the chimney is only operating for relatively short periods.

Air to Water Heat Exchangers

Heating water requires care because of the potential pressure rise as water boils. Pipes full of water can corrode or fill with mineral deposits. Except for these problems, water is a great storage medium for heat. Per pound water stores 5 times more heat than rock. (The density of rock offsets this difference to some degree.) One BTU will raise the temperature of one pound of water one degree F. To raise the temperature of rock or adobe requires only 1/5th of a BTU.

For this reason heating water is a very efficient way to capture the heat of a fire before it slips away into the sky. The efficiency of heat transfer into large containers of water can be very good and water stores and holds heat for a long time.

Advantages

1.) Can provide very efficient heat transfer.
2.) Retains more heat than other thermal mass.
3.) Allows for control of the amount of heat by opening or closing radiators.

Disadvantages

1.) Usually requires a thermostat
2.) And safety release valves
3.) Water can leak
4.) Minerals in water can reduce internal pipe diameter, leading to reduced water flow, greater temperature rise and increased pressure in the system.

Even the most carefully built wood fired showers at the research center occasionally leaked or even exploded! Air to water heat exchangers for house heating seem so full of potential problems that we have never installed one at Aprovecho. Imagine trying to repair lots of leaking pipes buried in your floor… so far the overwhelming complications and cost have steered us back to simpler solutions. Heating water is a theoretically great idea but it also seems overly complicated.

Environmental Building News (Volume 11, Number 1. January, 2002) concludes that radiant water heating isn't necessary in insulated, tight houses. Controlled air exchange into the house (say, better than one air exchange per hour) and enough insulation (Oregon code requires R-38 in the roof and R-21 in the walls) works so well that a heating system can be smaller, simpler and inexpensive. Insulation and air tightness make heating simple and easy.

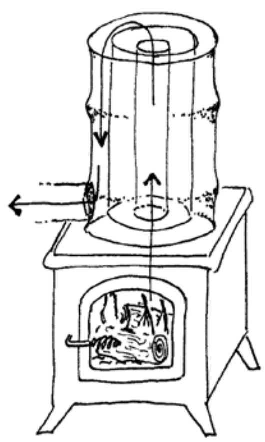
The Air to Air Heat Exchanger Is Hotter and Cheaper

The high mass type stove can get away with short hot burns. An air-to-air heating stove has a harder task to accomplish: to create an equally hot, smaller fire that matches the heating demand of the space. The air-to-air type of stove is more dependent on doing things right to reduce emissions since it's not creating one huge hot fire. The big factor favoring air to air solutions is that they can be built inexpensively and quickly.

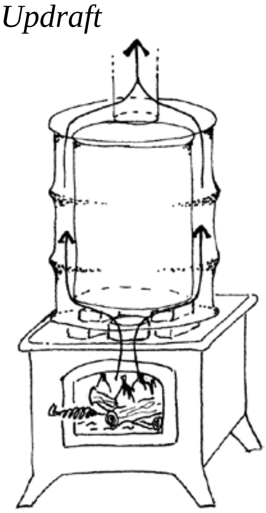
Stoves with Air to Air Heat Exchangers

After making sure that the combustion chamber will burn cleanly, Dr. Winiarski adds two basic types of air to air heat exchangers to the stove: either downdraft or updraft.

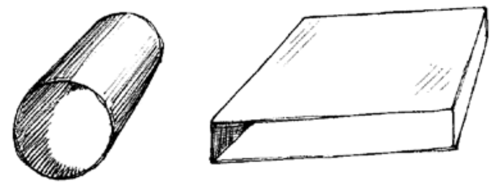
Downdraft



Updraft



The heat exchangers must do at least two things to work efficiently. While maintaining about the same cross sectional area as the original chimney, the heat contacts a much greater metal surface area. As well, the hot flue gases travel in reduced channels that force the heat to rub against the metal instead of shooting up the middle of a cylindrical chimney pipe. Heat warms the metal which then warms room air.

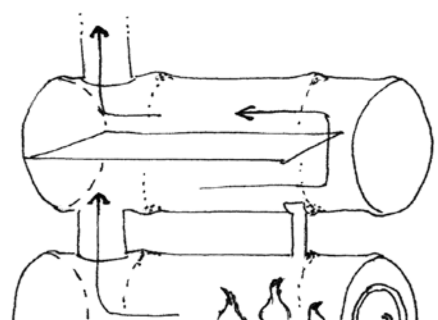


Good air to air heat exchangers have the following characteristics:

1.) Large surface area
2.) Great difference between temperatures. A really hot surface looses a greater percentage of heat to a room than a cooler surface. The surface of the heat exchanger should be as hot as possible.
3.) Force as much hot air through the system as possible
4.) The walls of the heat exchanger should have high conductivity (metal not ceramic, for example).

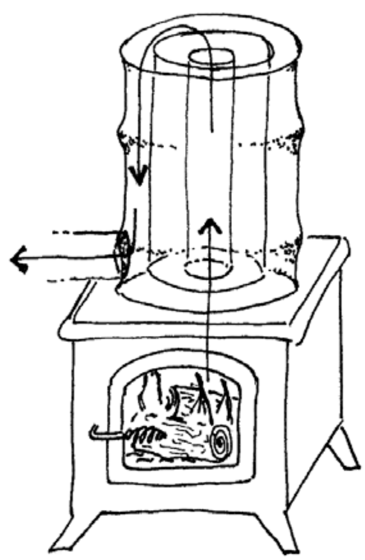
The following are three examples of air-to-air heat exchangers that can be quickly built and added to existing heating stoves. They are all made cheaply out of 33 and 55-gallon drums. Each has been used and tested at Aprovecho.

Two barrel stove



The barrel stove is great is many ways. It is easy to make and is fairly fuel efficient. Firebrick protects the thin walls of the combustion chamber, which then can last for ten years! The upper chamber captures the heat and helps to reduce exit temperatures from the chimney pipe, keeping more heat in the room.

33-gallon drum within a 55-gallon drum



The drawing illustrates a Winiarski heat exchanger in which a 33-gallon drum filled with insulation surrounds the chimney pipe. The hot air then passes down a gap between the 33 and 55-gallon drums before exiting. The insulated chimney creates a powerful draft that can force the heat down the anulus (the circular gap between the 33 and 55 gallon drums).

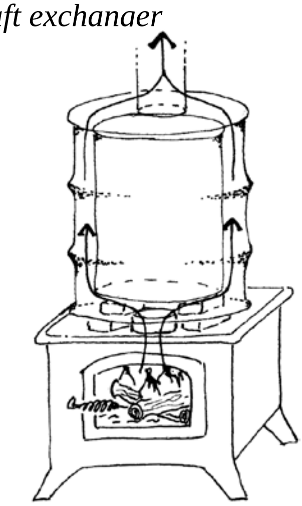
DESIGN HINT: Insulating the interior chimney in the heat exchanger helps downdraft designs to function by increasing draft.

The downdraft version has the advantage of heating the top cover of the barrel directly. This very hot surface, out of reach of children, efficiently radiates heat into the room. In this respect it's better than the updraft design.

The Updraft Version

The simpler version in which heat always flows upwards is simpler to make. It's great as a first project. The draft is not potentially compromised by the downdraft requirement. The same cross sectional area is maintained throughout the whole heat exchanger. Unfortunately, the hottest surface is inside the barrel. But, this simple design works well and is very easy to construct.

Updraft exchanaer



You can't beat a thin walled, low mass metal combustion chamber for effective radiant heating. The waves of radiant heat from a really hot metal surface can sure warm up a cold body quickly. The outer surfaces on a high mass stoves, on the other hand, may not get hot enough to send much radiant heat at a shivering body. The warming effect of a high mass stove/heat exchanger is more subtle.

Adding insulating bricks to a metal walled combustion chamber in an effort to raise temperatures (and protect steel from degrading) has this one drawback. The insulating bricks lower the temperature of the metal walls and reduce radiant heating. Matthew, the thin, hard working forester at Aprovecho Research Center takes insulating bricks out of his stove right quickly!

The amount of heat emitted per square foot is dependent on the temperature of the radiating body. Because surface temperatures are lower massive heat exchangers need a lot of surface area to radiate heat into a room.

TEMPERATURE OF SURFACE (F)	TOTAL ENERGY TRANSFERRED BTU PER HOUR PER SQUARE FOOT
80	15
100	51
150	168
200	315
400	1230
600	2850
800	5430
1200	9370
1201	

Chart from The Woodburner's Encyclopedia, 1976

Even a relatively small heat exchanger that's truly hot can quickly deliver a lot of soothing radiant heat to a room. An insulated home usually needs something like 20,000 Btu's per hour to replace lost heat. If the surface of the heat exchanger is 100 degrees F it is necessary to provide 400 square feet of surface area to keep up with the house's heat loss. A hotter surface temperature of 400 degrees F. allows the heat exchanger surface area to shrink down to 16 square feet!

Before adding a heat exchanger to the chimney check the exit temperatures.

First insert a thermometer in the chimney pipe near the ceiling where it exits the house. We want exit temperatures to be around 250F. The flue gases need to be at this temperature so that there is sufficient draft. Adding a heat exchanger may reduce exit temperatures by about 400 degrees F. If the heat exchanger diverts so much heat into the room that your exit temperatures drop below 250 F, you may have to make a smaller or less efficient heat exchanger.

Creosote in the Heat Exchanger

Creosote is caused by the condensation of potential pollutants that were not initially burned up in the fire, creating heat. If there is efficient combustion there is little or no creosote. Cool burning heating stoves do not create efficient combustion. The tars and other substances that fly up in the smoke condense on colder surfaces, build up and can eventually catch fire inside the chimney.

The solution to creosote build up is to build hotter cleaner fires. The particles that make up creosote burn at relatively low temperatures. The good neighbor burns wood hot and clean.

The three heat exchangers shown previously have been used for many seasons at Aprovecho. In each design smoke contacts very hot surfaces directly after leaving the combustion chamber. Most of the unburned gases and tar droplets may be ignited at that point.

Any heat exchanger and chimney should be opened regularly and if dirty, should be cleaned. The removable lids on the fifty-five gallon drums used to make the air-to-air heat exchangers make great inspection ports! Make sure to open your heat exchanger regularly after installation, at least several times during the first season of operation.

Heating Stoves.

The following heating stoves have been built and used at the research center. We learned from them and loved some more than others:

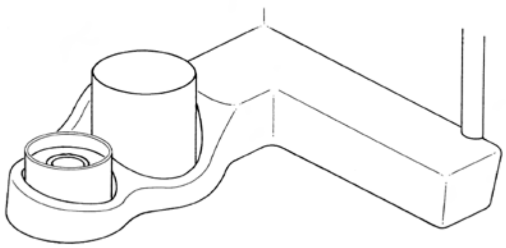
1.) A Downfeed stove in which heat warms an earthen bench

2.) A batch fed insulated stove with tower downdraft heat exchanger

3.) A tower stove including preheated air for secondary combustion

Your stove will probably be a little different from these ideas. You'll find slightly different parts available and come up with personal variations. The second stove will be better than the first and if you're like us, the third one might be good enough to give away to a friend…

Larry's Downfeed Heating Stove With High Mass Bench



This stove taught us a lot about heat transfer into mass. Studying the effectiveness of a buried chimney pipe in a bench made of sand, clay, mud and straw called cob began one of those wonderful intellectual adventures that can make life so interesting!

In 1990, the occupants of the Cob House at Aprovecho asked Larry to design and build a heating stove based on his down feed combustion chamber and downdraft heat exchanger. Larry added a novel extra to this stove: after the heat exited the heat exchanger it traveled 8' horizontally through a bench made of earth. His hope was to warm the bench and to create an experiment testing the effectiveness of this type of bench heat exchanger. The question was: how much of the heat would stay in the bench?

The combustion chamber is made from a 16 gallon drum. A clay cylinder (Mexican rain gutter) six inches in diameter, creates the burn chamber and three foot high chimney within the heat exchanger.

Wood ash is used as insulation and fills the space between the Mexican tile cylinder and the inside of the 16 gallon drum. Sticks of wood are fed vertically into the fire. They are supported by a brick that also reduces excess air for combustion. *The downdraft/down feed pattern creates the most preheating and also seems to be the cleanest burning.*

Air is sucked down toward the fire and is appreciably warmed which assists clean combustion.

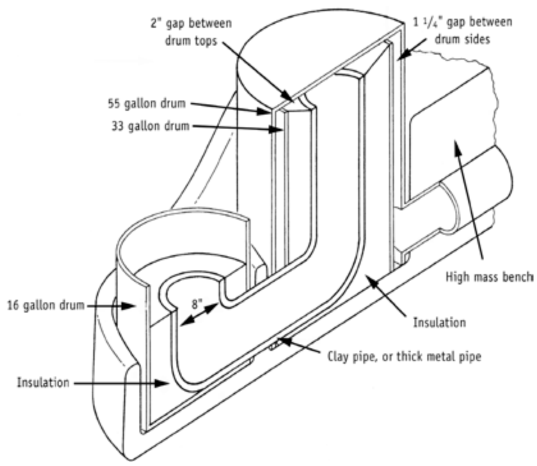
In the self feeding downdraft pattern only the tips of the wood burn. Smoke is pulled horizontally over a hot bed of glowing coals. This all helps to reduce emissions. Unfortunately, a downdraft/down feed combustion chamber can be hard to light. Pulling the air down requires a lot of draft. You can't have small leaks in the stove. The side feed pattern is usually experienced as more natural and friendly, but it is not self feeding.

The heat exchanger is made from two barrels: the outer barrel is bigger (55 gallons) and closes over a smaller 33 gallon barrel. Again, wood ash is used as the insulation that fills the space between the clay cylinder and the thirty three gallon drum. Perlite, vermiculite or light weight pumice can be used in place of ash.

The heat travels up in the middle of a thirty-three gallon drum inside the clay pipe. The insulation surrounding the heat increases the draft, since the flue gases stay very hot. The increased draft is sufficient to then force the hot air <u>down</u> the gap between the thirty-three and fifty five gallon drums. (This gap is called an annulus.)

The hot flue gases exit at the bottom of the fifty-five gallon drum and, in this case, travels 8'horizontally in a 6" in diameter stove pipe before turning upwards and eventually exiting the room.

To light a downdraft stove is fairly simple but it can be finicky. Practice helps. I like this method: put a piece of paper into the combustion chamber. Make a vertical grate out of say ten skinny sticks making sure that there is a space between each stick. Put a lightly crumbled piece of paper behind the sticks. Light the piece of paper in the combustion chamber starting the draft into the heat exchanger. Once the draft is established, light the paper behind the sticks and watch the fire as it is sucked through the grate, lighting the sticks. More paper can be lit behind the sticks until the fire is established.



Here are a few important construction tips:

1.
Always make sure that the 8” to 10” in diameter down feed magazine is not too tall. Six inches is a nice height, just enough to support the sticks. If the downdraft fuel magazine is too high it becomes a chimney and can back draft. Also, having a tall fuel magazine makes the wood hard to light.

2.
Make sure that the gap between the 55 and 33 gallon drums is equal. It’s good practice to bolt the two drums together to ensure that they stay in the correct position.

3.
We bedded the heat exchanger, the 55 gallon drum, in sand which worked very well, sealing the bottom of the drum so no smoke escapes.

Learning from the bench heat exchanger

In 1995, we measured the efficiency of this stove. To my surprise, there was only a 100 degree F. drop in temperature due to the 8’ horizontal run through the cob bench. Not much heat was captured by the bench. In fact, after a two hour burn in the stove, which heated air temperatures into the 90’s in the cabin, the middle of the bench wasn’t noticeably warmer to the touch.

Exit temperatures in the chimney pipe leaving the room were still very high, around 500 degrees F. We had overestimated the ability of the cylindrical stove pipe going through the bench to transfer heat to the earthen bench.

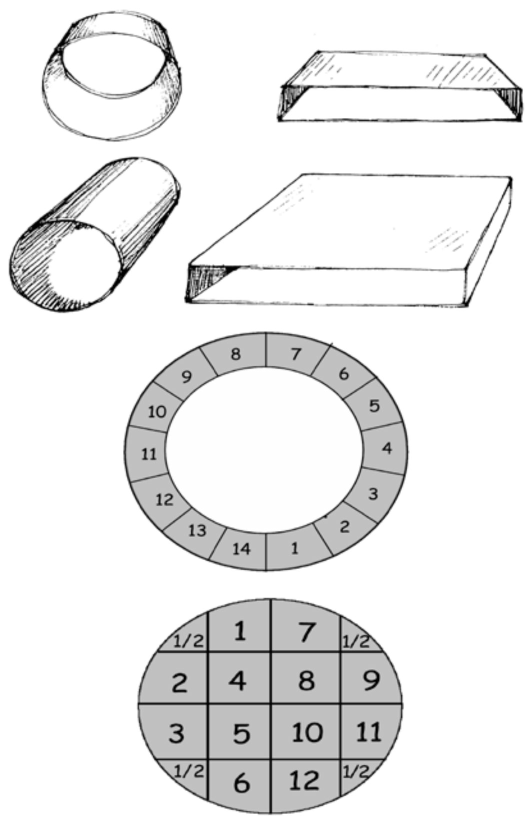
Getting Heat Into Things Is Hard

After years of thinking about and experimenting with air to mass problems Larry and I have **realized after many**

experiments that getting heat into things is hard, not easy.

It is pretty darn hard to get a large percentage of heat into substances like rock, water, cement, or air. To optimize heat absorption, flame and hot flue gases must be forced to intimately contact the surface of the mass, *to rub against it*. (Also for optimal heat transfer there should be a big difference in temperatures, good conductivity, etc.) Heat in a flue pipe mostly shoots up the middle of the pipe, not much heat is transferred through the wall of the cylindrical pipe.

Use a Different Shape



To optimize heat transfer it's better to make a chimney with a different shape, not cylindrical, but with the same cross sectional area. The shape should be wide, shallow, and rectangular. Even though the same amount of hot gases pass through the inside a great deal more surface area on the outside is in contact with the substance you want to heat.

It takes about one square meter of optimized surface area, in a heat exchanger, to lower exit temperatures from the stove about 100 degrees C.

Temperatures in the combustion chamber are above 1,100C degrees when yellow flame is present. We want exit temperatures to be around 150C. So, in an optimized design approximately ten square meters of optimized surface area is needed to transmit this much heat into the room.

To summarize: even in an optimized design a heat exchanger requires a lot of surface area. Just piling mass near a stove will result in poor heat transfer to the mass. Only a small percentage of the heat will end up in the mass. Heat needs to be forced to scrape against surfaces over long distances for efficient heat transfer to occur.

Stone or cement store approximately .2 Btu's per degree of temperature rise. An insulated house might require something like 20,000 Btu's per hour to stay warm on a cold day. 1,000 pounds of cement or stone warmed up to say 200 degrees F. only stores 40,000 Btu's which is enough to warm the house for two hours. Five tons of cement or stone, warmed up to 200 degrees F., can release enough stored heat to replace lost Btu's for about ten hours.

All of the design criteria that we've covered in this discussion are met in a good masonry stove: proper heat transfer, sufficient weight of material for ½ day storage, and sufficient area to radiate heat into the room. The high mass stove also encourages hot, fast, clean burns that do not over heat the room, all of which makes this type of stove very impressive. But, it is hard to drag any one part of the system away from the other design features. All work well together. A great book on the subject is: The Book of Masonry Stove By David Lyle Published by, Brick House Publishing Co. Andover, Massacheusetts

It's easy to overlook how hard it is to get heat into mass. It's also easy to hope that a small amount of mass will hold an appreciable amount of heat. Our advice would be to take the whole masonry stove as a system that works because all parts are tuned to function together. If you design anything along these lines it might be best to make sure that all parts are correctly proportioned and interconnected.

Hot Cob

Let's think about the bench that Larry wanted to use for heat transfer and storage. How can we design an earthen enclosure that would significantly lower exit temperatures? Why don't you take a few minutes and play around with the idea of wide rectangular chimneys in earthen enclosures. Make a few sketches and practice designing things, if you want…

Remember that hot air wants to travel up. Sideways travel in an optimized high drag passageway is limited to about 8 feet at the maximum, probably less, even if you have a really tall chimney outside. Downdraft severely reduces flow because of added friction.

For this reason, I like to limit my first musings and sketches to designs in which the flow is always upwards…these heat exchangers tend to function beautifully. Going sideways or down usually requires testing. On the next page you'll find one example of an earthen addition to a stove that has worked well. Your invention will be better, I'm sure.

Jayme picture of earthen heat exchanger

Testing Challenges Presumptions

Testing your inventions is how they improve. It's unlikely that a first attempt will be the best solution. Getting a baseline measure of performance is very important. If you know how something performs then changes to the prototype can be evaluated.

Finding the efficiency of a prototype heating stove is not difficult. Marcus Bull in the1820's built a special room in which he could burn a measured amount of wood in a particular stove and see the effect on the room. In a way, any house owner is in the same position. A good stove will heat the room using less fuel.

Another useful measure is to determine exit temperatures out of the chimney. A good heating stove should be pumping heat into the room not outside the house up the chimney. Inserting a thermometer in the chimney pipe near the ceiling gives us a lot of good information.

An easy way to get a feel for heat loss in your house is to use an electric heater or other heat source, which delivers heat at a known rate. See how much heat is needed to keep temperatures stable during a time of day when outside temperatures are not fluctuating. Start the experiment after the house is thoroughly warm.

Since there are about 8,600 Btu's in a pound of dry wood we can figure that at 100% efficiency the house loosing 20,000 Btu's per hour requires only about 3 pounds of wood per hour to maintain a comfortable interior temperature. At 50% efficiency it should take something like 6 pounds of wood per hour.

Using natural draft instead of a fan as the motor that pulls air through the stove makes it necessary to constantly allow a lot of heat to escape the room and fly up the chimney.

Figuring on 50% heat transfer efficiency is another rule of thumb that, being close enough to reality, allows estimates to roughly predict performance. Stove companies love to use much higher numbers but they are usually referring to combustion efficiency. In optimized designs we have probably done a bit better than 50% heat transfer to the room and we certainly are always aiming to do our best!

Inventor's Pride

Inventor's pride has steered the wagon on more than one occasion here at the research center. Inventors pride is amazingly powerful and difficult to guard against. That's why we like to have other people test our inventions. An inventor may be unable to keep from influencing the testing process!

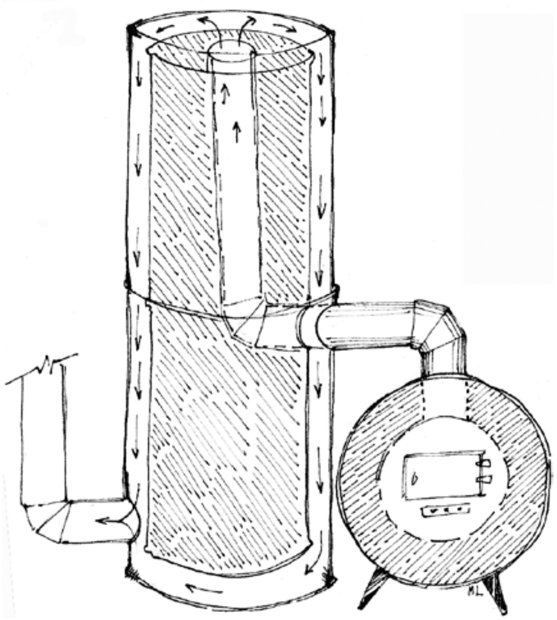
The Library Stove

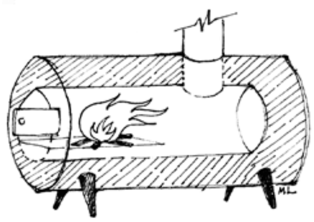
Our old library was an awful place. The building was uninsulated and terribly cold. It was the worst place imaginable for studying. In 1992, we got tired of suffering and built a stove that captured enough heat to keep readers comfortable. This stove was a great representation of a design slogan that we have come to respect, which is*:*

Separate Functions for Efficiency

Students are always ready to try to make a design perform many functions at once. But, in our experience, it is usually better to do one thing well. Trying to make the combustion chamber serve as the heat exchanger, for example, as in most modern stoves, makes for a nice small box but the trade off is reduced efficiency. The highly efficient heating stove that artfully combines functions is the high mass ceramic stove. It incorporates the heat exchanger and combustion chamber in one box. But that box weighs five tons or more.

The Library stove obviously separates combustion and heat transfer, attempting to optimize them both.





We even put the two functions in separate containers! The inner drum in the combustion chamber was made from a 16” in diameter, thick iron pipe. We cut a hole in its top for inserting the 6” chimney pipe and we enclosed the ends with welded steel plate, leaving an opening for a door and air holes.

A grate made from a barbecue grill was used to help separate the wood. Without a grate the logs would roll together at the bottom of the cylinder, which impeded air flow. Air entered beneath the grate into the combustion chamber through six 1” holes cut in the door.

Thick insulation surrounds the combustion chamber. We also put a piece of tin foil around the outside of the insulation to slow down the passage of infrared heat. Shiny tin foil emits radiant heat slowly. Old style cooking stoves were chromed on the outside so warm metal walls would emit less radiant heat keeping the cook cooler. The combustion chamber in the Library Stove was so well insulated (with wood ash) that it took about ½ hour after starting the fire for the outside to become warm.

One result of this super insulation was that even large split logs would continue burning, leaving behind a line of fine gray ash. The insulation kept the fire hot and reduced smoke. But, of course, the optimized super insulated combustion chamber didn’t help to warm the library very much at all…

Instead, it was the big tower heat exchanger that heated the room. A six inch chimney pipe rose up inside a cylinder made from three 33 gallon drums stacked vertically. The bottoms and tops were removed so the drums fit together. Insulation (vermiculite) filled the space between the stove pipe and the inside of the vertical cylinder formed from the three 33 gallon drums.

The insulated 6” chimney produced enough draft to successfully push the hot air all the way up and then down the outside of the stack. Two 55 gallon drums created the outside of the heat exchanger. The space between the 33 and 55 gallon drums was about equal in cross section area to the 6” chimney pipe.

Remember that if the spaces within the stove expand air flow slows. If cross sectional area narrows, the air flow (draft) slows again. Think of a river rushing into a pond. The water slows as the river banks widen. If a river enters a narrow canyon, the same thing happens. The speed of the water increases as the river narrows, but the total volume passing through the narrows decreases. The water rises behind the narrows.

But while cross sectional area is relatively equal in the heat exchanger the surface area of the original 6" flue is now greatly increased. Hot metal is in contact with a lot more room air. The air in the room is heated much more effectively which lowers temperatures inside the chimney and decreases fuel use.

This stove was on the right track. The Library was warm. The only problem was that people hated the stove!

The very tall downdraft heat exchanger reduced the initial draft so that unless a small intense fire was first created underneath the chimney leading to the heat exchanger, smoke could easily back draft into the room. The stove was difficult to start! Paula Gonzales, a 66 year old nun, who was an Aprovecho intern at the time, made sure that we realized that stoves should be easier to light!

Appropriate Technology devices are usually attempting to be efficient. Normal stoves or other tools offered for sale in non-conserving societies like the United States are primarily designed for simplicity of use. That's one reason why designing appropriate technology tools is so much fun: it isn't too easy to make something simple to use and conserving of resources. It takes a bit of experimentation to learn how to create something great that can last a good long time, please users and conserve resources and guard health.

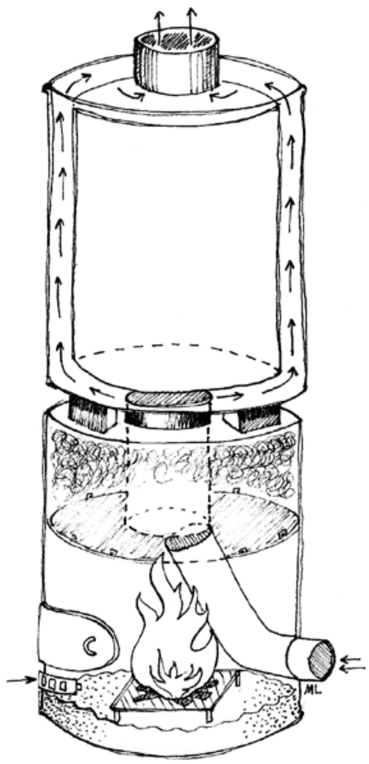
Even though it's a bit less efficient, we have come to appreciate heat exchangers with only vertical rise. Vertical rise does not depend on first establishing a lot of draft in the stove to work well. And, when the stove lights easily we think of our good friend Paula Gonzalez.

The Picasso Stove

In 1996 the students and I started a series of experiments designed to see if it's possible to preheat primary air coming into a stove. The idea of preheated air feeding a fire is tantalizing: if the air in the combustion chamber is above 1,200 degrees F. there should be much more complete combustion.

But, so far all of our great ideas have proven to be unworkable. Hot air wants to rise, not fall. Friction in a pipe easily defeats the slight draft created by a fire. Significant preheating of air for primary combustion is difficult to achieve. However, heating air to assist secondary combustion (combustion that takes place after the initial burn) is a lot easier.

The Picasso stove, named after a famous photo of Picasso sitting in front of a gorgeous French heat exchanger in 1939, features preheated secondary air.



Secondary combustion occurs where escaping smoke ignites. As you see, the tricks used in the Picasso stove are the same as those in the Library Stove but we varied things a little. And in fact, this is a very good stove.

The stove is made from a 55 gallon drum set up on concrete blocks. A thick bed of ash insulates the combustion chamber from the floor. Fire brick were placed around the combustion chamber inside the drum. A grate lifts the wood above the floor so air can circulate through the combusting pile of wood. Primary air is sucked through three one inch openings below the door.

Flames lick up into the entrance of the secondary combustion chamber, made from a six inch stove pipe and a false floor made from a lid to a 55 gallon drum that holds insulation, (vermiculite) around the stove pipe. Hot air flows into the mouth of this secondary combustion chamber through a 4" stove pipe that is exposed directly to flame. *We are trying to make sure that air, fuel, spark and sufficiently high temperatures are present in one place to burn up escaping smoke*. (I wish that there was more turbulence to create better mixing!)

The heat exchanger is again made from a sealed 33 gallon drum suspended in a 55 gallon drum by bolts which hold the two barrels in place. The path of heated air is only upwards through the gap between the two barrels. Good draft and ease of starting are assured.

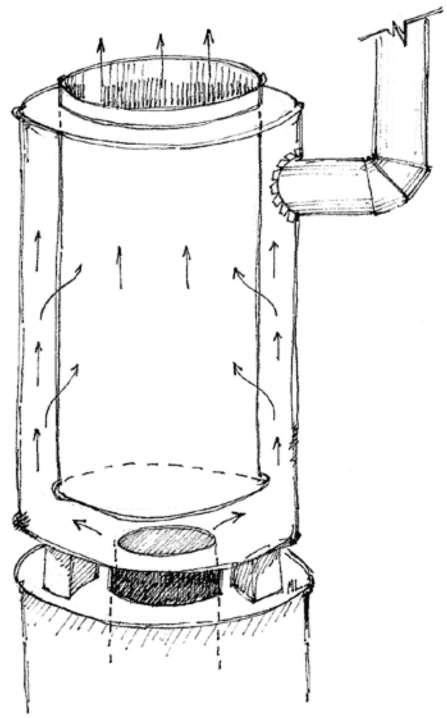
I like this simple stove and recommend it. It's simple to build, requires no welding and does seem to reduce the smoke associated with using overly large chunks of wood. There is a significant amount of secondary combustion. Air temperatures in the 4" tube can be over 1,000 degrees F.

A Quiz

The students and I were having fun building the Picasso stove when Larry happened to enter the shop. He lives on a quiet wooded farm about 50 miles north of Aprovecho. We were going to build and test his new Red Cross cooking stove the following day. Larry checked out the heat exchanger and then posed a question to the gathered staff and students. It was: Using exactly the same materials how could we nearly double the surface area of this heat exchanger?

I hadn't seen his Red Cross stove plans yet and I must admit that I was stumped. But, a couple of students figured it out.

Here's a chance for you to think about a design, trying to improve it. Can you see what was obvious to Larry?



By removing the top of the 33 gallon drum and exposing the interior of the drum Dr. Winiarski exposed a lot more hot metal surface area to the room air. This design is used in institutional stoves now being built by the World Food Program in Africa in which almost all of the interior drum, used as a pot full of food, is directly exposed to the fire.

Answer

This solution seems so simple and elegant to me…

The Improved Two Drum Stove

In the United States kits are available to change two 55 gallon drums into a popular and inexpensive heating stove.

The students at Aprovecho revised this stove and created quite a powerful and efficient heater for the 900 square foot shop building. Insulative firebrick was placed inside the bottom barrel which protects the steel from degrading and makes for hotter cleaner burning fires.

The upper barrel had large diameter pipes installed lengthwise through the entire barrel so that air could be blown through the pipes into the room.(See illustration). These pipes were sealed using stove cement which has lasted for three years so far. A box fan blows cold room air into the tubes that leaves at about 140 degrees F. In about 30 minutes the large volume of hot air has circulated through the shop and raised the temperature by 20 degrees. Without a fan the room stays cold for hours.

A Down Draft Pole Burning Stove

This is a radical 8' high stove design in which 2" poles or branches enter vertically into the combustion chamber. The downfeed pattern is very clean burning because like the pellet stove the wood is metered by gravity into the combustion zone. Only the tips of the poles are burning, as the wood is consumed the charcoal breaks off and fresh wood catches fire.

The fire is encouraged not to burn up the stick because a very strong draft pulls the flame horizontally into a 3' high insulated chimney. The insulated chimney, made from insulated fire brick inside a sheet metal cylinder, shoots the hot flue gases into a larger opening about 12" high. Entering this large opening slows down the flue gases.

It is necessary to slow the draft because if the gases were not slowed down the very fast draft developed by the 8' high chimney would pull the flame off the burning sticks of wood. This opening in the middle of the cylinder serves to create the right amount of air movement.

The hot flue gases are pulled up into a small gap between a 12" and 14" cylinder. The 12" cylinder is closed at both ends and filled with insulation. The gases scrape against the outer cylinder transferring heat to that surface. Room air is blown down the outside of the hot wall and enters the room at shoulder height. The fan forces lots of air down the gap between the largest cylinder covering the top half of the stove and the hot wall it surrounds.

The stove is very tall because the bottom half is the combustion chamber. The top half is the heat exchanger. Because the tips of the wood are burning there is almost no smoke produced. The downfeed burning pattern has many of the same advantages as the fancier more expensive pellet stove that burns prepared uniform fuel.

Fans Increase Both Combustion and Heat Transfer Efficiency

The push created by hot rising air is very gentle, even flame itself doesn't travel at much more than three miles per hour. Natural convection produces a lazy draft that cannot be asked to do too much. A cooking stove made in Honduras produced 23 Pascals of draft but a windstorm can produce over 100 Pascals of draft on the leeward side of a house.

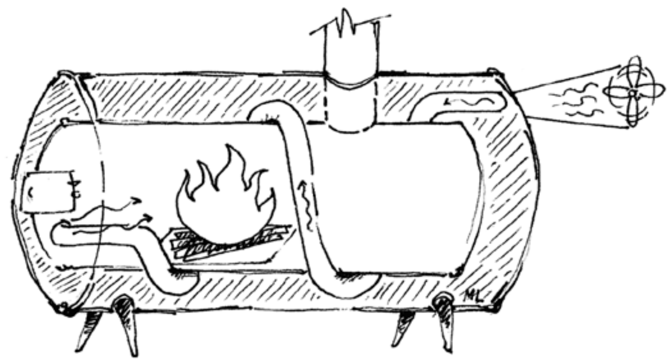
Can you picture in your mind's eye how fast cigarette smoke rises? Smoke rising is slow and languid, not fast and powerful. The draft produced by a hot fire can easily be defeated by friction inside of a chimney pipe if there are many twists or downturns.

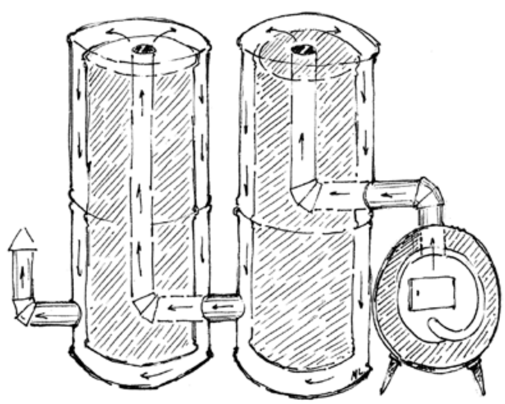
Many amateur designers hope that natural draft will overcome impressive obstacles such as long runs with little rise. Unfortunately, it just isn't so! The gentle river of hot flue gases is easily slowed by turns and twists and can also widen into a stagnant lake if spaces inside the stove suddenly increase.

Two Heating Designs Using Fans

Fans are great because **primary** air can be easily preheated, which greatly improves combustion. Forced air helps charcoal to burn down completely, leaving only a bit of ash. The rush of high velocity jets of hot air do a great job mixing fuel, air, and fire cleaning up combustion. A fan can also push air through such a long length of heat exchangers that close to 100% of the heat stays in the room! Fans make everything easy! And you can double fuel efficiency!

Here are a couple of ideas that we have built and successfully tried:





The fan is pushing air through a one inch in diameter pipe that is in contact with the very hot outer surface of the combustion chamber. Insulation around the combustion chamber and pipe keep both very hot! The air enters the combustion chamber at temperatures around 800 degrees F, depending on the heat of the fire. It is amazing to see the effect of a fan on fire, especially with preheated air.

The logs burn very brightly. The fire is very easy to light and combustion is much more complete. The combustion chamber is usually glowing red hot. (Only combustion chambers made from refractory cement or firebrick can withstand this kind of heat.) This is the cleanest burning stove that we've used at Aprovecho.

Due to the draft created by the fan, the heat is driven through lengths of heat exchangers that would obviously stall a stove dependent on natural draft. It's possible to add heat exchangers until exit temperatures are equal to room temperature air.

If you add a fan to a stove and don't rely on the movement of air caused by rising hot air (natural convection), almost 100% of the wood's heat can end up staying in the room. A pellet stove, using a fan, is so efficient that you can hold your hand over the chimney outlet and feel that most of the heat has already been used! The heat is very effectively transferred to the living space and the air leaving the chimney pipe can be at room temperature.

Adding a fan to a stove makes it easy to achieve clean combustion and very good heat transfer to the room. Air is pushed through pipes in contact with the fire until the swirling air entering the combustion chamber is very hot. The fan then pushes the hot flue gases through a big enough heat exchanger so that most all of the heat stays in the room.

Why aren't fans used more often in wood burning stoves? One reason is that if air is preheated and blown into the combustion chamber temperatures can easily rise up to the point where steel begins to melt**.** Blowing preheated air into a big fire can create a blast furnace. Also, being dependent on a fan means that stoves may not work correctly when they are most needed, like during a winter storm when the electricity fails. Some people dislike the whirring of fans, preferring the silence of natural draft. For best fuel savings and least release of harmful emissions a fan is required. The amount of electricity used by the fan is very small when compared to the benefit received.

A Blast Furnace Heating Stove

If preheated air is used, the combustion chamber needs to be made from stone or high temperature ceramic, refractory bricks, or refractory cement. Refractory cement is absolutely great stuff. It looks a lot like regular cement and it's mixed up with water in the normal way. The wet mixture can be poured into a mold made from any stiff material, like cardboard, eighth inch thick plywood, door skins, etc. Wall thickness can be as little as one inch but in a heating stove two-inch thick walls are recommended for added safety.

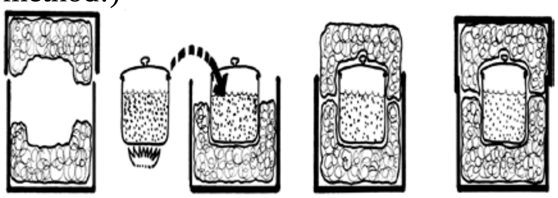
Refractory cement is available from North American Refractories Company. Their address is:
8361 Broadwell Rd.
Cincinnati, OH 45244 USA

In Central America a fired red clay ceramic ceiling tile called a baldosa forms the combustion chamber in Aprovecho designed cooking stoves. Fired clay brick can also withstand high temperatures. Test your local supply by heating it until red hot and then plunge it into cold water. If it doesn't crack it will probably last for years in your stove.

(See chapter on home made refractory bricks.)

The House as "The Best" Heat exchanger

We cook food at Aprovecho in an unusual way using a "Haybox". The pot of food is boiled for ten minutes on a stove and then the pot is placed in a well-insulated, air tight box. The beans inside the pot get soft and palatable because the retained heat is sufficient to finish cooking them. We end up using a great deal less fuel because the hay box has improved the heat transfer into the pot. (It's also a much easier cooking method!)



Hot House

If your house were perfectly insulated with you and your family inside it, would you have to heat or cool the interior?

Think about it for a minute.

Imagine yourself inside a Thermos bottle in which heat is very effectively captured…

What's your body temperature?

The reason that we normally simmer beans for two hours is because the pot constantly looses heat to room air. The reduced flame underneath the pot replaces lost heat. A furnace or a wood stove in the same way is replacing the heat in our houses because the house allows the same amount of heat to constantly leak away! The house looses heat and the burning wood constantly replaces it.

If the house looses a lot of heat we use a lot of wood per season. If the house looses a little heat, we can save forests of trees and are better stewards of this precious resource. If the house looses very little heat the stove is frequently not even lit because energy in sunlight and interior sources of heat now are equal to the heating demand.

To reduce energy use in a house:

Reduce uncontrolled air exchanges by filling cracks in the walls, around windows and doors and insulate the house. A house that works like a thermos bottle or a box full of hay does not require constantly burning wood in a stove to maintain interior temperatures.

The "Haybox house" helps to reduce fuel consumption just like the heat exchangers that can be added to a heating stove. Capturing the heat more effectively diminishes the need for constant burning.

We are half way finished replacing the old, leaky houses at Aprovecho with new, tight housing that doesn't require constant burning of wood to heat occupants. It's great to enter the straw bale dormatory on a chilly day and realize while taking off shoes and jacket that the wood stove isn't even lit. The heat from the cooking stove has warmed the entire 2,000 square feet. Today the best houses require no additional heating besides what is done daily when cooking, heating water, lighting, indoor work, etc.

The most fuel efficient heating stove is one that is never used!

People live in houses that exist. It costs money and takes time to insulate and reduce air exchanges in older houses. At the same time, however, it doesn't make sense to build and make the worlds most efficient heating stove and then use it in a building that could also be made less dependent on constant burning to just stay warm. Which part of your heating system is the least efficient? Is it the house or the stove?

Hopefully these stove design ideas will help to create better performing, simple, home made stoves. Just as Dr. Winiarski's cooking stoves vary tremendously from place to place, these heating stove examples follow a set of principles that allow for a flexibility and adaptation to local or individual circumstances. Learning how to design a stove is the intention, not to teach specific designs. Your perfect stove may be an amalgam of several of these ideas. It may be completely unique.

To be perfect the stove only needs to fit your needs. It may be true that like personal requirements a great stove matures and evolves over time. Maybe good technology will become a satisfying hobby, an expression of your genius.

Farm Sized Dehydrator

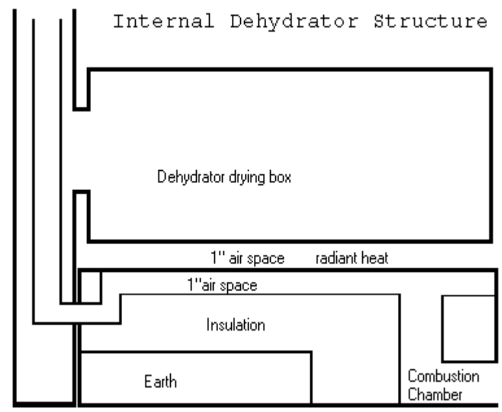
Because climates and conditions exists where food dehydration is not possible by solar energy alone, a wood –fired dehydrator is often helpful for preservation . The

foods it is sometimes most efficient to go up to 150 to 160 F. in the initial stages of drying when lots of moisture will be evaporating out of the food. A successful food dehydrator will be able to sustain these temperatures at a constant rate with even distribution for a variable period of time dependent on the type of food being dried.

For a piece of food to be dried, the water inside must be turned into water vapor and then moved out of the dryer. Hot air is able to hold more water than air at a lower temperature. An equally necessary component to effective food drying is air flow. Air that is completely saturated with water vapor will stop taking water from the food, and the dehydration process will be slowed. To efficiently heat air and create good air flow and circulation food dryers: a) have a heat source, b) are relatively air tight, c) create dry air, d) have a large chimney or fan that moves dry air past the food. A large chimney, that is at least the length of the body of the dryer, will usually create the draft necessary for good air flow and circulation.

The total drying time, and the amount of wood burnt, will vary according to the water content inside of the food. It is important to slice food evenly, so that each piece of food has an equal amount of moisture and drys at the same time. Opening the dryer many times to check food and remove dried food will decrease the temperature inside of the box, and possibly add water-saturated air into the dryer, all of which will prolong the total drying time.

optimal temperature for food dehydration is between 120 and 130 degrees farenheight. Temperatures that exeed 130 degrees can begin to cook the food. When starting to dry



Some Notes on Food:
As with many types of food preservation, treating the food will help to stop enzyme activity, slow the decomposition of the food, as well as maintain nutritive values. In the case of food drying, blanching is the best method. To blanch a food means to steam or boil the food for a short period of time, usually 2 to 3 minutes, before the drying process. The time that each food needs to be blanched varies from food to food.

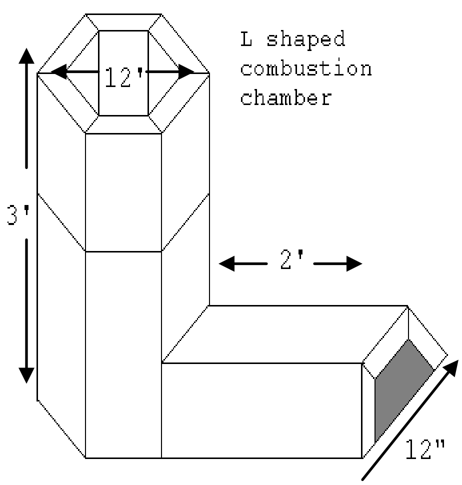
Food can be dried on trays with openings for air to pass through. Screens are often used to make the bottom of the food drying trays. The material for the racks or screens will vary from location to location. In the test dryer at Aprovecho we used 13 trays each four feet wide by two and a half inches long, stapling fiberglass screening to a wooden rectangle.

Dr. Larry Winiarsk helped to design and build a prototype wood fired dryer for cacao beans with farmers in the wet mountainous region of Nicaragua. The dryer is based on the Rocket style plancha (griddle) stove design. In the Winiarski dryer, a small fire is lit inside of an insulated Rocket elbow combustion chamber. ***The dryer uses about 10 pounds of wood per hour and as a rule of thumb consumes close to one pound of***

fuel to make a pound of dried apples or tomatoes. The shape of and insulation around the combustion chamber will keep the fire burning at a higher temperature, will decrease fuel use, and will assist cleaner burning.

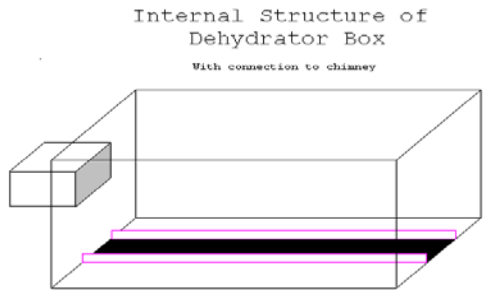
The combustion chamber is best built out of fire resistant tiles, fire bricks, or bricks that are as refractory and insulative as possible. (Please contact Aprovecho for easy to make recipes for home made fire brick.) Insulation completely surrounds the combustion chamber.

Insulation is air, pockets of air surrounded by a very light material. Earth, sand, adobe will not work here. Instead use wood ash, pumice rock, vermiculite or perlite.



The hot flue gasses rise out of the top of the"L" shaped combustion chamber and flow under a large steel plate four feet by ten feet. The hot gases travel through a one inch air gap underneath the steel plate for the entire length of the dryer. At the end of the dryer, the hot gasses, which have expended most of their heat, go down a small opening and into a chinmey. The draft created by the chimney helps to pull the hot gasses through this one inch air-gap but the rocket combustion chamber creates enough draft initially to push the first gases into the chimney. No priming in the chimney is necessary.

As the hot flue gases are traveling in the small one inch thick gap under the steel plate the heat is forced to rub against the underside of the metal efficiently warming it. The steel plate in turn heats up ambiant air above itself which is then pulled into a box full of shelves of sliced food. The dryer box is located one inch above the steel plate and supported by short spacers resting on top of the steel. The metal box holds the trays of beans. Cool air is sucked in through the one inch gap and warmed by the ambiant heat radiating from the plancha. The warmed air passes into the sealed box through a four inch wide opening in the boxes' metal floor which runs down the entire 10 foot length of the box. As the air inside of the dryer box begins to rise in temperature it increases the rate of evaporation in the food slices. The warm, humid air then travels through the drying box and exits towards the back of the box through a channel leading into a large chimney that surrounds the inner chimney connected to the combustion chamber. The larger external chimney, 20 feet tall, is warmed by the heat passing through the inner chimney, which helps to create better draft. This increased draft helps to shorten drying periods. The height of the external chimney provides enough draft to keep the air that is becoming saturaturated moving through and out of the dryer. The smaller chimney (12 inches in diameter, ten feet high) that is attached to the fire is inside this larger chimney that creates draft in the drying box.. The smaller chimney expells the hot flue gases five feet below the top of the larger chimney which increases draft in the larger and surrounding chimney.



Construction notes on sections:
The steel plate should be attached to the box on which it sits so smoke cannot escape and find its way into the air used for drying. We don't want smokey tasting food! A four inch strip of ¼" steel is welded underneath the edges of the plate inset 2" from the sides. This smoke barrier enters a gutter full of loose material like pumice rock, perlite, vermiculite, sand, fine dirt, etc. so that if the steel plate distorts when hot the smoke cannot escape.

The frame is placed within a gutter. This gutter surrounds the dryer on three sides, there is no gutter in the front of the dryer (the front being above the Combustion Chamber) Insulation is placed within the gutter. This is done to keep the hot flue gases within the chamber, not adding a smokey flavor to the food being dried.

The gutter is an example of what was done with the food dryer at Aprovecho. The dryer in Nicaragua was not constructed with a gutter. Larry instead filled the base with insulation and then placed a finer layer of insulation along the perimeter of the plancha. Once the frame was placed on top of this base of insulation it became embedded within the smaller particle insulation, and was able to keep the hot flue gases from escaping.

This is simply a brief explanation of how the food dehydrator works. If you are intested in a more detailed description you may write
Aprovecho Research Center
80574 Hazelton Rd.
Cottage Grove, OR 97424

We can then send you a booklet explaining the specifics of making the dehydrator and a mini dehydrator project that is currently in the working. Our recommendation would be to build the dryer and then spend a week or so playing with the variables until temperatures are as even as needed. If you prefer, we can assist the process here by doing some of the experimentation with you. Please feel free to get in touch!

Composting Toilets

I love our composting toilet. As I've said before, it is a perfect example of the simple system working better than the complex. Today I gave a lecture to a class from Humbolt State University. The class of 20 people stayed for the weekend at Aprovecho. We had to post signs on both the Clivus-Multrum and the Sun Mar that they were "off line" unable to handle the increased input from our flock of visitors. But the "experimental back up toilet", our pit privy that predates codes, was only too happy to handle any sized load and without bother or fuss turn it into fresh smelling, pathogen free compost.

The success of the outhouse toilet reinforces for me how important it is to **test the simplest model first**, before creating more complex designs. A lot of time and trouble could have been circumvented if the open fire had been adequately tested initially and appreciated as pretty darn efficient!

In the same way, the pit privy seems to work very, very well. Unwarranted assumptions are often made that evolved and traditional systems are inefficient. Technologists create their own beautiful inventions without testing the original first. Let's hope that Second Millennium technologists don't have to make the same mistakes!

Human manure becomes compost without fuss or bother in the ground. But, adding a box around the manure separates the manure from a natural source of microorganisms. Even if earth is added into the chamber, it's quite possible that the climate in the box may become unsupportive. In the earth itself, there is a replenishing supply of small bugs, worms, fungus, microorganisms, etc. that will eventually eat the food you have so thoughtfully provided. The microclimate in your box, on the other hand, can easily go wrong.

Digging a hole in the ground doesn't cost anything. The house that provides shelter to the contributors can usually be built using found materials. In most soils, urine soaks through the pile and drains into the soil. No turning is required. In fact, in Mexico, my buddies would plant a fruit tree above a used privy and put the next hole where the second tree would eventually go. We would make jokes about the extra rich quality of grandpa's fertilizer as we enjoyed oranges from a tree he planted above a filled hole. What a sensible composting system! There's little labor and great results.

We've used the composting pit privy for 20 years at Aprovecho. Folks just throw half a handful of dried duff, leaves, straw, or sawdust in after each use and year after year, without fuss or bother, are blessed with fertilizer for the orchard. It is possible that the composting pit privy does not require any added carbon, at all. Maybe the active life in the soil would eat this food as actively without added carbon. We will experiment to determine if that's correct.

But for now we continue to add it because the system works so well. I assume that the manure is being digested by microorganisms that are self selected to prefer this diet. Composting, in which heat is generated, does not seem to occur to a great extent. The pile does not usually heat up a thermometer past air temperatures. Perhaps this type of toilet should more accurately be referred to as a *moldering toilet*. The active life in the soil is eating the human manure, it is really not "composting".

The important factors in setting up a pit privy are 1.) To make sure that ground water is not contaminated, 2.) Build the privy close enough to the house for ease of use, 3.) Be certain that urine cannot pool up in the hole. Most soils are porous enough that urine leeches through the pile into the earth. (The VITA handbook states that if the bottom of the hole is at least 10' above the water table, there is little danger that water will be polluted. The handbook also recommends that outhouses be placed downhill at least 25'from wells.)

At the Research Center we divert the urine into 5-gallon containers and use it as fertilizer, diluted with water, in the garden. It is not poured directly on plants but near them. A funnel is placed under the front part of the toilet seat. Both females and males find that a 4" funnel captures nearly all the urine from seated patrons. A hose attached to the funnel empties into the 5-gallon container.

But even though urine is twice as high in nitrogen as humanure most people find that captured and stored urine is too unappealing for use in the garden. Vomiting is not unheard of when emptying the jug for the first time. But, the smell can become less offensive with practice. After a while, the smells from a outdoor privy aren't really offensive. Some cultures can deal with stored urine and others will not. In Mexico, the idea of storing urine is offensive to most folks.

The latrine house in our version of the composting pit privy covers one of three holes dug in a line. Each hole is six feet deep by five feet wide by eight feet long. The little shed has two sides, one for sitting and one for squatting. A human being deposits about three cubic feet of manure per year. Ten residents and visitors in about a year will fill one of these pits at Aprovecho. The little house is then picked up by ten people and placed over the next hole that will then be used for another year. Following this pattern, the third hole will be filled when the first hole has rested for two years, which is plenty of time for decomposition to occur.

One of the most radicalizing experiences at Aprovecho is to jump into a pit of two-year-old human manure shovel in hand. The first couple of times you keep on expecting to hit something very unpalatable while digging deeper into the pit. But I can tell you that it does not happen. Coarse sawdust seems to survive intact but duff from the forest floor and chopped up straw become a part of the fine and sweet smelling uncompacted earth. Manure and toilet paper completely disappears. The pile shrinks over the years until it is only about half filling the hole when finished.

Two tests of finished material were negative for fecal bacteria. There is, of course, a chance that very hardy pathogens could have survived but tests have not located them. We continue to test each batch as it is used. Since contact only happens once a year, the potential for passing disease seems very small compared to the daily wiping of one's own after end.

If such a moldering system were to be designed for indoor use I would recommend experimenting with the following: It seems that a multitude of life eats up the manure. A box around the system would cut the manure off from a replenishing supply of microorganisms. So, the operator needs to be tuned into the state of their box, manually resupplying the bugs that are doing the eating. And it's hard to be as smart as nature. But, I'm sure that it's possible!

I guess that I would add dirt on a regular basis to the box, maybe from around a new compost pile. Instead of adding something like sawdust, I would add forest duff or leaves that might contain more microorganisms. The box would be filled for the same period of a year and then rest for two. I imagine that the box could be removed and replaced with another. Perhaps resting boxes could fulfill some decorative function in the yard? Perhaps three large boxes could find a place in the basement?

In the case of the indoor moldering toilet, the urine would obviously need to be diverted into a container or lost into the regular sanitation system. People urinate a lot more than they defecate. If not diverted, the urine would form a lake in the box. The Clivus-Multrum has a deep sump, which requires regular pumping to rid itself of urine. The Sun Mar uses heat and fan to evaporate it. Either system could be added to the indoor pit privy.

I have always found that the Clivus-Multrum does smell a little in houses. The added chimney doesn't seem to suck all the smell out of the room. This isn't surprising since the bottom of the flue will frequently be cooler than the top. Remember that even a great chimney doesn't generate much force. Air rises only if it's hot, so the chimney will not function unless the bottom of the pipe is hotter than the top!

Trying to cool a house with a natural draft chimney can suffer from the same problem. The lower end of the chimney is inside an insulated house, which should be cooler than the summer air. If the top of the chimney is hotter than the bottom, you'll generate very little helpful draft! It might work in uninsulated buildings but it's a lot less efficient in insulated, temperature, moderated environments…(like houses, composting toilets, and refrigerators). PICTURE

A fan attached to a chimney will make the toilet smell ok (until the electricity fails…). It seems to me, much safer and more esthetically, pleasing not to shit where you sleep or eat.

Simple Refrigeration

Refrigeration is great for those who have it. But most people do without it. In the desert of Baja, California we thought that it was fantastic when Roberto or Dona Rosa managed to get a Servel propane fired refrigerator to run for a year or two. We were happy to pay for cold pop and it was delicious. Some people are willing to go to truly extravagant lengths to have cold beer.

But, eventually the propane would run out or the tubing which held the ammonia would crack and we were left drinking 81 degree well water and warm pop. It wasn't a big deal one way or another. In the hot season of the year, leftovers rot almost immediately. So you learn to eat everything. In my opinion, refrigeration is not a necessity for common folk, but it is a help. I love cold lemonade after sweating all day!

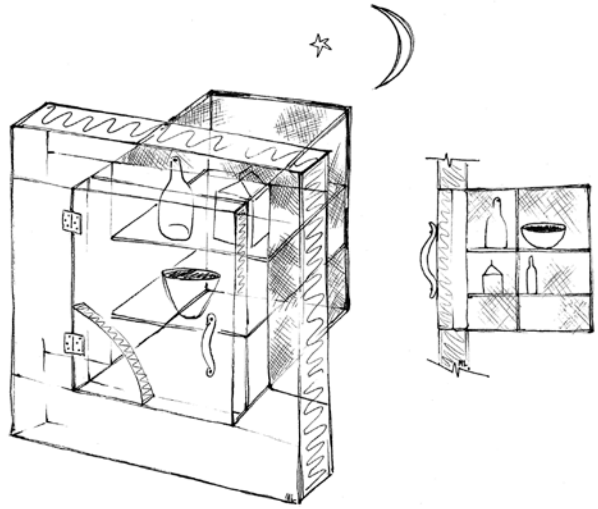
Refrigeration is necessary for storing medicines. Truckloads of ice are brought over very bad roads to fish camps in Baja California every week to store fish. Refrigeration might have saved a lot of gas! Air conditioning saves the lives of older and sick people in tropical climates. Stores cannot sell fresh milk, etc. without the storage that refrigeration provides. It's nice to be able to eat leftovers.

Here are the A.T. options that we've thought about, built or used so far:

- The Draft Box
- The Cob Box
- Shaded Salt Water Box
- Earth Box
- Icy Ball and Servel (Ammonia Absorption)
- Night Sky Radiation Tray
- The Wet, Windy Towel

- Solar Refrigerators

The Draft Box



Aprovecho has used a draft box for many years in both the Lodge and Dorm. The draft box works very well all winter long without using one watt of electrical energy. And it is simple to add to most any kitchen. Just cut a hole through the wall and insulate a door in the opening. Build a small, screened addition on the outside of the door.

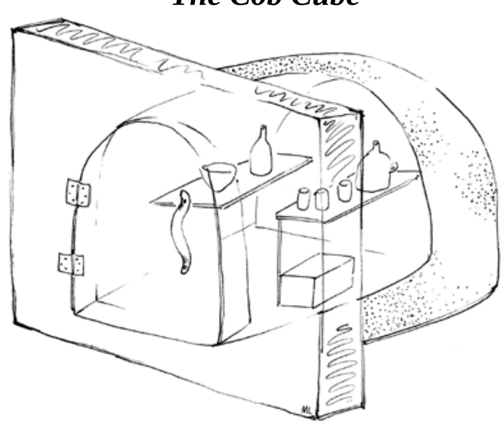
The draft boxes are on the north side of the Aprovecho houses under shaded porches. The enclosures are about three feet long, deep and wide. An insulated door opens from inside the room into the box that is covered with screening to keep the bugs out. Shelves hold the food in the outside air.

Cold winter air keeps food safe and cold here in the Willamette Valley where winter temperatures hover just above freezing for many long months at a time. The insulated door keeps the cold outside but allows easy access to the food. Obviously, the shaded northern side of the house is a preferable location for the wonderful draft box.

During the Spring and Fall, we sometimes put wet cheesecloth around milk bottles, etc. The evaporation of the water cools the bottle. This system works best if the cloth directly touches the surface of the container! But, we have found that except during the summer, a draft box is all the refrigeration we need. Try it out!

Imagine how silly it is to use a lot of stored and basically irreplaceable energy to keep a box cold, in a house that uses more costly and basically irreplaceable energy to become warm, when outside, the whole world is the same cold temperature as the box!

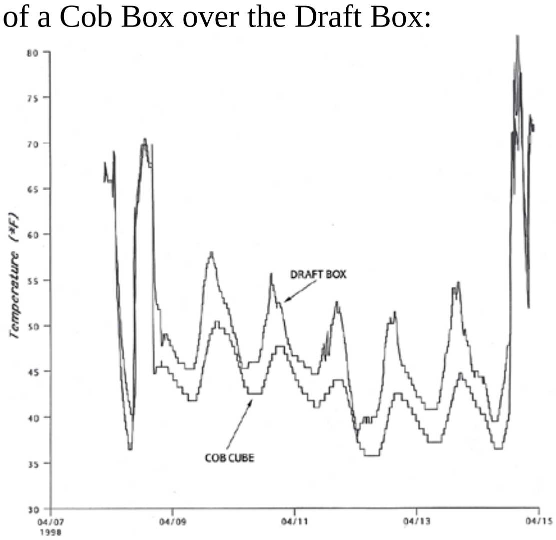
The Cob Cube



In the Spring and Fall months temperatures can rise up into the 50's during the day. Food in a draft box is exposed to these elevated daytime temperatures. However, the nighttime temperatures are still cold and can remain in the 30’s. The average temperature, around 40, is low enough to create a beneficial cooling effect. Refrigeration would work better if it were possible to level out the daytime higher spikes in temperature and retain only the average temperature instead.

Fortunately, thermal mass, like water in drums or cob walls, tends to stay at the average 24 hour temperature. A very thick wall will hover around the average temperature of several 24 hour days. Massive walls around a box can dampen the high and low swings of air temperature, so that daytime spikes in temperature don't spoil food. A large mass is also not effected very much by the temperature of the stored food, absorbing the BTU’s without a great rise in temperature.

A Cob box exposed to outside temperatures should help to extend the cooling season. The following temperature chart shows the advantage of a Cob Box over the Draft Box:

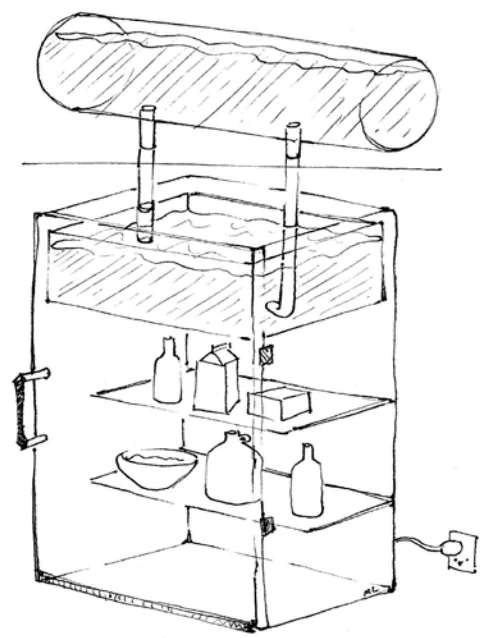


The massive box in our test was made from very heavy walls of bricks. Cob has an R value of around .25 per inch of thickness which is similar to brick.. The mass will help to both protect against freezing and over heating.

It may be that an operable flap on top of the box would allow hot pots to dissipate heat into the air rather than excessively heating the mass. At any event, food should be allowed to cool before being placed in a Cob Box. Of course the Cob refrigerator will be of greatest help during the warmer day.

Using added mass to dampen daytime rises in temperature uses a passive assist to aid refrigeration. The low R value and great weight of tamped earth combine to create a neat assist to the draft box. Keeping the Cob slightly moist would lower the R value (resistance to the passage of heat) and assist the dampening effect of the mass. The effect should be most noticeable when using thermal mass with high conductivity, great density and low R value.

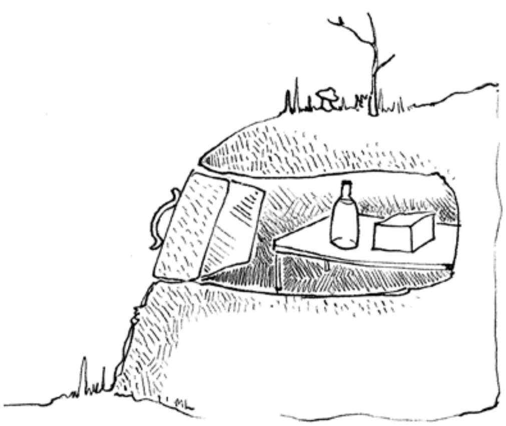
Shaded Salt Water Box



While there is not a lot of sunshine in our part of Oregon during the winter, there is a spectacular abundance of cool damp shade, mostly on the northern side of trees, rocks, buildings, etc. A large tank full of salty water will stay very cold for many of the winter months. Salty water resists freezing. Two pipes connecting this water tank to another tank in the disabled freezer compartment of a refrigerator will create a thermosiphon. Hotter water from the refrigerator in the kitchen will rise in one pipe pushing cold water down and cooling the box. The lower half of the refrigerator will be cooled by the flow of cold from the upper compartment, cooled by the shaded water on the roof.

In this way, a normal refrigerator in a house should be cooled by the cold water from the north facing roof. The refrigerator could either be unplugged or stay connected so the compressor can assist the cooling process. But, if the salt-water tank is big enough and the thermosiphon is working well, the cold water should keep the box cool enough without mechanical assistance. (Gotta try this one of these days!)

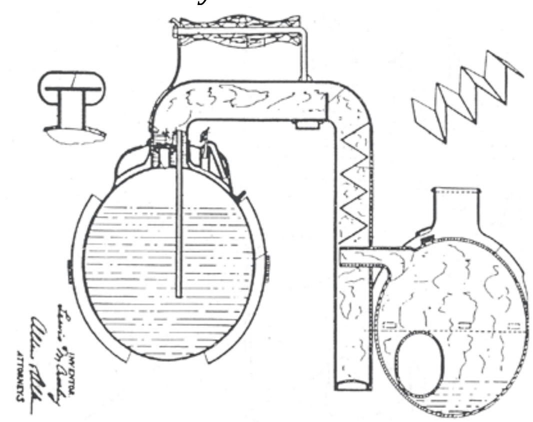
Earth Box



Our planet Earth is the biggest mass available to us without resorting to very reliable transportation. Unfortunately for refrigerator designers, the interior of our world is very hot and the soil below the frost line stays pretty warm- usually between 52 and 58 degrees. So an earthen box, buried in the ground, will keep vegetables from rotting very quickly but it will not provide much protection against the spread of bacteria in food. 52 degrees is just a little too warm for a refrigerator.

But, in the summertime a buried box cools perishables and is certainly helpful. In the wintertime, the warm earth helps to moderate freezing temperatures. Without building a fancier refrigerator, a box buried in the ground can be a great help. Lemonade in the fifties goes down pretty easy on a hot summer day! For most people, a buried in earth refrigerator is the best you can do in the summer. (Unless you build a machine.)

The Icy Ball and Servel



Both these refrigerators use ammonia, and water to cool an insulated box without the use of electricity. The ammonia is boiled out of the water and collects in a chamber where pressure generated by heat forces the ammonia to liquefy. When the pressure is released (by removing the chamber from the heat source) the liquid changes into a gas. This is called a phase change. The phase change occurs inside the refrigerator and cools it by pulling Btu's of heat from the inside of the box into the refrigerant which flows to the exterior of the box.

Both the Icy Ball and the Servel use the pressure generated by flame to pressurize the ammonia and squeeze it until the molecules are so close together that the ammonia gas is forced to become a liquid. The electric refrigerator in your home uses a pump to pressurize the refrigerant, instead of pressure generated from heat.

The electric refrigerator works because a small amount of Freon is pressurized until it changes from a gas to a liquid. The Freon then enters a space where the pressure drops, forcing the liquid to expand and become a gas. When a liquid changes into a gas heat is required. The heat is drawn out of the refrigerator cooling the food. The refrigerant now warmer is pushed away from the cooler box where is gradually looses the heat into the room.

In an electrical refrigerator the cycle is constantly repeated. But in the Icy Ball a large amount of refrigerant cools the box in one cycle for 24 hours. Ammonia is a great refrigerant. It boils at temperatures well below 0 degrees F. Each pound of ammonia that changes state pulls about 500 Btu's from the box. Freon is less than 1/5 as effective, but it doesn't smell like ammonia.

Both the Servel and Icy Ball systems have been around for more than 60 years and have no moving parts. The Servel is used in RV's now. Modern kerosene and propane refrigerators use this system. More than 100,000 Icy Balls were sold in the U.S. in the 1930's. Both can provide reliable refrigeration without the use of electricity.

Aprovecho staff, lead by Frank Hall, rebuilt the Icy Ball in 1995. The Icy Ball was built from 5 and 3 gallon propane cylinders and steel pipe and seemed to work well. It lowered the temperature of two gallons of water and anti-freeze an average of 44 degrees per 45 minute firing. But completing the development of a A.T. version of the Icy Ball was a complicated and worrisome task.

Larry and I became worried about the potential for explosion. The simple soldered "freeze plug" that we had depended on to give way before pressures rose too high, proved unreliable. Safety relief valves were too expensive for an A.T. gadget. No one was ever hurt but we didn't want to pass something on to others that might be dangerous. A team at the University of Texas has taken over the project. In fact, they started with our last version of the Icy Ball and we hope that their version will solve all problems!

Larry is more impressed with the Servel system. We have toured a factory that repairs Servel type refrigerators and were very impressed with the simplicity of the system. The working parts are all made from steel tubes. It should be possible to make an A.T. version of the Servel that could be built in other countries. We plan to investigate replacing the candle flame that runs the Servel with solar generated heat. But all of this waits for us or someone else to catch up to it…

Night Sky Radiation Tray

There is only about six miles of air between the ground and the intense cold of space. (You could walk there in about two hours.) Space is more than minus 400 degrees F., it's very, very cold. The blanket of air around the earth keeps us warm. (Air makes great insulation.)

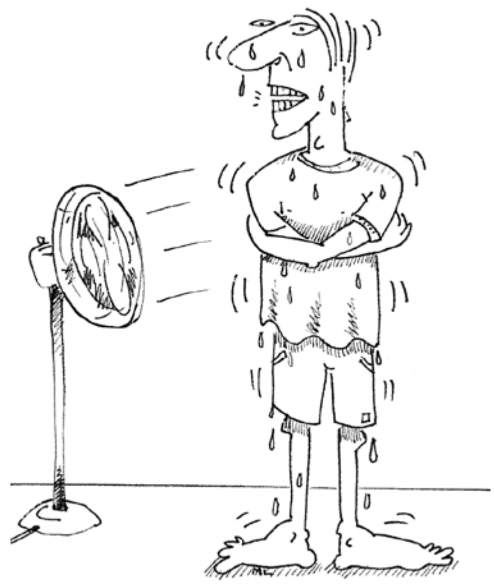
You may have noticed that the warmth of a campfire radiates toward you. On a cold night, exposed skin is kept warm by the fire even though the air next to your skin stays cold. The rays of the sun obviously do not warm the earth by heating up all of the space between the sun and earth first. Radiation from the sun directly heats our planet just like a open fire warms exposed skin, by radiation not convection.

The intense cold of space can be used for cooling in the same fashion. Heat travels in one direction only: from hot to cold. A tray of water on the ground radiates its warmth towards colder objects. On a clear still night the water in the tray radiates a lot of its warmth out into space. The big difference in temperatures, between the water and the deep cold of space, draws a considerable amount of heat out of the water. That's why ice can form on clear, still nights when the air temperature is above freezing.

In ancient Egypt trays of water formed ice during the night which, when collected in the early morning, cooled the pharaohs. We did a bunch of experiments In Baja California, Mexico which resulted in cold Pepsi’s. Trays of water were exposed to the clear night sky. Each tray had about ½ inch of water in it. By morning, if the temperature was below 45 degrees, the tray was frozen solid. Larger amounts of water were lowered an average of about 20 Btu’s per square foot per hour.

This technique did not work on cloudy or windy nights. We were lucky to be in the desert with clear, calm nights. But it is useful to keep the night sky radiation tray in mind as an option. It was lovely to live the pampered life of a pharaoh in the desert!

The Wet, Windy Towel



Anyone who has emerged from a lake on a hot summer day will have noticed a considerable chilling effect if the wind is blowing. This chilling of the skin is caused by rapid evaporation. Evaporation is a phase change from liquid to gas. This change robs heat from the immediate environment, in this case, your skin. (Remember that an air gap between the shirt and skin would insulate you, lessening the chill.)

The heat leaves your skin with the water vapor as it is carried off by the wind.

Water is one of the best refrigerants, requiring 1,005 Btu's per pound to change from liquid to gas! 1.5 gallons of evaporated water results in approximately 12,000 Btu's of cooling. Water isn't used in refrigerators because it has a high boiling point and because it freezes at 32 degrees. But water is admirably suited to chilling food.

Swamp coolers use this principle to chill vegetables, houses, cattle sheds, etc. The problem with a swamp cooler is that the humidity rises as the temperature falls since the water vapor stays in the enclosure. The high humidity makes people uncomfortable. But contained food in a refrigerator might not complain as much…

As stated, a pound of water requires the input of 1,005 Btu's to change from liquid to gas. If the same water vapor then condensed on a surface, the surface would be warmed by the 1,005 Btu's, being given up as the gas changed into a liquid.

This is why a pot of water boils faster if covered by a lid. The heat regained from condensation helps to warm the pot.

A gallon of milk in a windy location will cool down if placed in a shallow bowl of water that wets cheesecloth draped over the container. The cheesecloth wicks up the water. Wind passing over the cloth increases evaporation. Evaporation on the surface of the milk container cools it. The liquid water is turned into gas, sucking heat from the cloth. The hot gas is blown away.

If the wind stops, however, the milk warms up again. If the wick dries, the milk heats up as well. If the cheesecloth isn't touching the container the effect is lessened.

Swamp coolers are air conditioners that work by blowing air past water. The evaporation of the water chills the air, which then cools rooms. This device works best in dry climates. Humid climates decrease the rate of evaporation.

It should be possible to construct an A.T. swamp cooler that would chill food. Either natural draft creating a flow of air or the wind generated by a fan would increase the rate of evaporation producing the phase change. A fan would work a lot better than a chimney.

A chimney works because hot air rises. The molecules in a volume of air are further apart if the air is hot. Cold air sinks because the molecules are closer together which makes denser air. A chimney that is colder near the bottom will not draw very well. If it is hot outside, a chimney carrying room temperature air will not cause a lot of draft (wind). Normal sized chimneys at best provide a gentle upward pull. This amount of wind will not create a lot of evaporation. But, theoretically, at least, a small fan could generate a sizable amount of cooling!

Water is amazing stuff…It increases in size when it gets colder, it stores more energy than most anything else, it creates a great deal of cooling as it evaporates, it gives back a great deal of heat when it condenses. And we get to drink it…

Solar Drying and Solar Desalination

Farrington Daniels in "Direct Use of the Sun's Energy" suggests that both drying and desalination are perfect solar jobs. Neither requires high heat so the diffuse character of solar radiation is not an impediment. Only flat plate heaters are required to warm water and air**. Flat Plate is Great**: they need no adjustment to absorb heat effectively as the sun travels across the sky. PICTURE

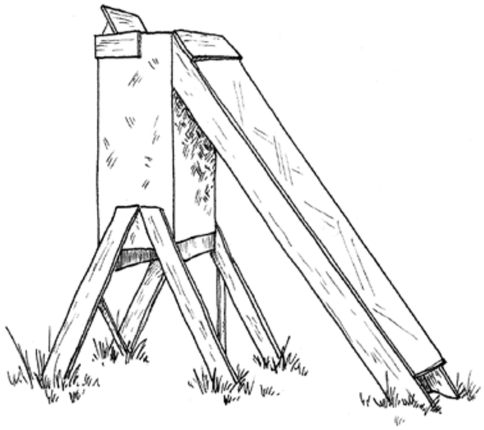
I love teaching these subjects because understanding how drying and desalinating work is simple. I'll write the design criteria on a blackboard and then trade ideas with students on how to best embody principles in a design. Sitting in a group setting helps because new thoughts and positive criticism happen quickly. In a while, we'll most likely come up with a new "invention", which usually is a variation of some historical device. The class then builds their idea and tests it, comparing the performance to older models. They write up the results and challenge the next class to improve on their model.

Learning how to build a better solar food dryer is great practice for A.T. designers because there are only a few important design factors. In the case of drying these are the principles to keep in mind:

- Encourage evaporation
- Heat the food (130 F. or so) but don't cook it
- Keep bugs off the food, if you can and
- Keep it out of direct sunshine.
- (Both 3 and 4 improve the quality of the food, but people can eat food that's been exposed to both the bugs and the sun, if they have to.)

All over the world crops are lost because they rot. Drying is a natural and low cost method of preserving food. If the moisture content can be reduced to 12% or less foods are preserved and can last for long periods of time. On the farm where I lived in Baja California we had strong tables made from palm on which foods were dried. Tons of dates were dried every year on these tables. Fish fillets hung on clotheslines and were exposed to the wind. In four days, they were dried as hard as wood. Of course, the desert likes to dry things. Drying in Oregon is more of a challenge.

The dryer that we used at Aprovecho for years was a box that held the food on shelves made from screen. The box was attached to a large flat plate collector that heated air. Air entered the collector at the bottom and as it rose the air was warmed by the sunshine as it warmed the black interior. The hot air heated the food, which increased the rate of evaporation. Lost moisture was drawn out of the box with the rising air.



It took two days to dry thin slices of apple, which seemed a bit long. So a class added a second pane of glass, which raised the interior air temperatures. But the gardeners got mad at us because their herbs were fried in the hotter air. So the next class added a very tall chimney to the box. The added draft was helpful in two ways: temperatures dropped into a more acceptable range and the increased air-flow improved the rate of evaporation which decreased drying times.

Apple slices now routinely dried in a day and a half. But, a year ago, the Spring semester group challenged the concept of drying in such a complicated way. They were sure that if we were trying to increase evaporation, the box might just be getting in the way. They brought up the example of drying clothes outdoors on a line. Wouldn't the clothes dry much slower, they thought, if each wet shirt was inside a box?

Following the four principles of solar drying the class believed that food should be directly exposed to the heat and wind of a summer day. The summer wind in Oregon is very much stronger than the draft produced by a chimney. The heat in several places on the farm is almost equal to the 130 degrees inside the box. So the group built a bunch of very simple prototypes and we tested them. All of their simple dryers outperformed the fancy box and double paned dryer.

Do you want to guess what they built? Take a minute and make a sketch or two to create your own world's best A.T. Solar Food Dryer!

PICTURE

The best performing dryer was a screen box with shelves made from screen. A black piece of sheet metal was tied on as a roof, blocking the sunlight. The box was placed on the hot metal roof of the dorm. Actually it was outperformed by another screen box that was tied onto the hood of a car, but since the students took a drive in the car to increase evaporation, we had to disqualify their effort as too "active". (A sun shielded bag made from mosquito netting hung on a clothesline did very well, too.)

Even in Oregon, optimized drying didn't necessarily mean solar collectors and chimneys. The only time the box works better than its screen box cousin, is on cloudy days without any air movement. The hot air inside the box creates draft that assists evaporation and the heat drives moisture from the food. But sometimes simple and cheap is more efficient by a long shot!

The greatest thing about these experiments is the grins we get to wear when someone asks to see our best solar dryer…or composting toilet.

Solar Desalination

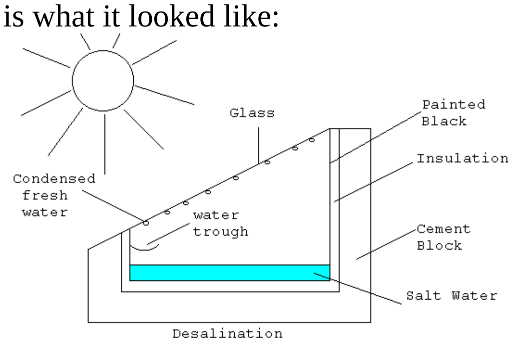
Every year fishermen in Mexico loose their lives when they try to walk home. The outboard fails, the wind drives you thirty miles from home and you loose your fresh water as the boat flips in the surf. The canyons are steep, you are 50 years old and one out of many doesn't make it. People can usually go a month without food but only three days without water.

There is a fishing village called Agua Verde on the Baja California coast that is about 80 kilometers from the nearest well. 200 people live there. All drinking water is brought in by pick up trucks. Of course, a lot of people get sick when baby puts a dirty hand in the water barrel.

The first Spanish town built on the west coast of America, Loreto, Baja California Sur, ran out of fresh water about 8 years ago. Salt water replaced the fresh water in the aquifer and soap became glue when you tried to wash in the shower. (Salt water and regular soap don't mix.) The town frantically searched for a solution and three years later completed a pipeline 28 kilometers north, stealing water from the most fertile local agricultural area. During these three years, we all drank bottled water brought from a delicious spring, 10 K south of town.

The world is running out of good drinking water. One of the ways to provide a family with water for drinking is to build a cheap solar desalinator. Studying how to produce more water from a solar still is another excellent project for the amateur A.T. designer. A solar still can change most any foul water into pure drinking water. All we have to worry about is how to optimize evaporation and condensation.

In 1872, the owners of a copper mine in Chile built a solar still that produced 6,000 gallons of drinking water per day. It was built of cement and glass and covered an acre of ground. The shape of each individual cell was the same as it reproduced all over the globe today. This is what it looked like:



This is how solar desalination works:

Sunlight enters the box through the glass and passes through the transparent water. When the sunlight hits the blackened bottom of the evaporation tray it is absorbed and emitted as infra-red radiation or heat. The heat passes into the salt water, which gets warmer. Obviously, the black heat exchanger should be insulated from contact with anything but the water.

As the water heats up it starts to evaporate faster. At 140 degrees the first evidences of evaporation become visible. It is unlikely that the water in the still will get much hotter than 140 unless it's in a very hot location. We need to make sure that the sides of the still are insulated as well as the bottom and make sure that there are no air leaks. The hotter we can make the water the more evaporation occurs.

The glass is inclined at least 15 degrees. Clean glass “wets out” instead of forming droplets, which is great because water droplets are shiny and reflect back a large part of the sunlight. A film of water on glass is still transparent. For this reason, glass is preferred over plastic. If plastic is used, the angles need to be much steeper or drops of fresh water will fall back into the evaporation tray.

Water vapor condenses on the underside of the glass because the glass is colder than the air in the still. The glass is colder because of convective losses to the outside. Stills of this type produce the most water on sunny days when the wind is blowing and the air temperatures are brisk. The greater the difference in temperature between the water vapor and the surface of the glass the greater the efficiency of production. If the day is hot and still, it is quite possible that more drinking water will be made at night.

A trough at the bottom of the glass catches the condensate (the pure water) and it flows into a jug, which can periodically be emptied. If a tube brings the water into the bottom of the jug it is quickly covered with water and is sealed. It’s great if the fresh water container is kept cool and out of the sunshine.

How do we improve production from a solar still? Improvements are made by encouraging evaporation and encouraging condensation. Getting water hot in a low temperature flat plate collector is usually pretty efficient. But since the glass condenser is exposed to heat inside the box (and is warmed as water vapor liquefies) there is a lot of room for improvement on this side of the equation. Condensing is the least efficient part of the process so we start to work on this side of things first.

It takes 10 to 12 square feet of glass to produce one gallon per day from this classic type of still. Glass is usually very expensive. If we could double the efficiency of a solar still perhaps poor people would consider them a better deal…

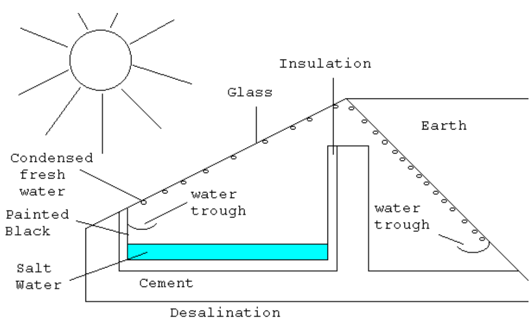
I built a solar still in a small fishing village in Baja California. The village had no source of drinking water. The glass for the still was purchased in Loreto. It was a old sliding glass door that was about 3’ by 7’ or 21 square feet. The glass cost 30 dollars. We poured a cement trough and three walls. The glass fit tightly into the cement, which was sloped at about 20 degrees from the horizontal. We didn’t insulate the still. A trough was made from a piece of PVC pipe cut longitudinally. It emptied into a five gallon container buried in the sand.

The still produced an average of about 2 gallons per day during the winter when we conducted our tests. It had cost about 50 dollars. I have to admit that I considered it sort of foolish as we were doing the testing. $50 seemed like a lot of money for two gallons of water.

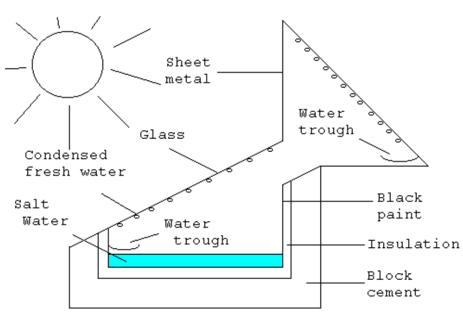
But, when I visited the village a year later I had to change my mind. The still was continuing to pump out water every day. Two guys could live from its production. In the morning I saw an older guy carefully walk down to the sea, fill a bucket and refill the evaporation tray through the little door we had cut in the side wall. He sat and smoked a cigarette, watching the first droplets of fresh water condense on the glass as the sun warmed up.

That day, he told me how wonderful the still was. He didn't have to always watch how much he drank and ration his water on fishing trips. For the first time while fishing, he wasn't thirsty! He was 68 years old and I was glad that he wasn't thirsty.

So how can we cool the glass condensing surface? And perhaps make water for three or four people per day instead on only two? Why not make a list of ideas of how to make a better condenser and I'll include a few sketches of ideas on the next page…Students at Aprovecho did double the production, by the way.

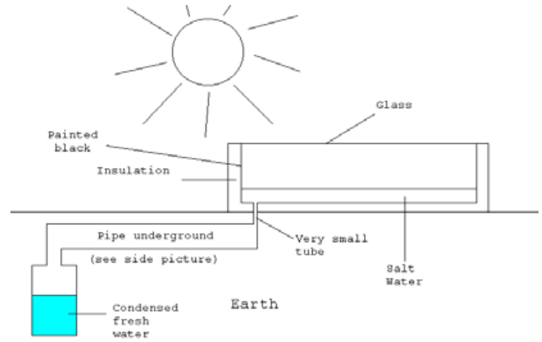


Still with back buried underground

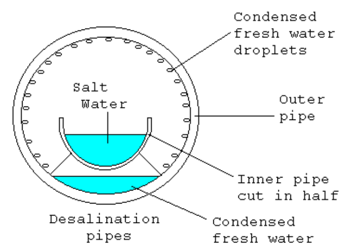


Reflector Still

SKETCH OF AIR DRIVEN STILL



Still with underground tude



The inside of the underground pipe

Did you think of spraying water over the glass, or did you go all the way and completely separate the functions? Let's check out some of the student's ideas:

The earth cools the condenser made from sheet metal. A bucket of salt water is dumped onto the earth above the condenser every day, which helps to get rid of the heat generated by the water condensing (1,005 Btu's per pound!) The perfect condenser would be one that lost heat as quickly as it was absorbed, which is difficult to obtain.

The water still gets hot as the sun shines through it. But since the earth-backed condenser is colder than the glass most all of the condensation takes place on the sheet metal not the glass.

Reflector Still

The still faces south. A reflector is added to the still which increases the heat inside the evaporation unit. The reflector is hollow and shades a condensing plate located behind the reflector. The sheet metal condenser is cooled by convective losses to air and is aided by any wind.

Air Driven Still

This still produced one gallon/day per 4.7 square feet of glass exposed to sunlight. Humid air is pulled by the draft created by a chimney into the earth where the air drops its fresh water before exiting up the chimney.

Air is preheated in a 4’ by 6’ flat plate collector before it is pulled into the flat plate collector that holds the salt water tray. The evaporation unit does not have a inclined top because we don’t expect condensation to occur on the glass. The glass is horizontal lessening the air space inside the box and increasing temperatures. After picking up humid air (fresh water) a six inch in diameter chimney pipe descends underground where the dew point is reached and most all of the moisture condensed out of the air. A 30’ high chimney drove the apparatus, pulling air through the machine.

It turned out that the chimney wasn’t powerful enough to pull all of the moisture under ground. We would need to add a bigger chimney to the unit because there was still condensation on approximately ¼ of the glass above the evaporation tray.

Tube in the Ground

The tube in the ground desalinator performed in the same range as the more complicated air driven still. Separation of evaporation and condensation is complete in this design.

Salt water is heated in a flat plate collector. The glass is horizontal and we added a reflector to the north side of the box. Another reflector could be added to the south side, as well. These two reflectors will not block sunlight as the sun travels from east to west. East and west reflectors cannot be used as they would shade the glass.

A tube carries water underground. The tube carries away a little more water than will condense assuring that the condenser does not run dry. The salt water runs downhill in a half a tube which is surrounded by a whole tube. The half tube is made from PVC pipe cut longitudinally. The whole tube is also cut in half longitudinally. The half tube is positioned within it and then the whole tube, made from larger PVC, is glued back together. Small blocks hold the half tube in place.

Hot salt water evaporated inside the tube and condenses on the inner roof of the whole tube. The fresh water is carried by gravity in the bottom of the tube to a catchment basin. The salt water goes on a bit further where it is drained into another jug. This jug is splashed on top of the ground where it also serves to cool the condenser.

These are four examples of desalinators that we have built at the Research Center as experiments. All worked a bit better than the classic model. Both solar drying and desalinating are fields in their infancy. It would be easy to make contributions that would perform more efficiently than the models currently available.

I love messing about with each subject because I'm sure that one of these days some bright student will look beyond the paradigm and say something obvious that ends up in a design that is: simple, cheap, and efficient. Once we test it, the students can build them in every fishing village in Baja, California and do a great thing: relieve thirst.

You could do it.