Cooking with Less Fuel: Breathing Less Smoke

Aprovecho Research Center
World Food Programme, School Feeding Service (PDPF)
Partnership for Clean Indoor Air
Shell Foundation

Introduction

This manual was initially designed to help school feeding programs use cleaner and more efficient cooking stoves by reducing smoke emissions and fuel wood consumption. Then, we realized that its contents could also be adapted and used in other settings. We encourage anyone interested in improving their cooking stoves to use this manual. The book teaches how to design and develop better cooking stoves, train local stove producers, and cooks how to use and maintain improved stoves. Teachers can use this manual to educate their students about the importance of reducing indoor air pollution and alleviating the negative social and environmental impacts of fuel wood consumption. Most importantly, they can teach students how to apply these recommendations in their every day lives.

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Table of Contents

Chapter 1

Improved Cook Stoves

What happens when we don't use an improved stove?

Fuel wood is wasted: If you are using an open fire or an unimproved stove most of the energy does not enter the pot. This makes your stove inefficient. Cooking will take more time and it will use more fuel wood.

Local forests are under threat: Using more fuel wood than necessary to cook contributes to forest degradation and loss of forest cover. Forest degradation affects plants, animals, and water cycles. Soils also are left unprotected and can be damaged by wind and water erosion. As resources disappear, people have to walk longer distances to find fuel wood.

Cooks suffer health problems: Unimproved stoves emit large amounts of smoke that is inhaled by cooks. Smoke is harmful and may cause health problems such as: coughing, eye irritation, asthma, headaches, lung problems, etc. The World Health Organization estimates that 1.6 million people worldwide die each year from breathing wood smoke.

The advantages of an improved cook stove

- Cooks are more comfortable and cooking is a more pleasant activity
- Reduces cooking time so cooks can take care of other activities

- Produces less smoke, and a chimney removes harmful emissions from the kitchen
- Facilitates better hygiene and cooking practices
- Cooks can choose the type of stove that best suits their needs

- Consumes less fuel wood
- People spend less time gathering wood from local forests

What is a good stove?

A cooking stove has to please the cook because a stove that is disliked may not be used. A stove should make cooking easier, cleaner (in terms of hygiene and less smoke production), and more pleasant. It should cook food as well or better than the traditional method.

It is equally important for the cooking stove to save fuel and to reduce the smoke in the kitchen. If the new stove can please the cook then it is likely that cooks will use the stove and feel that it is a real improvement.

A good stove should at least meet all of these criteria:

- Please the cook by making cooking easier, cleaner, and more pleasant.
- Cook food as well or better than the previous stove.
- Use less fuel to cook food.
- Reduce the amount of smoke in the kitchen.

How and where to begin?

There are different ways of getting started. A recommended approach is to design and develop a prototype stove that can be field tested in one or two schools, homes, or wherever the stove will be used. The stoves should be tested to make sure they meet all the required criteria before they are built and installed.

Who should participate?

It is a good idea to form a stove design committee consisting of the people who will be using the stove. At minimum, the committee should include the cooks (since they know how food needs to be prepared), technical staff with experience building stoves, and project managers.

The information in this booklet will help the stove committee to design one or several experimental stoves. The committee members can then work with local crafts people to create the experimental stoves. These experimental stoves will then need to be used and evaluated.

The last chapter, "Testing Your Stove", contains a simple test that the stove design committee can use to evaluate stove performance. Eventually a suitable stove will be created that meets local needs. Once the final stove has been selected, the manufacturer builds as many as required to be distributed or sold to schools or homes.

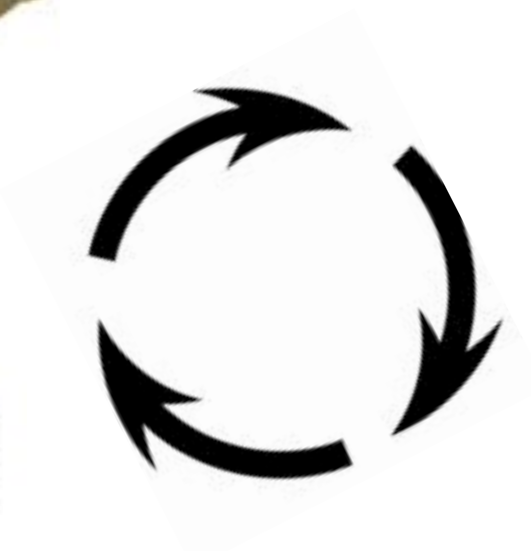
Training should be provided to cooks on how to use and maintain the improved stoves. The stoves need to be checked several times per year. Chimneys and all parts of the stove have to be cleaned and inspected. Worn out parts will have to be replaced. If possible, the committee should continue to manage the stove project as long as the stove is being used. Committee members can help teach others about the new stove and become stove promoters and project managers.

The cycle of designing and implementing cook stoves

1) Identify schools or homes

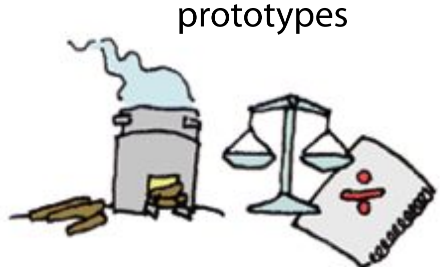
2) Form a stove design committee

3) Develop a plan of action



4) Construct or rehabilitate prototype stoves

5) Field-test prototypes



6) Improve prototype stoves, construct and distribute final stoves to other participating schools or homes

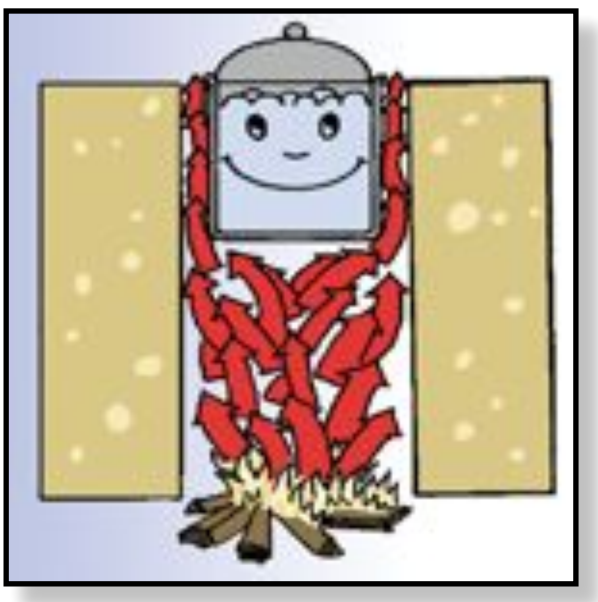
7) Train cooks how to use efficient stoves, how to provide regular maintenance, and how to use energy saving cooking practices

General theory to keep in mind when designing an improved cook stove

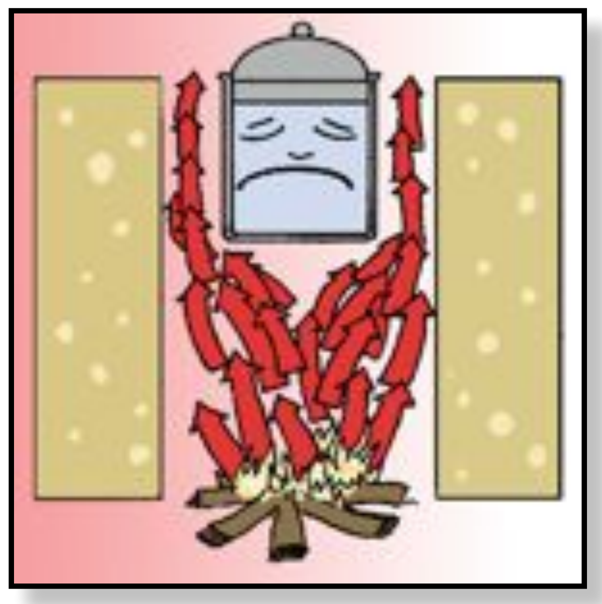
What makes a stove consume less wood?

Getting more heat into the pot is the best way to reduce the fuel used when cooking. Forcing the very hot gases from the fire to rub against the bottom and sides of the pot is the most important technique that saves fuel when cooking.

Many stoves do not force all of the heat to flow close to the pot. These stoves throw away a lot of heat into the air.



When the hot flue gases are forced to flow close to the bottom and sides of the pot in a narrow channel, more heat will be transferred to the pot. This is an effective technique for improving fuel efficiency in a stove.



Heat is not efficiently transferred to the pot if the hot flue gases have too much space between the pot and the sides of the stove.

How can we get rid of the smoke in the kitchen?

The best way to remove smoke from the kitchen is to use a chimney. If the smoke is pulled through the stove and up the chimney without leaking, essentially all of the pollution leaves the room.

If a stove without a chimney is used indoors it is important to let as much air into the kitchen as possible. Placing the stove next to a window, making a gap between the walls and roof, and creating a wind that pushes smoke out of the room are all helpful. However, these partial solutions will not cure the problem. Breathing even small amounts of smoke every day can cause medical problems, especially in children.

Another effective technique is to place a hood above the stove that guides the smoke out of the room (shown on right).

The best stoves make as little smoke as possible. The following chapter, "Ten Design Principles", explains how to make a cleaner burning fire. The design principles also show how to force the hot gases to rub against the pot so that cooking uses less wood. The design committee can use this information as they develop their experimental stoves.

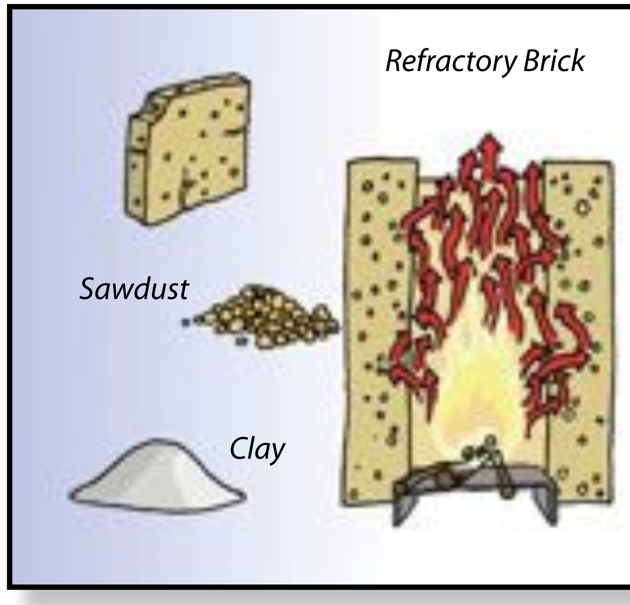
Smoke is harmful, causing health problems such as coughing, eye irritations, asthma, and respiratory infections. The World Health Organization estimates 1.6 million people worldwide, mostly women and children, die each year from breathing wood smoke!

Chapter 2
Ten Design Principles

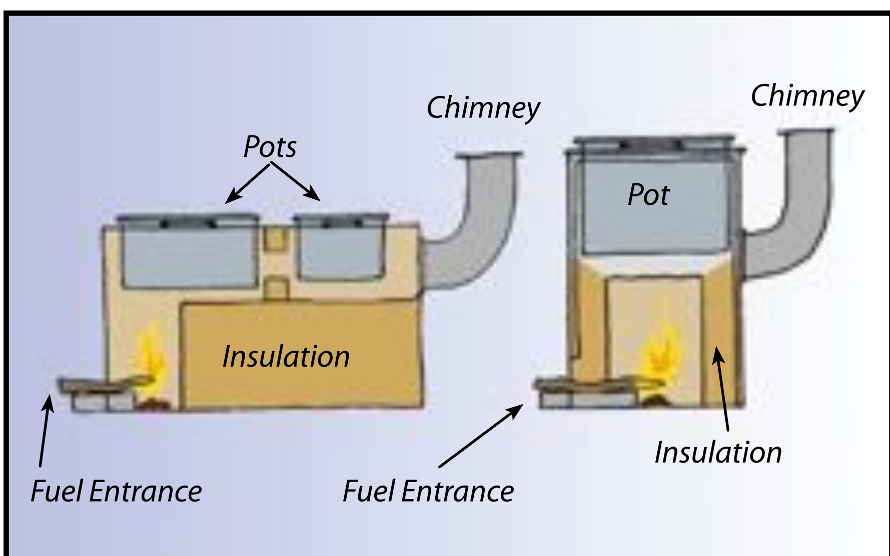
Principle One

Insulate the combustion chamber. Surround the fire using lightweight heat-resistant materials.

Insulation is light and full of small pockets of air. Examples of fire resistant insulation include pumice rock, wood ash, rice hull ash, vermiculite, perlite, and fire brick. Fire brick can be made from sawdust and clay. Recipes and instructions for making light weight fire brick are included in Chapter 6. Locally made ceramic tile can often be used to make a combustion chamber that is then surrounded by any of the loose types of insulation materials listed above.



Insulating the combustion chamber reduces heat loss into the stove body.



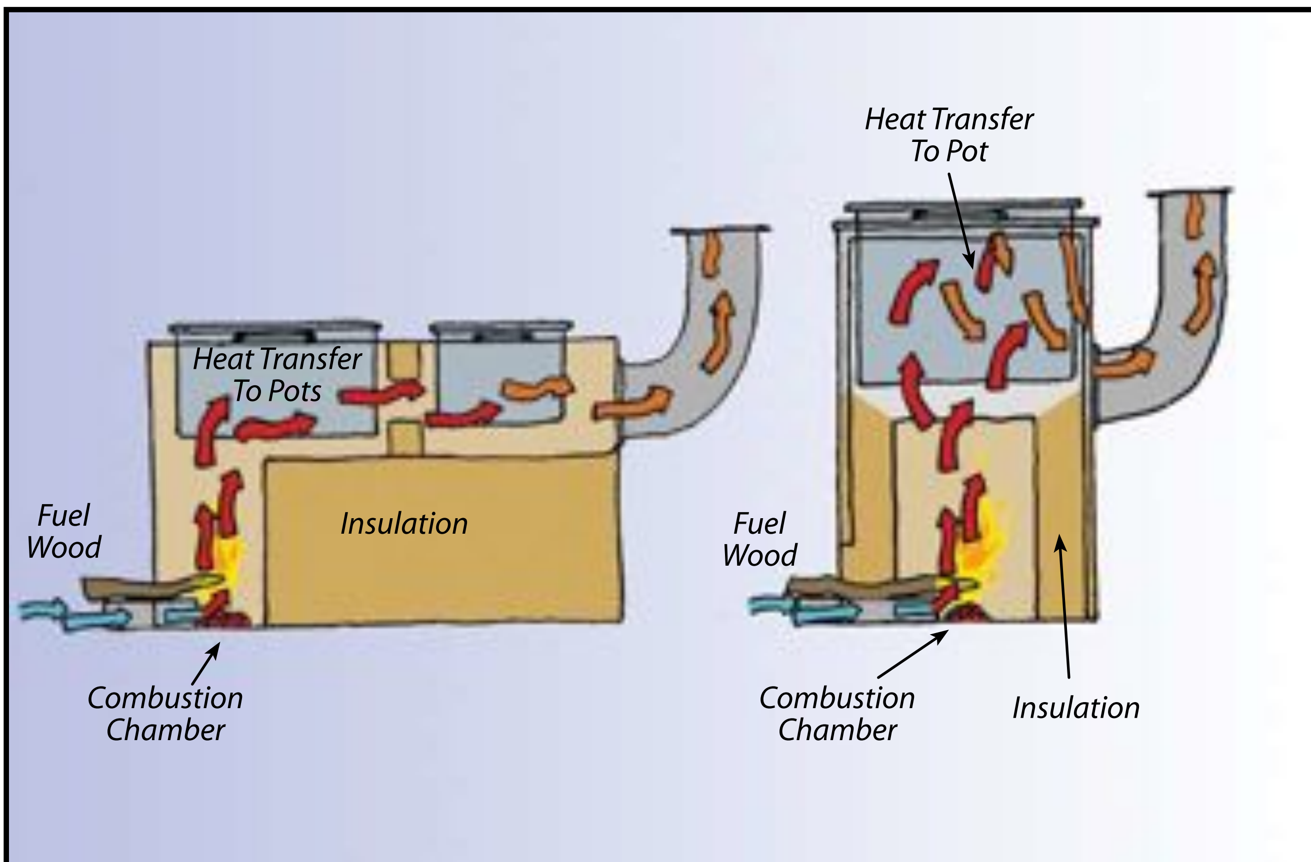
Important: Avoid using heavy materials like sand, clay, or cement around the fire. Heavy materials cool the fire robbing heat from the pot. Additionally, when starting a cold stove the heavy materials slowly warm up. It does not make sense to heat up 50 kilos of stove when the cook wants to cook 10 kilos of food.

Principle Two

As well as insulating around the fire, also insulate the path between the fire and the pot(s) or griddle.

It is best if every space within the stove is insulated with lightweight materials except where hot gases are flowing close to the the pot(s) or griddle. Insulation reduces the heat that passes into the stove body so more heat is available for cooking. Insulation keeps the gases as hot as possible which helps to reduce the fuel needed.

Remember that insulation is light weight and full of tiny pockets of air.

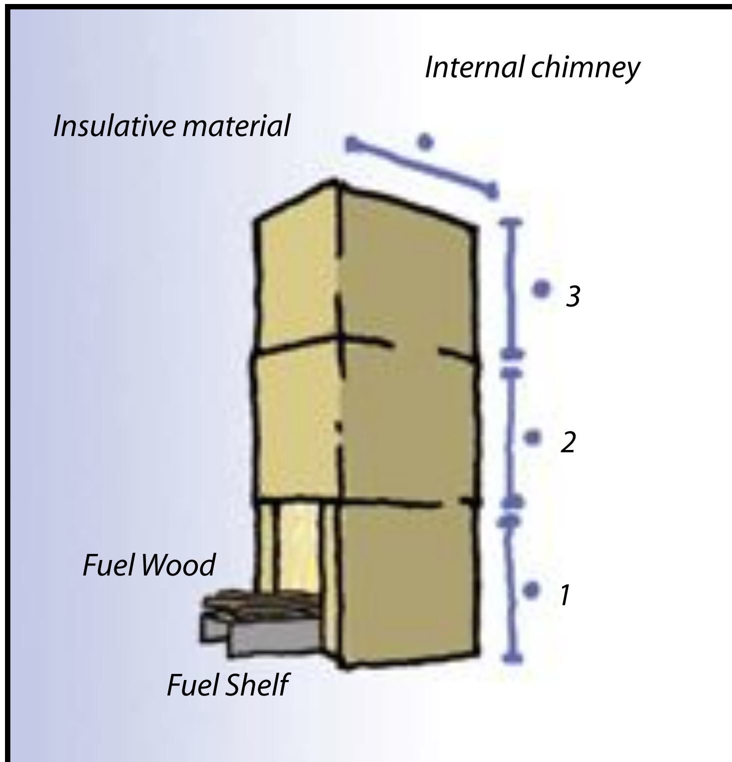


The path of the heat from the combustion chamber to the chimney is insulated everywhere except where the hot gases flow close to the pot or griddle.

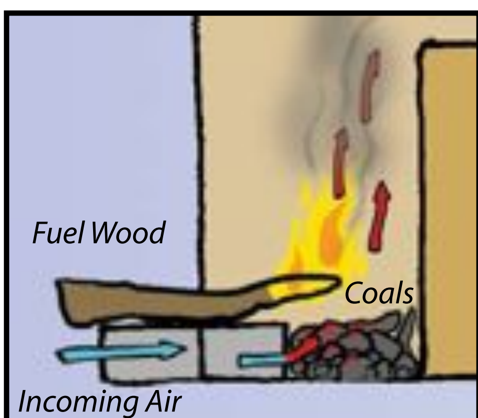
Principle Three

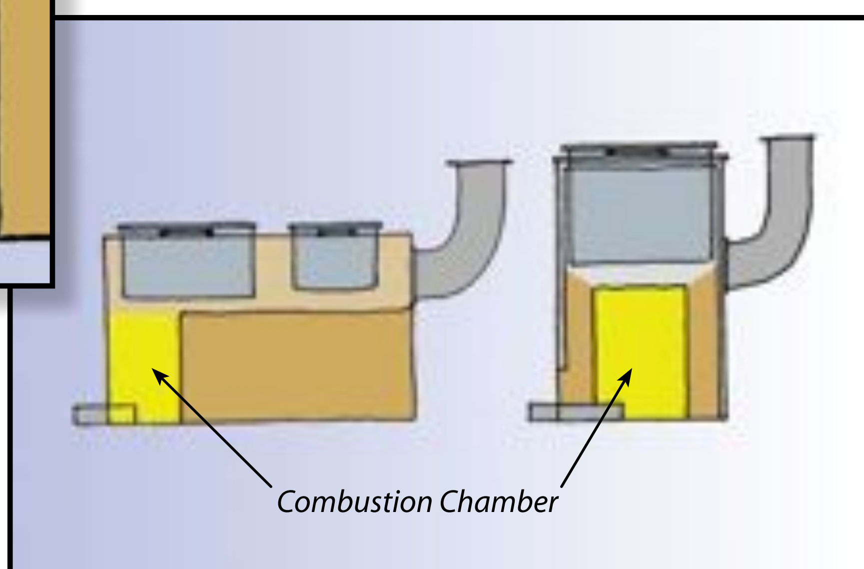
Include an insulated enclosed space (like a short internal chimney) above the fire in the combustion chamber.

If the fire is made under a short insulated chimney that is about three times higher than it is wide, the flames and smoke will be forced to mix. It is good mixing that helps to burn up the harmful smoke. The short chimney above the fire increases the speed of the air drawn into the fire, which helps the fire to burn at a higher temperature. The pot should be placed above the short chimney so that very hot gases hit its bottom and sides. Forcing the hot gases to rub against the pot at a higher speed helps to heat up the food more quickly while using less fuel.



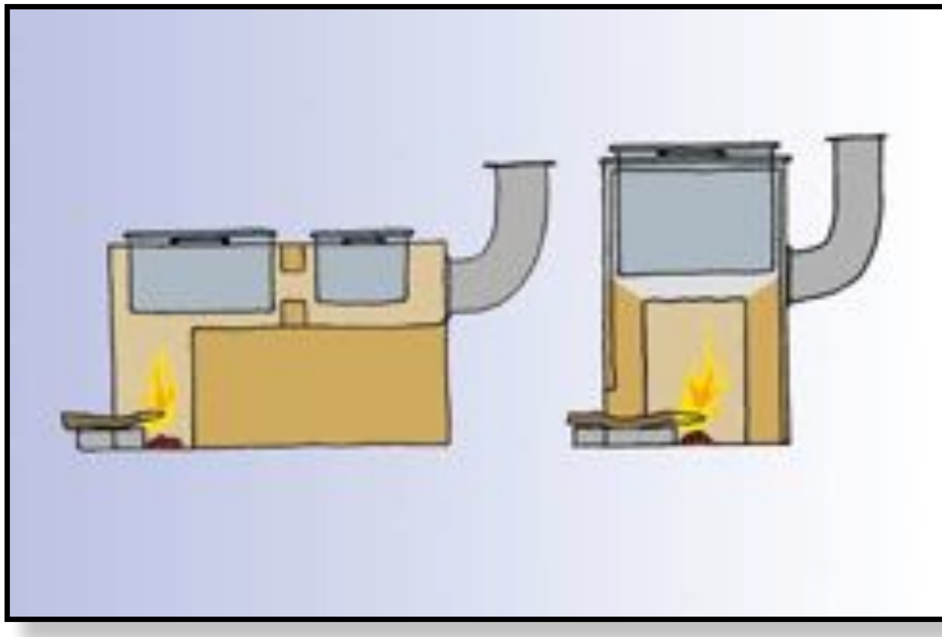
To reduce harmful emissions, the combustion chamber should be an enclosed space that is about three times higher than it is wide and should be made from heat resistant insulative materials.





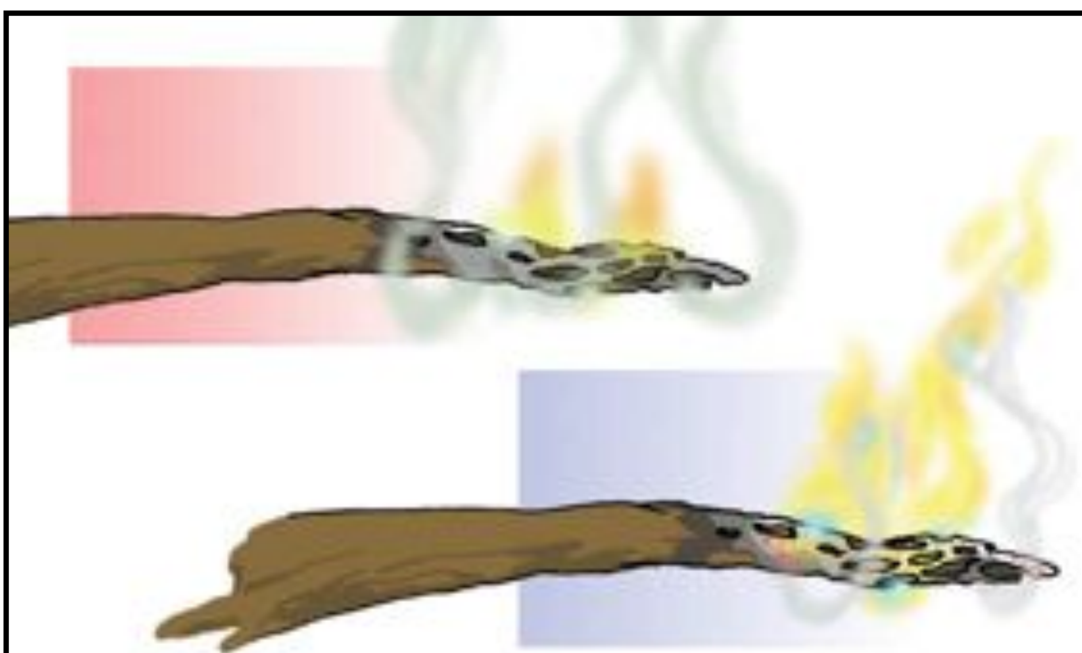
Principle Four

Heat and burn the tips of the sticks, pushing only enough wood into the fire to make flame, not smoke.



Wood that is burning makes some smoke. The smoke will burn up if it passes through a flame. Escaping smoke is made from the wood gases that have not been burnt up by the flame.

Try to keep the parts of the sticks that are not burning cold enough so that they don't smolder and make excess smoke. The goal is to make the proper amount of wood-gas so that it can be cleanly burned.

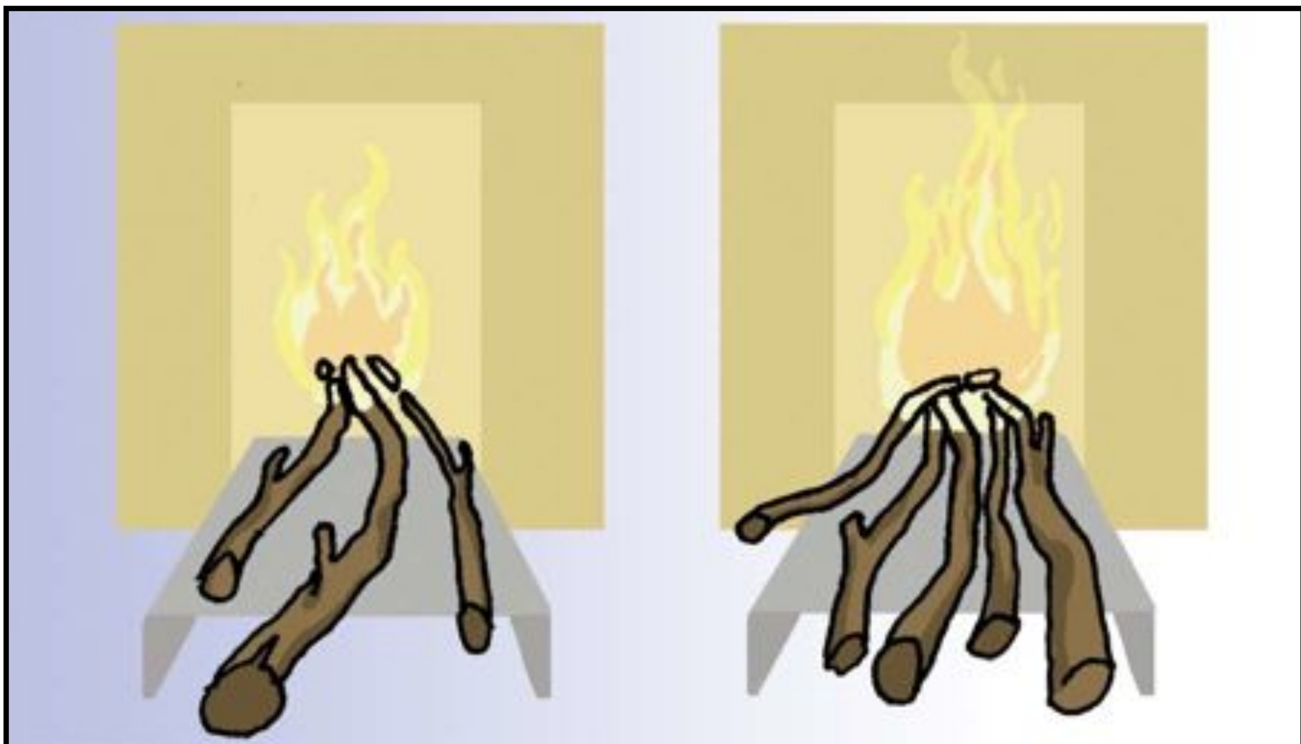


Smoke is unburned wood gas

Principle Five

High and low heat can be controlled by how many sticks are pushed into the fire.

When wood gets hot enough, it produces gas that catches fire and cooks food. If a few sticks are pushed into the fire, there is a small fire. When more sticks get hot and release more gas, the fire gets bigger. The amount of heat is controlled by the amount of wood pushed into the fire, not by reducing the amount of air entering the fire. Reducing the air needed for burning makes a lot more smoke.

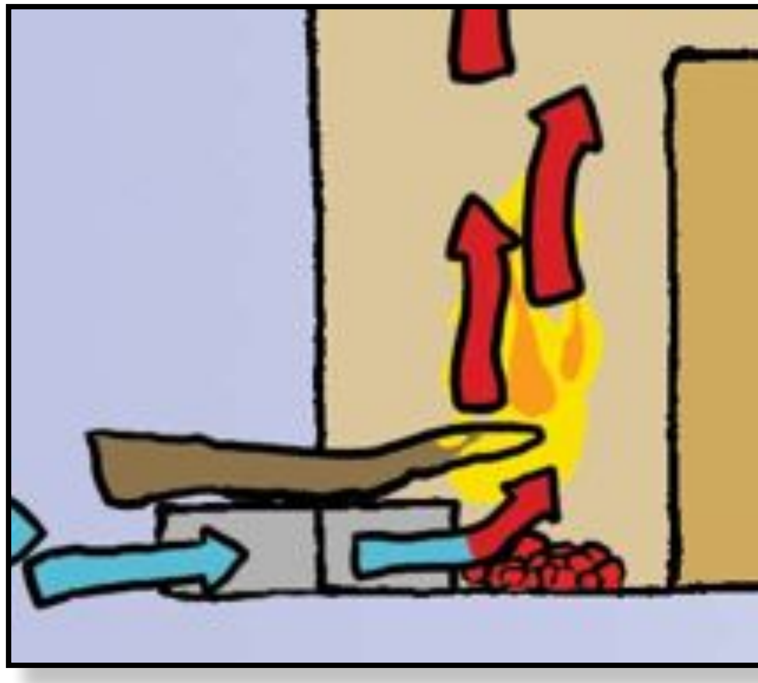


The amount of heat is controlled by the number of sticks pushed into the combustion chamber.

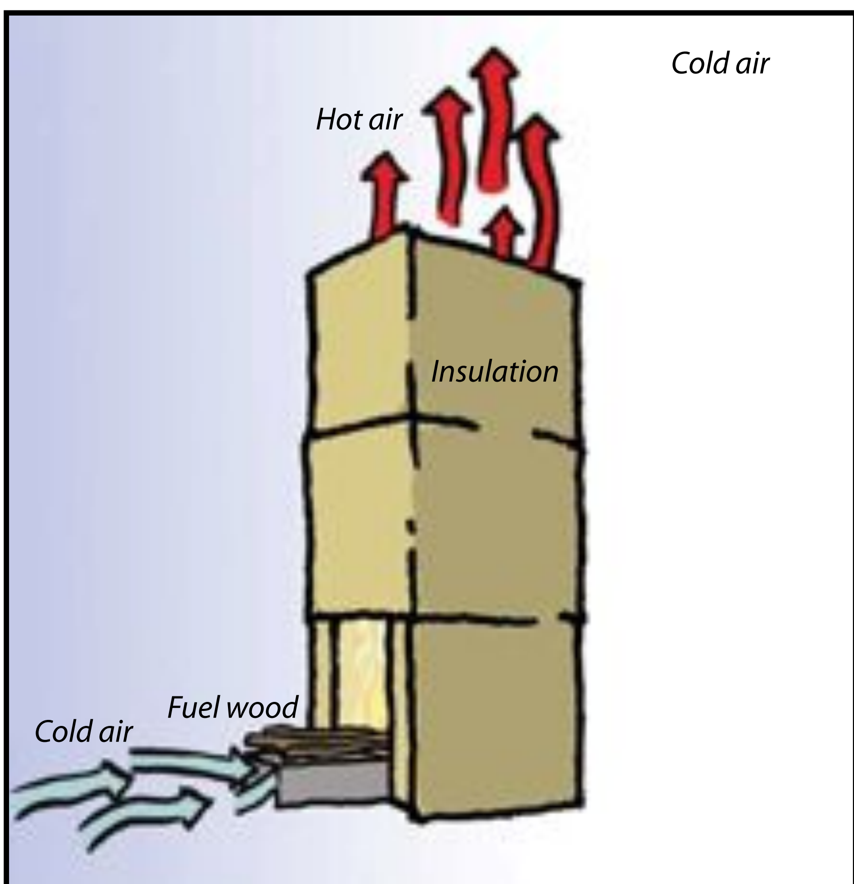
Principle Six

A short insulated chimney directly above the fire creates a faster draft that helps the fire to burn hotter and cleaner. Air should be drawn under the fire into the coals.

Drawing air under the fire into the charcoal makes the fire hotter. The stove should create a continual flow of air into the fire. This will help to keep high temperatures in the stove. The air passing through the coals helps to raise the temperature of the fire so that more of the gases become flame.

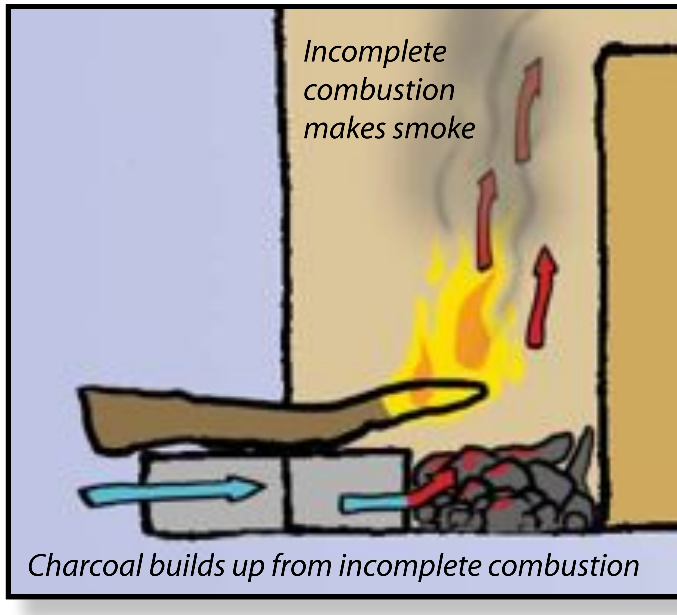


The air should be aimed at the coals and not above the sticks into the flame. Drawing air into the flames can cool the fire.



Principle Seven

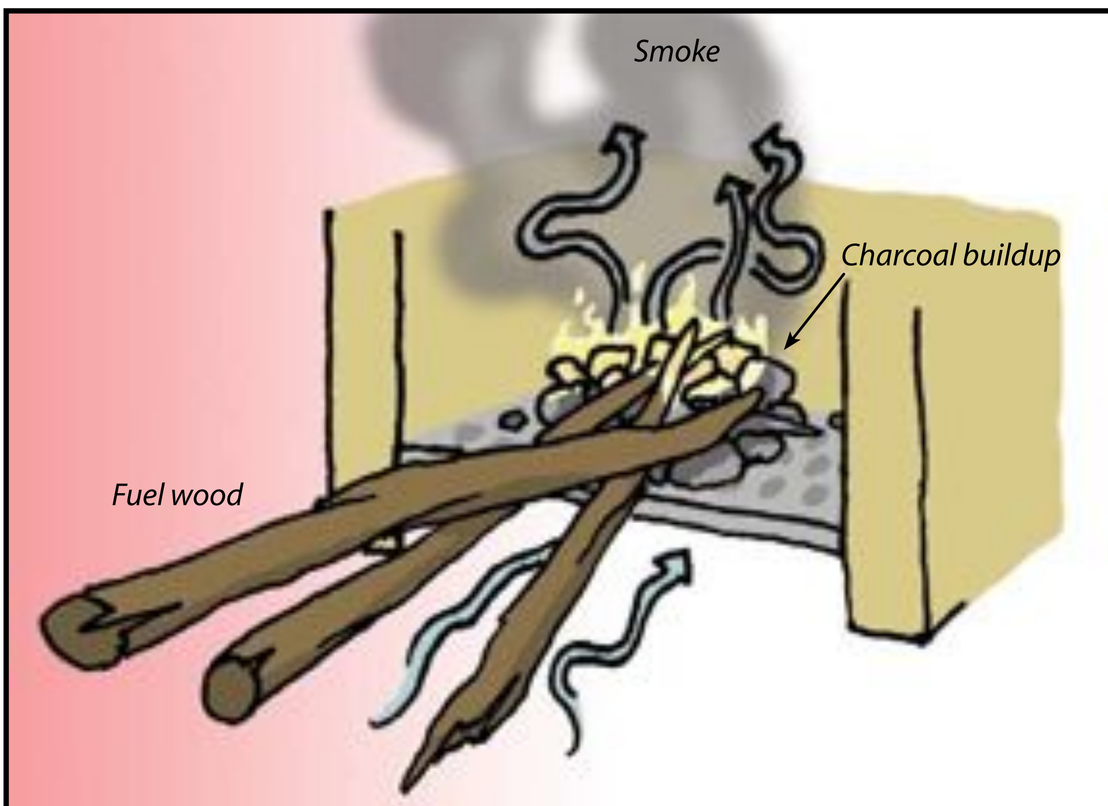
If a lot of charcoal is being made by the fire then there is too little air entering the combustion chamber.



Charcoal builds up from incomplete combustion

It is normal for a fire to make some charcoal as the wood is burnt. However, if the charcoal starts to pile up under the fire, there is too little air entering the combustion chamber. A fire that makes a lot of charcoal is producing too much harmful carbon monoxide.

A hot clean burning fire will not make a lot of charcoal as it is being used. Make sure that enough air is freely flowing under the fire into the coals.

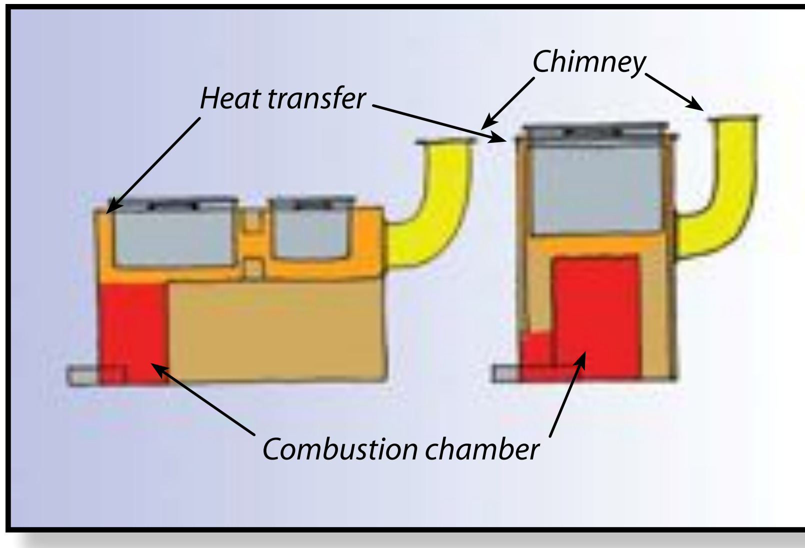


Charcoal building up in the combustion chamber is an indication that the stove is not burning the wood as completely and efficiently as possible.

Principle Eight

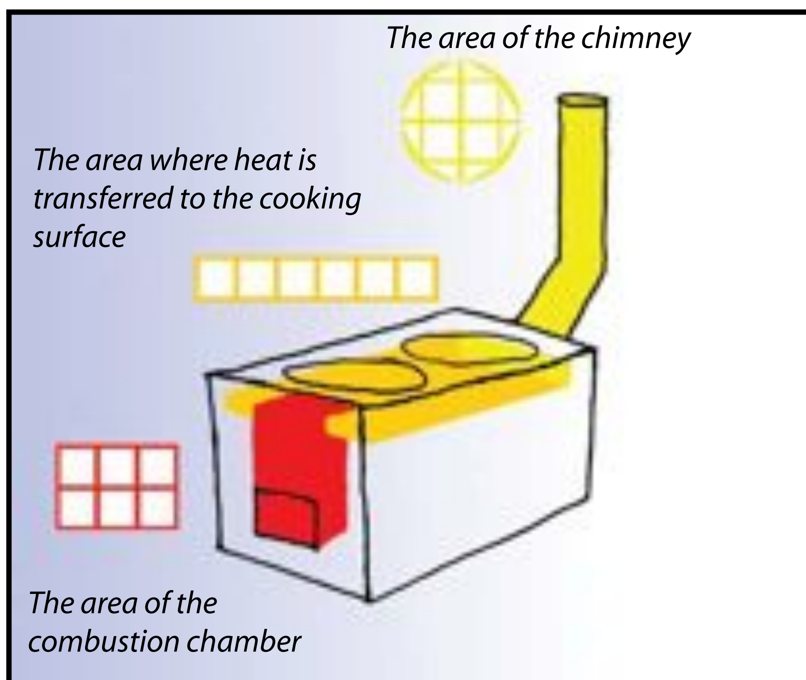
Do not restrict the air moving through the stove. All of the spaces in a stove should have about the same cross sectional area so that the air flowing through the stove is slowed down as little as possible.

The fuel entrance, the spaces in the stove through which the hot gases flow, and the chimney should all have about the same cross sectional area. Size all the spaces in the stove so that the same amount of gases can flow through the stove and up the chimney.



Air drawn into the coals keeps the fire hot. The hot gases also carry the heat to the pot. The gases are very light and do not carry much heat, so a lot of hot gas needs to flow close to the pot to effectively cook the food. Slowing down the hot gases reduces the amount of heat that enters the pot. If less heat enters the pot then more wood is used for cooking. The goal is to keep gases as hot as possible **and** flowing as quickly as possible.

Larger fires need more air because more wood is burned per hour. The spaces within the stove have to be bigger to create better draft.

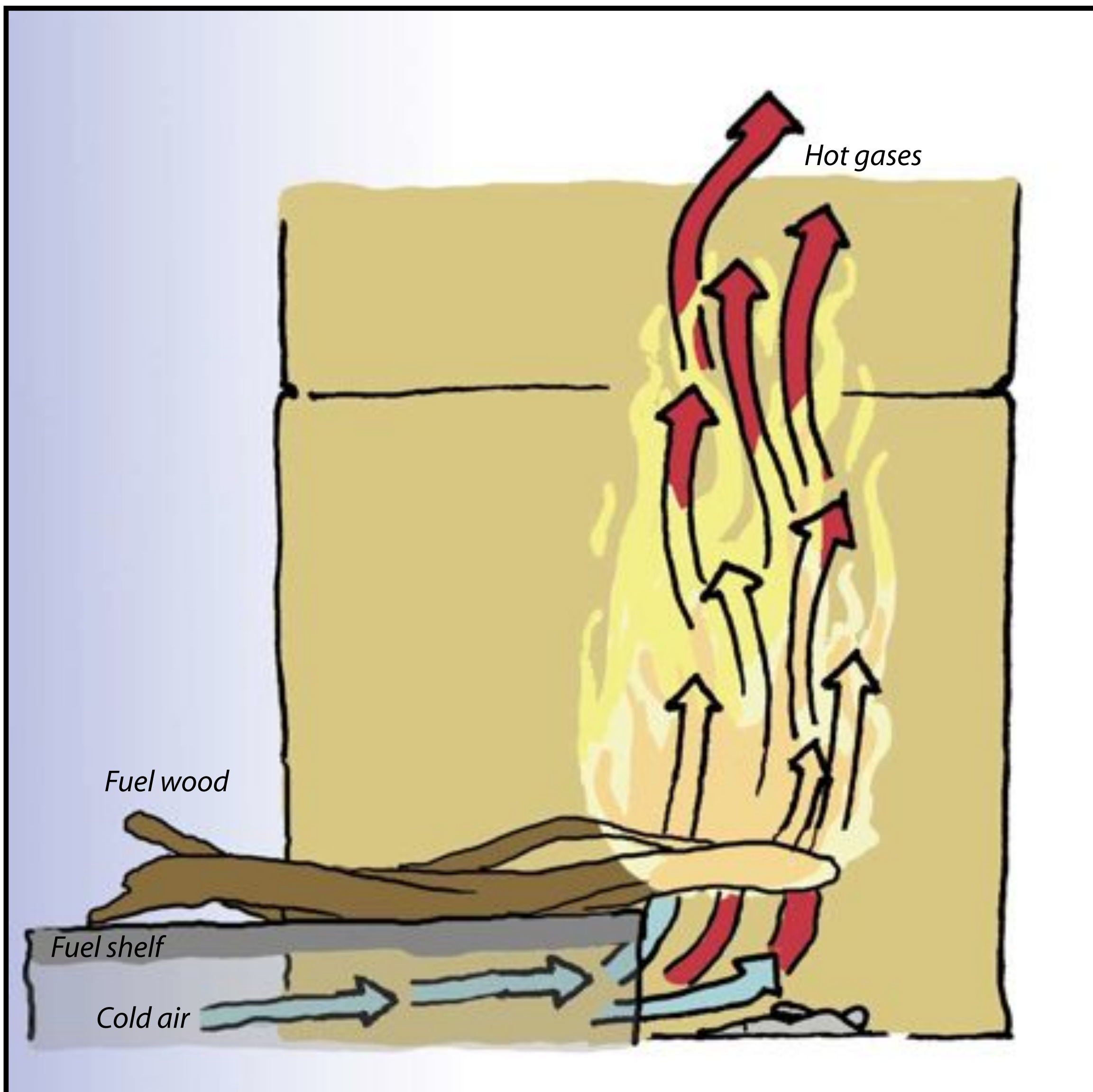


Throughout the entire stove, the cross sectional area that the hot exhaust gases must travel through remains constant

Principle Nine

Use a grate or shelf under the sticks and fire.

Do not place the sticks on the floor of the combustion chamber. Air needs to pass under the sticks, through the charcoal, and into the fire. A shelf in the fuel entrance lifts the sticks up so the air can pass underneath them. When burning sticks of wood it is best to have them side by side with an equal air space between each stick. In this way, each stick helps to keep the nearby sticks burning. This kind of fire is hotter, which helps to reduce smoke.

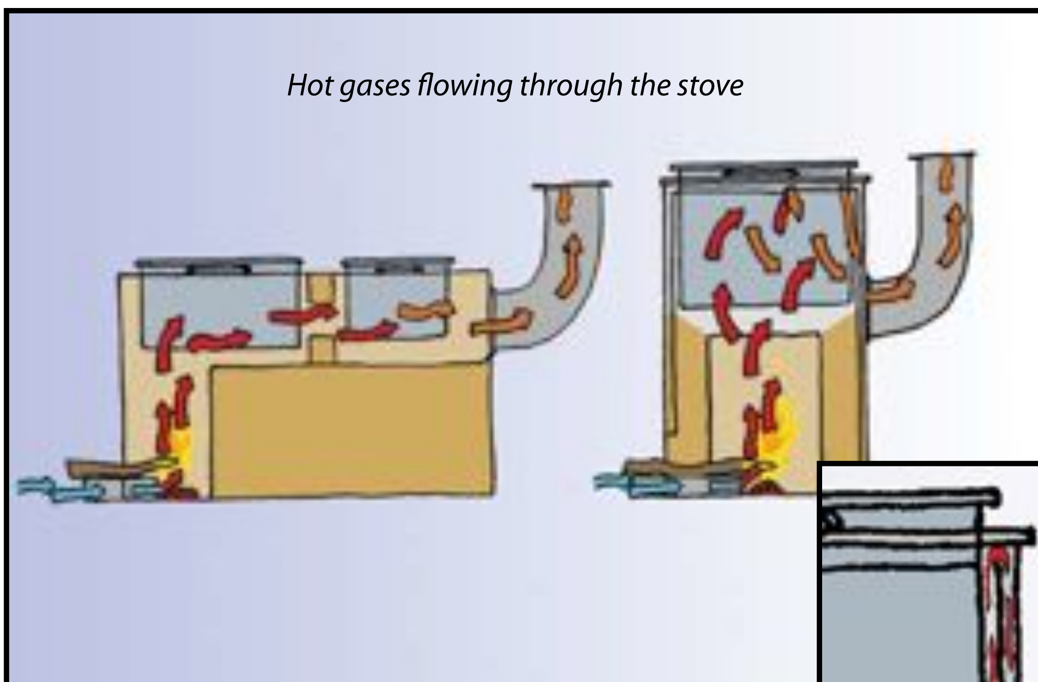


Air entering the stove must pass under the fuel shelf and through the fire

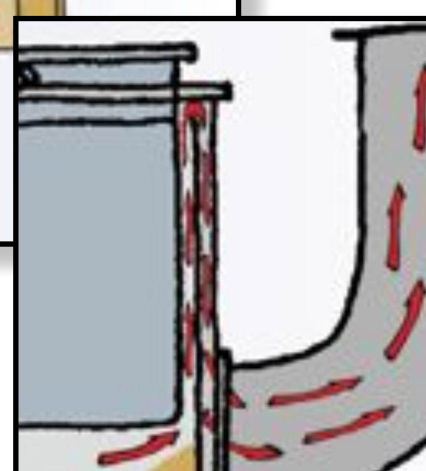
Principle Ten

The hot gases from the fire should contact the sides as well as the bottom of the pot(s). Force as much heat as possible into the pot(s) or griddle by using properly sized channels.

The hot gases flow against the pot(s) or griddle in properly sized channels. If the spaces are too small then not enough air can pass through the stove. Smoke can back up and pour out of the door where the fuel enters. If the hot gases flow through big spaces next to the pot(s) or griddle the gases go up the middle of the space, avoiding the contact needed for effective heat transfer. If the hot gases do not rub against the bottom and sides of the pot(s), more wood is used when cooking.



Hot gases flowing through the stove



When hot gases are forced to scrape against the bottom and sides of the pot, the stove will consume less fuel to accomplish the cooking tasks

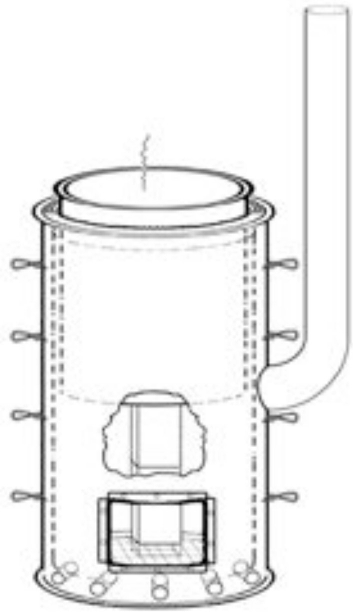
Chapter 3

How To Design Improved Stoves

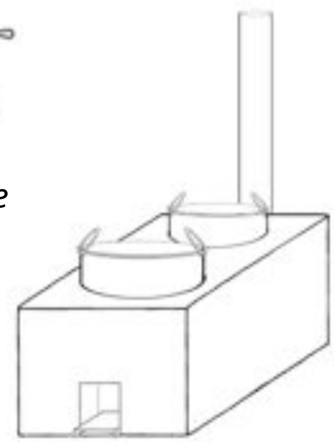
As explained in the Design Principles chapter, both combustion efficiency and heat transfer efficiency can be optimized in cooking stoves. Getting more of the heat into the pot(s) reduces the fuel needed for cooking. Burning the wood more completely helps to reduce the harmful emissions that damage human health.

The following stove ideas demonstrate how the design principles can be incorporated in the actual stoves created by the stove committee. All three of these stove designs use chimneys to protect cooks from harmful emissions. The Baldwin stove has improved heat transfer efficiency, but does not have an insulated combustion chamber . The other two stoves have improved heat transfer and insulated combustion chambers. This kind of stove is called a Rocket. The Rocket stoves produce less smoke than the Baldwin stove, but are more difficult to make.

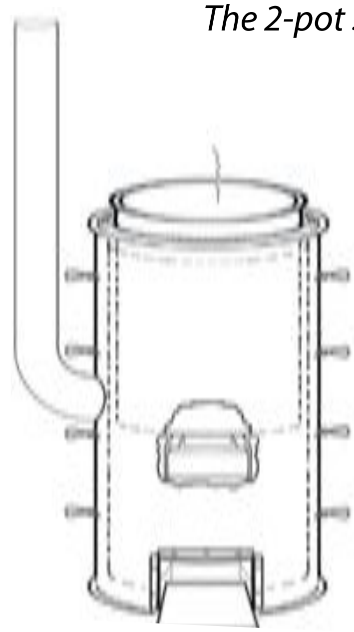
Reviewing these stove suggestions gives the stove committee a better idea of the options and strategies available to them. It is important to make sure that the stove that is built pleases the cook.



The Baldwin Stove



The 2-pot Stove



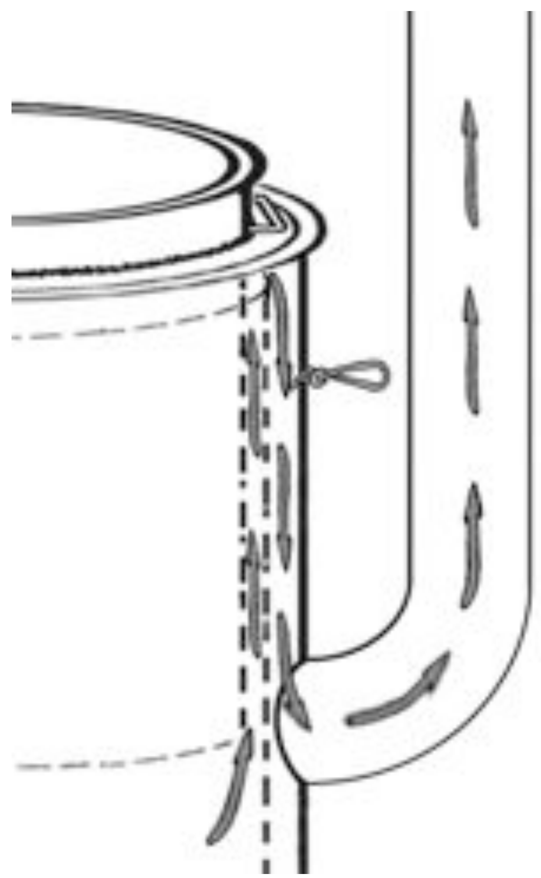
The Rocket Stove

The Baldwin Stove

Larger pots have greater surface area exposed to hot gases compared to smaller pots. Using a larger pot with a lid means that both less wood and fewer harmful emissions are made when cooking. Each liter of food is made more effectively in larger institutional sized stoves.

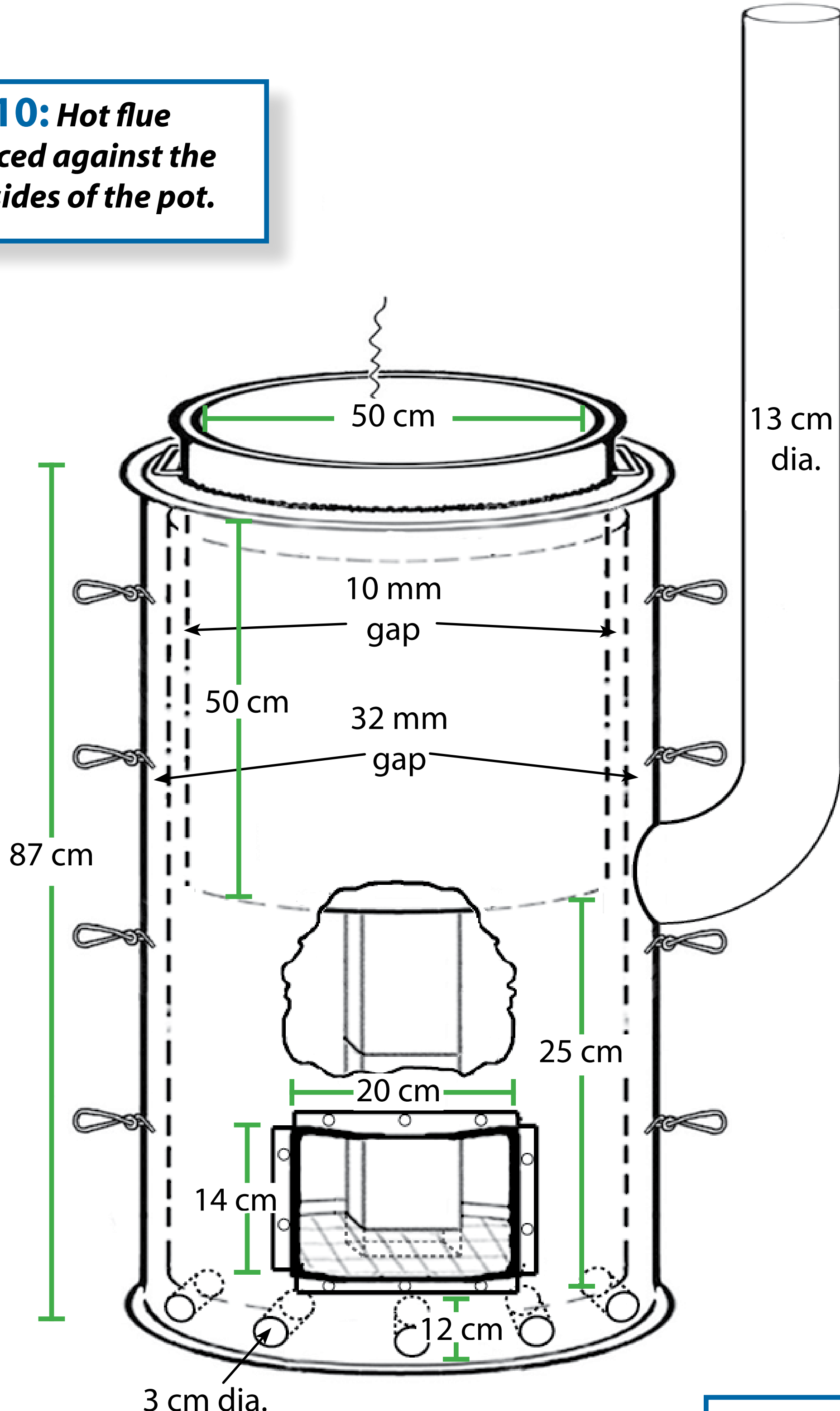
The chimney is attached to the Baldwin stove using a technique that forces the heat to flow against the sides of the pot. The heat then passes down in another channel that leads to the chimney. In this way, adding a chimney does not affect the heat transfer to the pot. It is highly recommended that the Baldwin stove be built with a chimney. Chimneys have protected cooks and families for more than one hundred years. If the stove and chimney do not leak, essentially all of the dangerous emissions are drawn out of the kitchen.

Of course, it is necessary to clean the chimney whenever it becomes dirty. If the deposits block enough of the chimney, the hot gases cannot pass up and out of the kitchen. Dirty dangerous air is then breathed in by the cooks, causing disease and possibly shortening life.



Heat is forced to flow against the sides of the pot before passing down the outer channel and out the chimney.

Principle 10: ***Hot flue gases are forced against the bottom and sides of the pot.***



Principle 6: ***Primary air is pre-heated by entering from below the combustion chamber.***

Principle 9: ***A metal grate holds fuel off of the ground.***

Principle 8: ***Constant cross sectional area is maintained throughout the stove***

The Baldwin Stove

Instructions for Building

Materials Needed:

Tools - such as tin snips to cut the metal, a drill or punch to start holes.

Two large pieces of sheet metal and sheet metal for top and bottom.

Cloth or cardboard

Steel bars or thick wire

Cooking pot to be used

Bolts or wire

Screws

Chimney

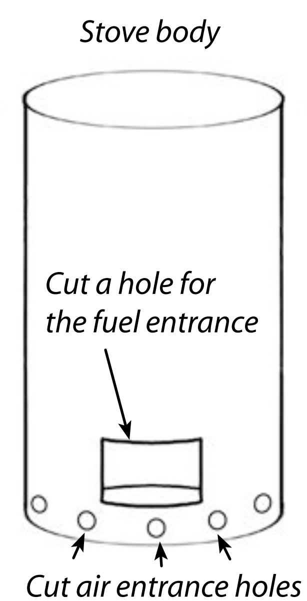
Steel pipe

Step 1

Make the outside of the stove from a large piece of sheet metal. The diameter of the stove body should be equal to the diameter of the pot plus 8.4 cm to account for the channels that direct the flue gases up past the pot and down into the chimney.

Cut a hole in the stove body to make the fuel entrance. The fuel entrance is 20 cm by 14 cm. It is 12 cm above the bottom.

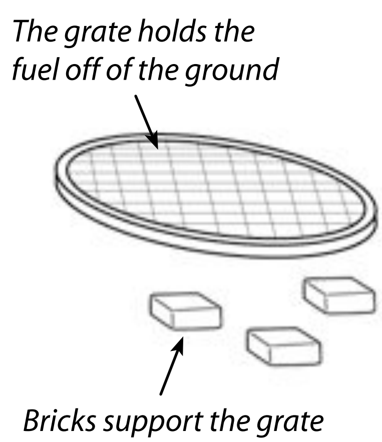
Cut 12 equidistant holes that each hold a 3 cm in diameter pipe in the stove body below the level of the grate. Air will enter the stove through these holes.



Step 2

A grate is made from locally available material. Make sure that the holes are less than 2 cm so the coals do not fall down too easily below the grate. A grate can be made from steel bars or thick wire.

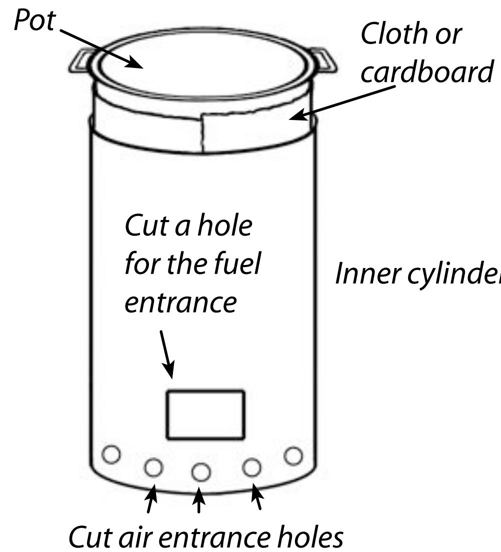
12 cm high bricks hold the grate up level with the bottom of the fuel entrance.



Step 3

Wrap a 10 mm thick piece of cloth or cardboard around the pot. Make the inner cylinder of sheet metal the right size by wrapping it around the pot covered by the cardboard wrapping. The inner cylinder is 20 mm shorter than the stove body.

Cut a hole in the inner cylinder to make the fuel entrance. The fuel entrance is 20 cm by 14 cm. It is 12 cm above the bottom. Cut 12 equidistant holes that each hold 3 cm in diameter pipes in the inner cylinder below the level of the grate.

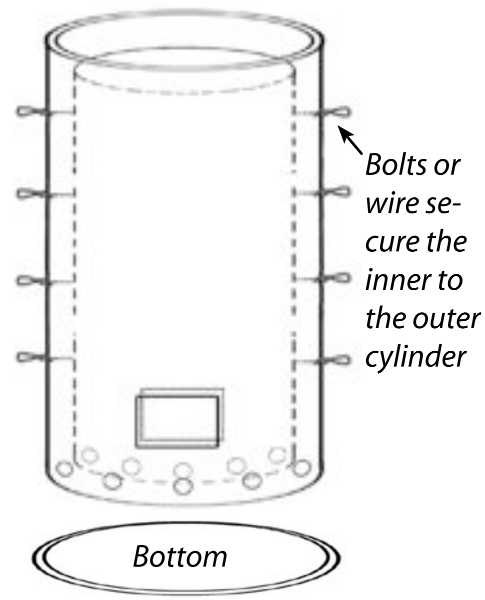


Step 4

Place the inner cylinder inside the stove body. The inner cylinder is secured inside the body of the stove with bolts or pieces of wire.

There is a 32 mm gap between the inner cylinder and the outer cylinder. The outer gap is greater than the inner gap to create equal cross sectional area between the chimney and the inner cylinder.

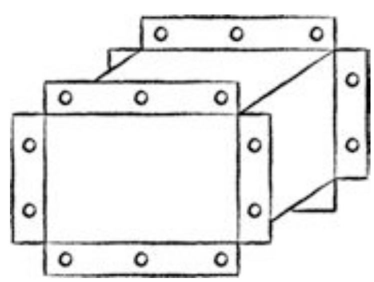
Wire or bolts hold the inner cylinder in place, making sure that an even gap is created all around the inside. Add a bottom to the stove body if necessary.



Step 5

The inner cylinder is now inside the outer cylinder. A piece of sheet metal is cut to fill the open space between the fuel entrances in the inner and outer cylinders. Screw the piece in place.

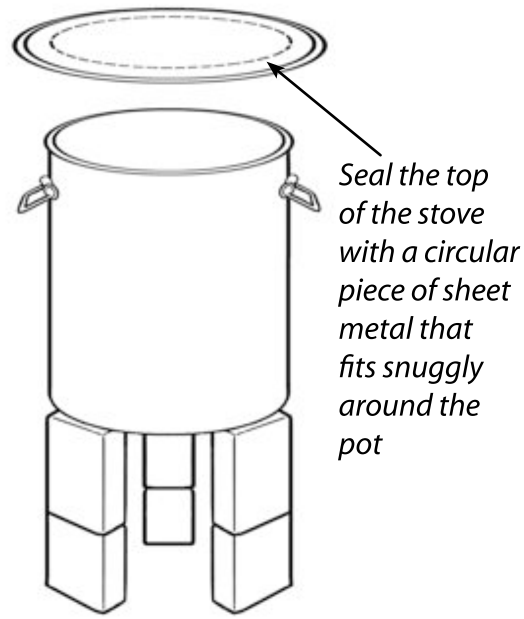
Insert and fasten the 12 pipes that bring air into the fire under the grate.



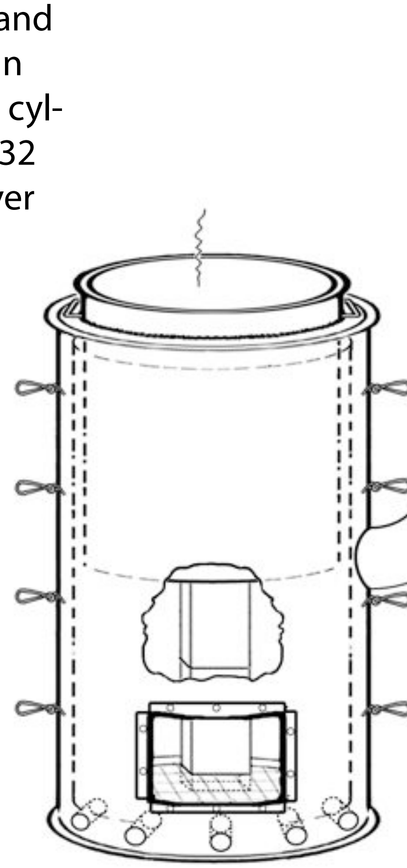
Step 6

The pot is held up on well made, heavy fired clay-bricks. The pot should be 25 cm above the grate.

The top of the stove fits very tightly around the pot. By sealing the top of the stove, the smoke and hot gases do not go into the room but instead go up the chimney. Cut the hole in the top carefully to make a good seal. The top seals around the pot under the handles.



The large Baldwin stove demonstrates how the heat from a fire can be forced to enter the pot. This reduces fuel use. Having only the waste heat leave the stove is a good technique. In this way, a chimney can take all of the smoke out of the kitchen without increasing wood use. The chimney is attached to the outer body of the stove. The fire and hot gases are forced to scrape against the pot in the 10 mm gap between the pot and the inner cylinder. Then the hot gases flow down the outer 32 mm gap to the chimney. In this way, only leftover heat leaves the stove.



The 2-Pot Stove

Adding a second pot to a stove is helpful because the extra heat that passes the first pot can be used to warm food in a second pot. However, if the first pot uses most of the heat, then not enough is left over to boil water in the second pot. If it is necessary for the second pot to boil, a helpful rule of thumb is that the second pot should hold about half as much water as the first pot.

It is important to improve the entire system in a cooking stove by following the design principles. In an improved cooking stove, an insulated short "chimney" directly above the fire delivers very hot flue gases at a high velocity to the first cooking pot. The leftover heat then travels through an insulated tunnel or passageway that maintains a constant cross sectional area equal to the size of the 'chimney' above the fire. Hot flue gases are forced to scrape against the first and second pot before exiting out of the chimney.

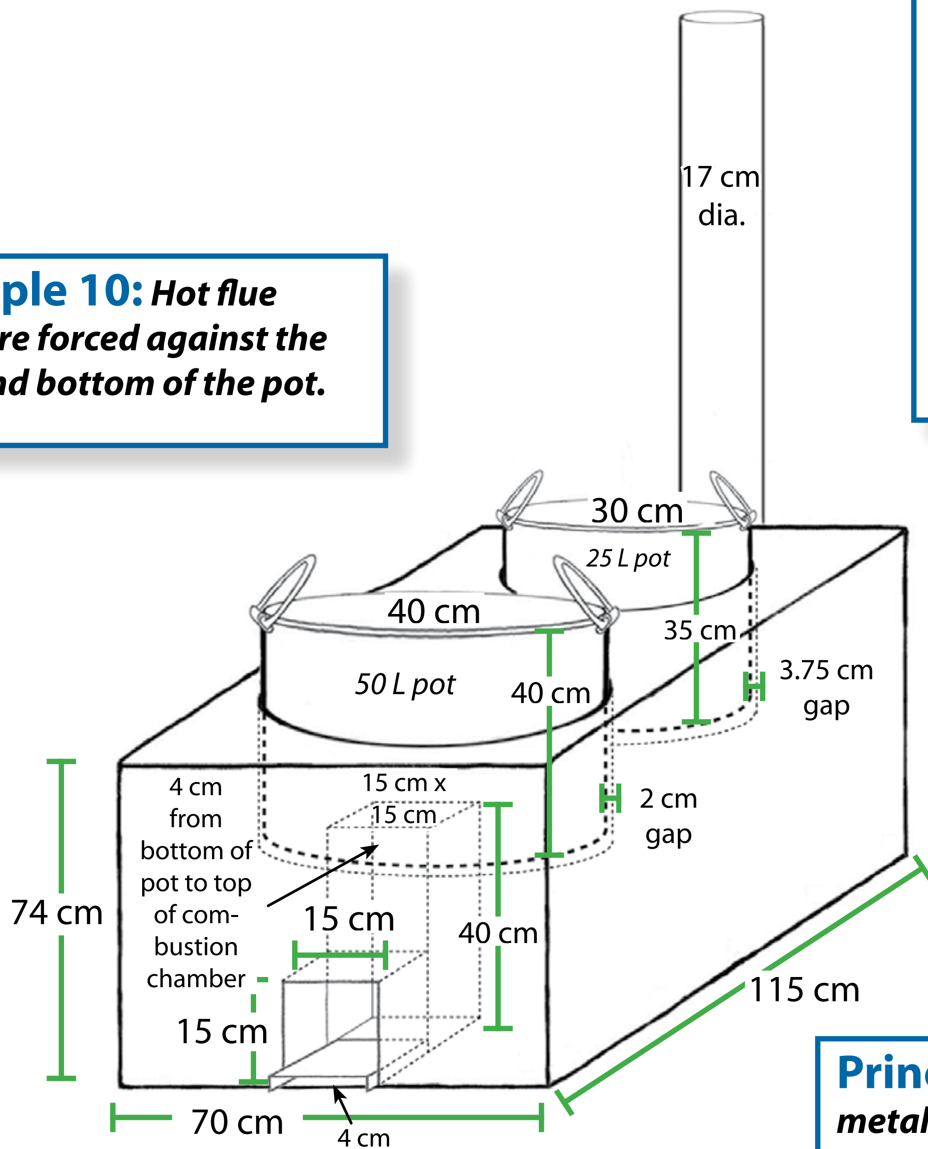
Both combustion and heat transfer efficiency are improved by increasing the speed of the hot flue gases. In this arrangement slowing draft is detrimental. Low exit temperatures in the chimney are the result of the best possible heat transfer to the pots, not slowing draft by reducing the size of the spaces that brings the hot gases to the chimney.

Stoves with chimneys can remove the smoke from the kitchen. Wood burning heating stoves can burn large amounts of wood without adding to indoor air pollution. It is only necessary to remove all incomplete products of combustion out of the chimney for a stove to protect the health of the family.

Some stoves with chimneys have too little draft so that smoke can exit out of the fuel entrance. Backdrafting out of the fuel entrance often results in unacceptable levels of indoor air pollution.

Principle 3: ***The combustion chamber is a small internal chimney made from insulative refractory bricks.***

Principle 10: ***Hot flue gases are forced against the sides and bottom of the pot.***



Principle 9: ***A metal shelf holds fuel off of the ground.***

Principle 1: ***The combustion chamber is surrounded by light weight insulative material.***

Principle 6: ***Primary air is pre-heated by entering from below the combustion chamber.***

The 2-Pot Stove

Instructions for Building

The two pot stove has an insulated combustion chamber that includes a short chimney above the fire. The hot flue gases flow very close to the bottom and sides of the first pot before going through an insulated tunnel. This extra heat is then used to warm a smaller second pot. In this type of stove, the bigger first pot is usually used for boiling while the second pot provides a moderate amount of heat.

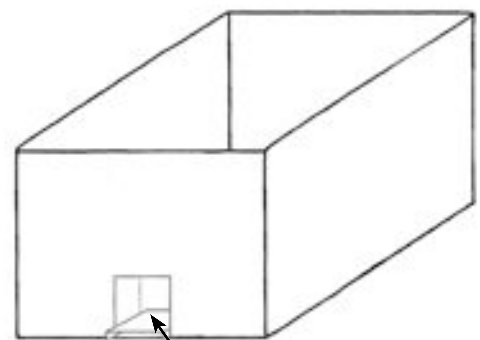
Materials Needed:

Tools - Saw, brick laying tools, tin snips

Stove Body - Regular clay bricks, cement mortar, insulative refractory bricks, chimney, sheet metal, screws and bolts, angle iron

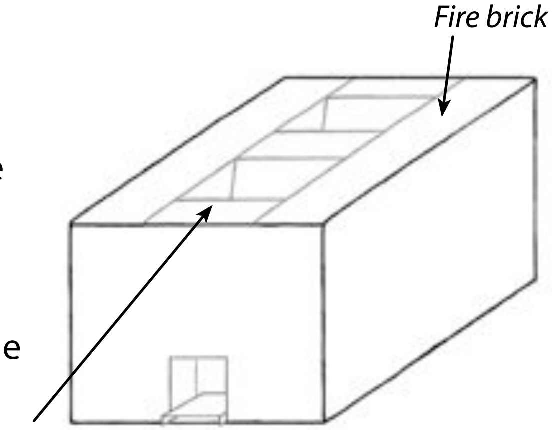
Step 1

A box is made, usually from sheet metal and angle iron. A fuel entrance in the front of the stove is cut to fit the combustion chamber. The fuel entrance is 15 cm x 15 cm with a sheet metal shelf that sits 4 cm off of the bottom of the stove.



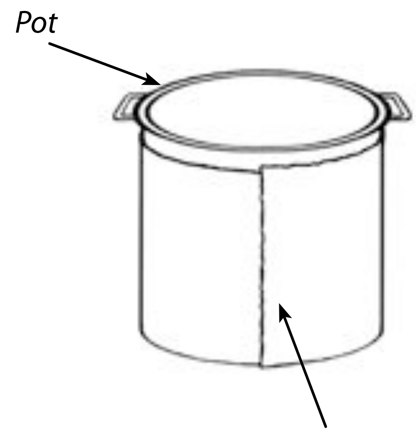
Step 2

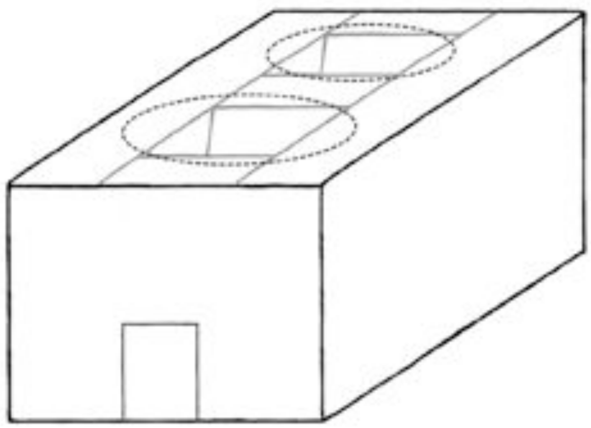
The box is partially filled with purchased or locally made lightweight fire brick (less than 0.8g/cc). See chapter 6 "Options for Combustion Chambers" for recipes. The fire brick insulates around the fire and throughout the stove. Combustion will take place under the first pot in the first enclosure, nearest the fuel entrance.

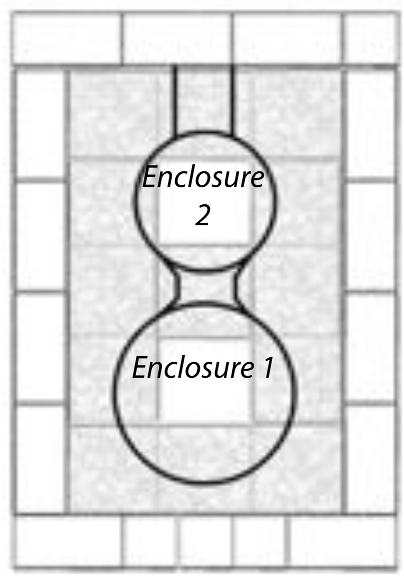


Step 3

2 cm of cardboard or newspaper is wrapped around the first pot. The second pot needs to be wrapped with 3.75 cm of cardboard or newspaper. The pots are then placed above the enclosures in the stove and two circles are drawn onto the top of the fire brick. The size of the surrounding gaps will alwahs depend on the size of the pots being used







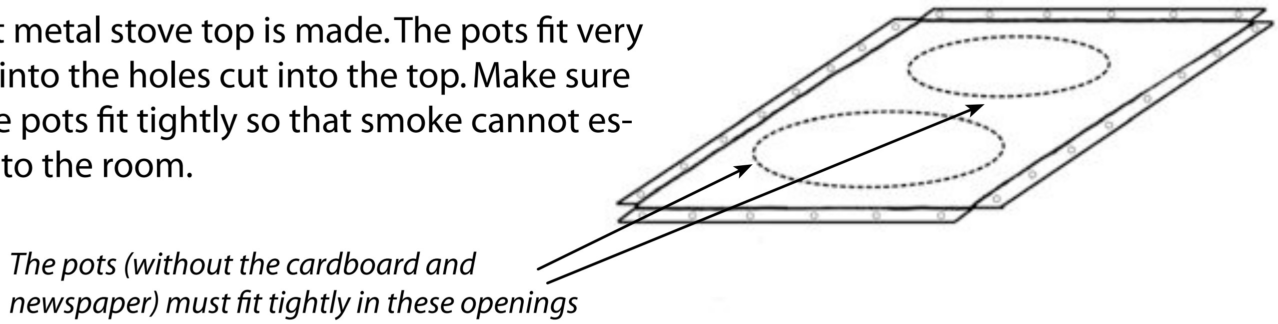
15 cm x 15 cm tunnels connect the two enclosures and the chimney

Step 4

Two cylindrical holes are carved into the soft firebrick. The diameter of the first hole is 4 cm larger than the pot and 4 cm deeper than the pot. The diameter of the second hole is 7.5 cm larger than the second pot and 3.75 cm deeper than the pot. A 15 cm x 15 cm tunnel is cut through the fire brick to connect the 1st and 2nd enclosures. Both ends of the tunnel must be beveled to allow for unobstructed passage of the hot gases. Another 15 cm x 15 cm tunnel is cut to connect the 2nd enclosure to the chimney. Both tunnels should maintain the same cross sectional area as the fuel entrance and the chimney above the fire.

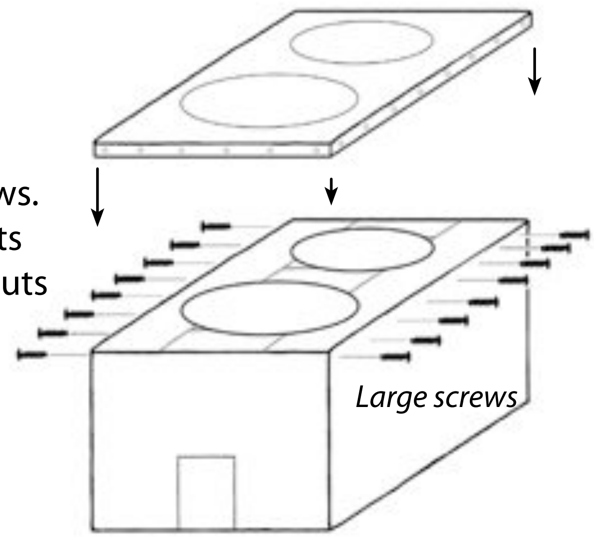
Step 5

A sheet metal stove top is made. The pots fit very tightly into the holes cut into the top. Make sure that the pots fit tightly so that smoke cannot escape into the room.



Step 6

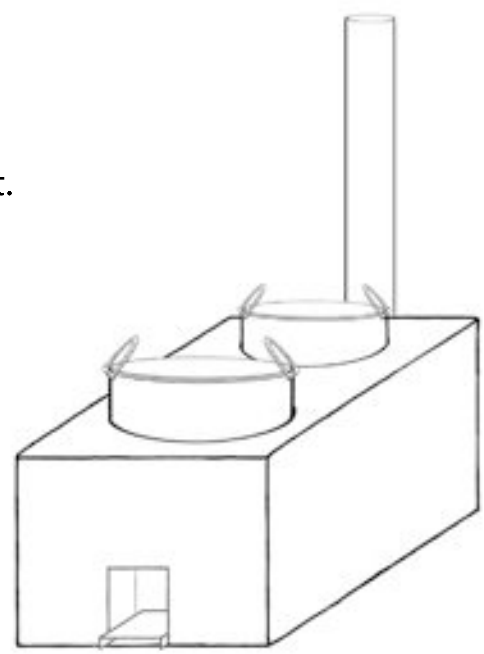
The top is attached to the stove using large screws. Make sure that the top is strongly connected. Pots will be pulled out of the stove every day which puts stress on the fasteners.



Step 7

A chimney is connected to the back of the stove. The chimney should have the same cross sectional area as the other spaces within the stove.

Light the stove and determine if there is good draft. If the draft seems slow, open up the spaces within the stove until the fire is hot and jumpy. Make sure that there is at least 4 cm between the top of the combustion chamber and the bottom of the first pot.



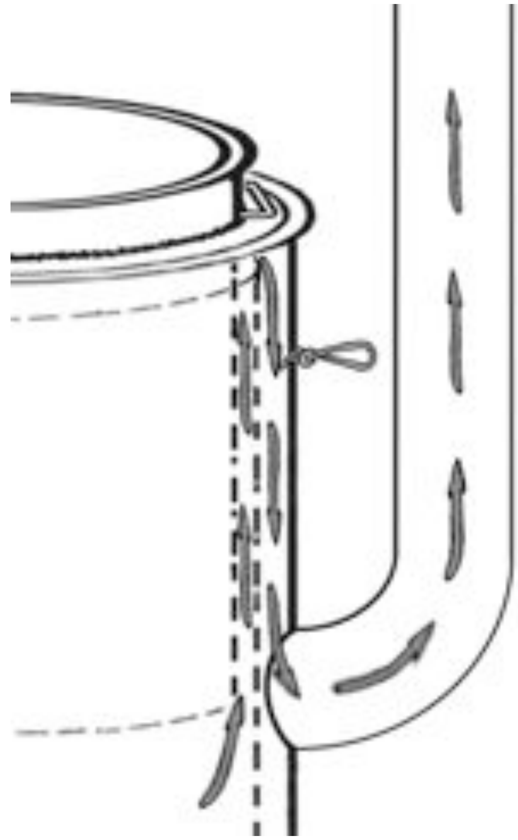
The Rocket Stove

Designed by Dr. Larry Winiarski

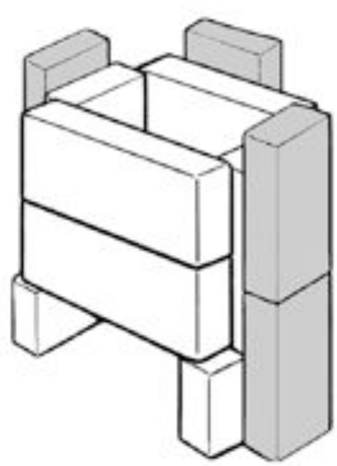
The institutional Rocket stove combines the same strategies that increase heat transfer in the Baldwin stove while adding an insulated combustion chamber for cleaner burning. A cylinder surrounds the larger pot creating a 1.75 cm gap that directs hot gases to flow next to the pot. Larger pots have more surface area so greater amounts of heat pass into the food. In fact, using larger pots decreases the amount of fuel used per liter of food made and helps to reduce the emissions when cooking larger meals.

The drawing shows how the hot gases are forced to flow down another gap on the outside of the inner cylinder (as in the Baldwin stove). In this way, adding a chimney to the stove does not increase fuel use. The hot gases have passed most of the heat to the pot before exiting out of the chimney.

The light weight bricks used in the institutional rocket stove insulate the area directly around and above the fire. The fuel wood burns more completely, reducing harmful emissions, because the flame and smoke are forced to mix. Mixing helps to burn up the smoke. The stove in the following drawings can handle pots up to 100 liters.

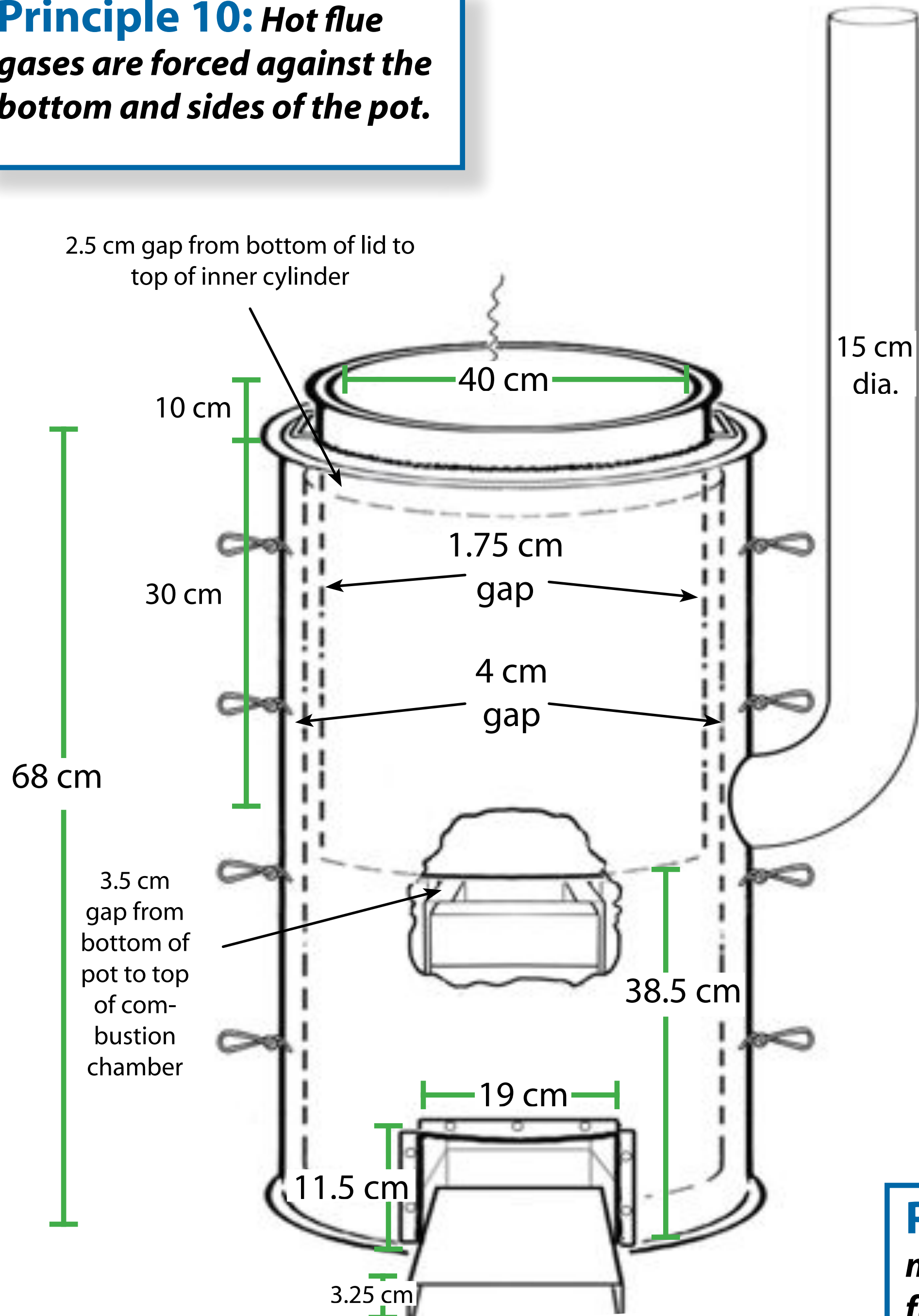


As with the Baldwin stove, the hot gases are forced to scrape against the bottom and sides of the pot before passing down the outer channel and out the chimney.



An insulated combustion chamber made from light weight refractory bricks helps to reduce harmful emissions.

Principle 10: ***Hot flue gases are forced against the bottom and sides of the pot.***



Principle 8: ***Constant cross sectional area is maintained throughout the stove.***

Principle 3: ***The combustion chamber is a small internal chimney that increases draft.***

Principle 9: ***A metal shelf holds fuel off of the ground.***

Principle 1: ***The combustion chamber is surrounded by light weight insulative material.***

Principle 6: ***Primary air is pre-heated by entering from below the combustion chamber.***

The Rocket Stove

Instructions for Building

Materials Needed:

Tools - tin snips to cut the metal, a drill or punch to start holes.

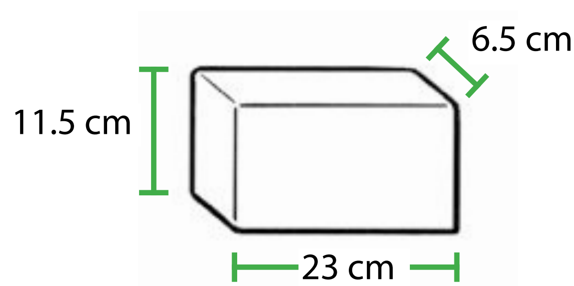
Two large pieces of sheet metal, and sheet metal for top and bottom.

Combustion Chamber - refractory light weight bricks that can be purchased or made (see Chapter 6 p. 49 for instructions). Six dense bricks used for construction hold up the pot. One heavy brick protects the back of the combustion chamber from abrasion.

The Combustion Chamber

Step 1

The insulative bricks used are 23 cm x 11.5 cm x 6.5 cm in size. The brick in back of the combustion chamber is a heavy ceramic brick which is 19 cm x 11.5 x 6 cm. The heavy brick will not be damaged by sticks hitting the surface.

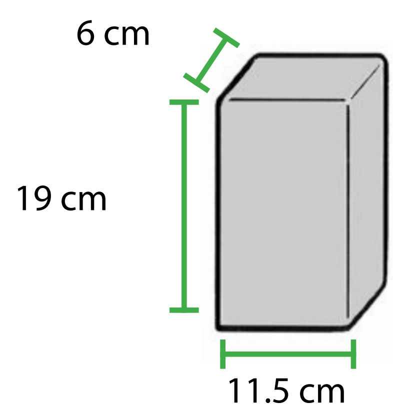


Insulative "lightweight" ceramic bricks

Except for the one heavy brick, most of the bricks used in the combustion chamber are lightweight insulative ceramic bricks. The inside of the combustion chamber is 34.5 cm tall, 19 cm wide, and 11.5 cm deep.

Step 2

Six heavier bricks are used as pot supports. The pot cannot rest on the lightweight insulative bricks because they are not strong enough to hold up a heavy pot full of water and food.

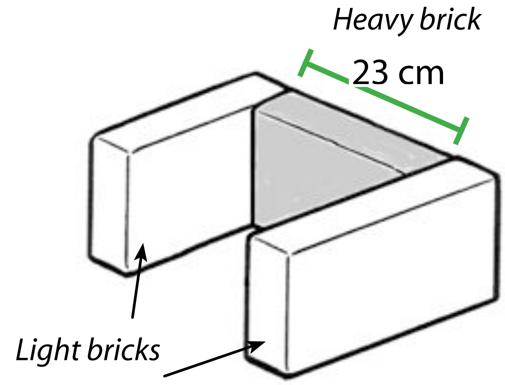


Regular "heavy" ceramic bricks

The pot supports are 38 cm high. This makes them 3.5 cm taller than the combustion chamber.

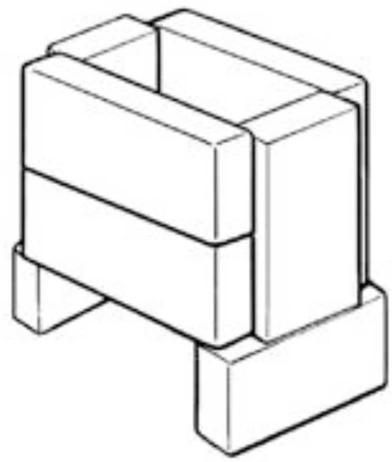
Step 3

Place the heavy brick as shown between two of the insulative bricks. This heavy brick is used so that sticks pushed in will not cause damage to the back of the combustion chamber.



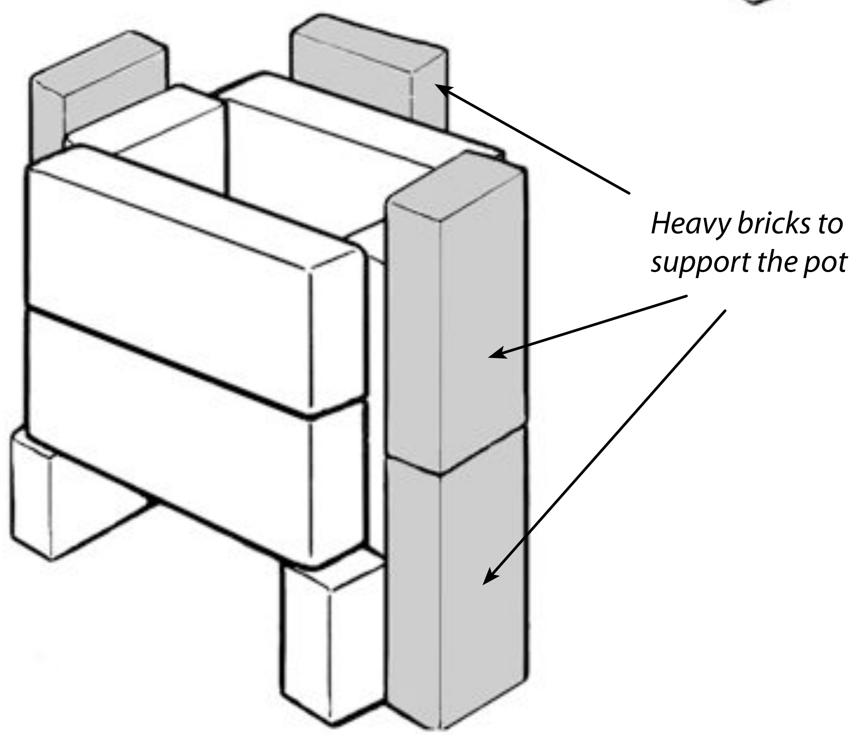
Step 4

Arrange the remaining six lightweight bricks on top of the three lower bricks as shown in the drawing.



Step 5

Using the remaining heavy bricks construct the three columns around the combustion chamber that will support the weight of the pot.



Finished combustion chamber using all 11 bricks

The Stove Body

Step 6

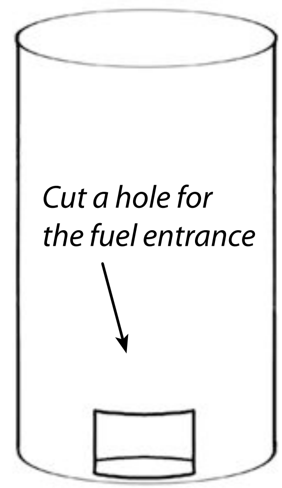
Cut a hole for the fuel entrance that will line up with the lower opening in the combustion chamber. The hole should measure 19 x 11.5 cm.

The combustion chamber with pot supports is 38 cm high. The pot should be submerged 30 cm into the open cylinder (up to the handles).

In this example, the outside of the stove body is 68 cm high. This leaves room for a distance of 3.5 cm between the combustion chamber and the pot. Depending on the pot used, your stove will have different dimensions.

The inner sheet metal cylinder creates a 1.75 cm gap all around the pot.

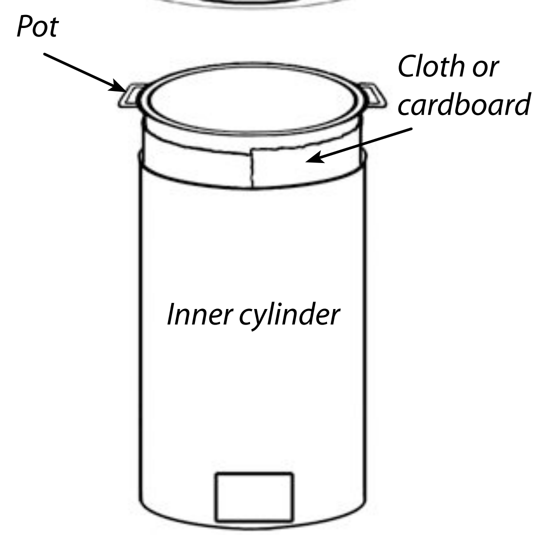
Stove body



Step 7

The inner cylinder is made by wrapping 1.75 cm of cloth or paper around the pot. The sheet metal fits over the paper or cloth. A 19 x 11.5 cm opening is cut into the cylinder that lines up with the hole cut into the stove body. The top of the inner cylindar should be 2.5 cm below the top of the outer body of the stove.

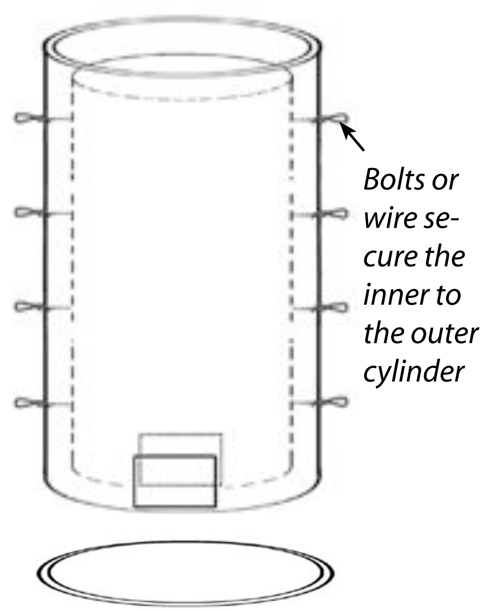
There must be at least a 4 cm gap between the inner cylinder and the inside of the stove body.



Step 8

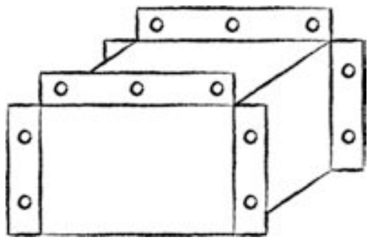
The inner cylinder is secured inside the stove body with bolts or pieces of wire. The connections create an even gap between the outside of the inner cylinder and the inside of the stove body. Use as many connections as needed to create a secure even gap.

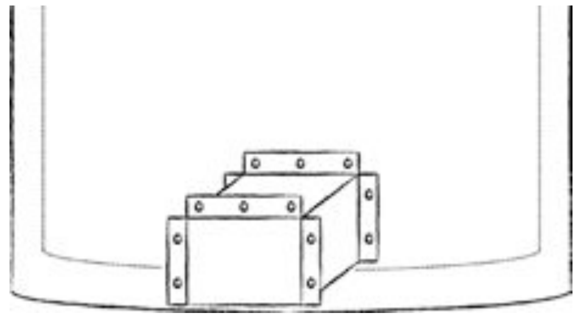
Cut a circular piece of sheet metal and secure it to the bottom of the stove



Step 9

A piece of sheet metal is now cut to fill the open space between the inner cylinder and the stove body. Screw the piece in place.





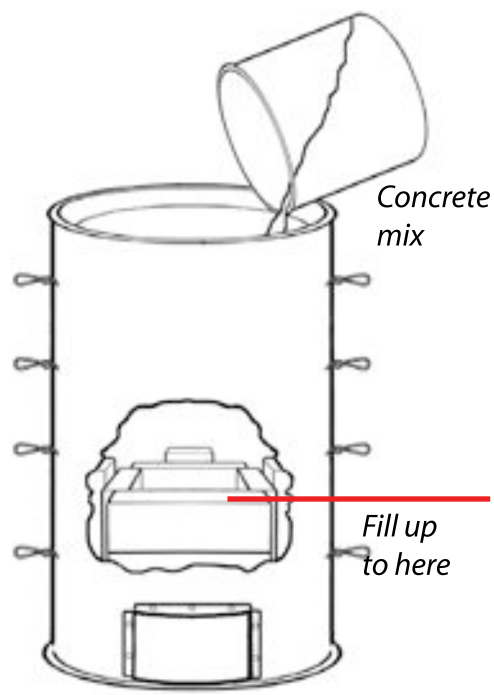
Step 10

Mix together enough concrete to fill between the outside of the combustion chamber and the inside of the inner cylinder. The cement secures the combustion chamber in place. A strong recipe for making concrete is:

1 part sharp sand
2 parts cement
3 parts coarse gravel

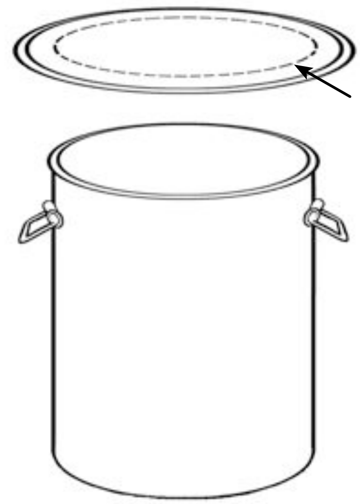
Mix the dry ingredients together and then add water. Do not make the concrete mix too wet or "soupy".

Fill up to the top of the outside of the combustion chamber made from lightweight bricks. The tops of the pot supports made from heavy brick are 3.5 cm higher than the cement.



Step 6

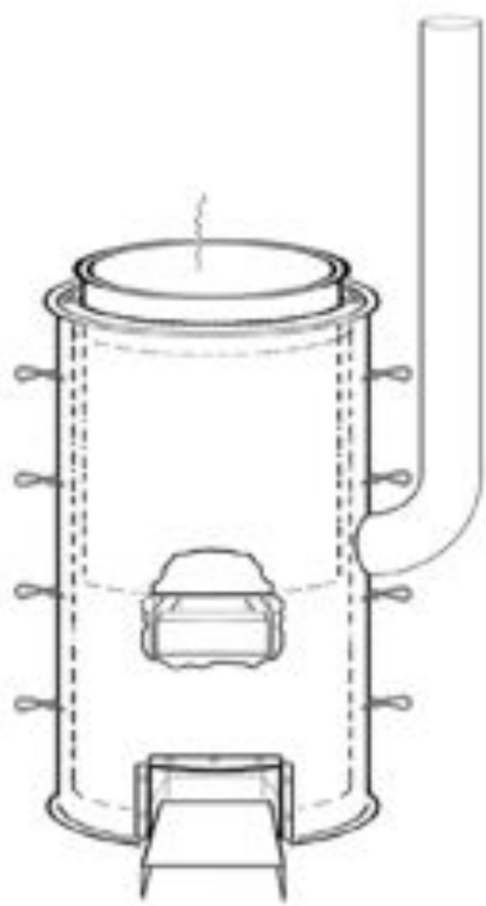
Cut out a top for the stove that fits tightly around the pot and also seals around the stove body so that smoke cannot escape. Since the smoke cannot leak out of the top of the stove, it is forced down the outer gap between the inner cylinder and the stove body, where it exits out of the chimney.



Seal the top of the stove with a circular piece of sheet metal that fits snuggly under the handles of the pot

Step 7

A 15 cm in diameter chimney is attached to the outer body of the stove. The fire and hot gases are first forced to scrape against the bottom of the pot in the 3.5 cm gap above the combustion chamber. The hot gases then pass upward through the 1.75 cm gap between the pot and the inner cylinder. Finally, the hot gases flow downward to the chimney in the 4 cm gap between the inner cylinder and the inside of the stove body.



Chapter 4

Retained Heat Cookers

A retained heat cooker ("haybox") is an insulated, air tight enclosure that a pot of food can be placed into after being brought to a boil. The food in the pot will stay hot enough in the container to finish cooking the food. The simmering process is done without needing to continuously feed a stove or watch over the food to prevent scorching.

Fireless cooking is an age-old idea that has been used by people all over the world to save fuel. Hayboxes can be made in many ways. The insulation traps heat inside the pot and the hot air cannot escape. Much less fuel is then needed to cook the food.

Retained heat cookers are:

- **Efficient-** Can reduce fuel consumption by up to 70%.
- **Safe-** Reduce the risk of burns and exposure to smoke due to shortened cooking time on the stove.
- **Convenient-** Food does not burn, stick, or boil over. The food can even have more flavor from the slow cooking process.
- **Simple-** Can be constructed almost anywhere in the world with locally available materials.

Retained heat cookers are well suited for institutional feeding. They are more effective when cooking large amounts of food. It is the mass of the food and water that stores the heat needed to cook.

The following are key steps for designing and constructing a retained heat cooker.

Step 1 Insulate

Find some type of insulative material to use. Any very light weight material which consists of small isolated pockets of air will insulate well. The trapped air acts as a barrier to heat loss. Lots of materials make great insulators. Straw, wood ash, feathers, raw cotton, or wood shavings work well as long as they are kept dry.

Even better are materials that insulate when wet, such as: wool, fur, rigid foam, and styrofoam peanuts.

Step 2 Stop Air Leaks

Make the container as air tight as possible. Choose a pot with a tight fitting lid as well as one that will fit snugly into the cooker. If the pot is smaller than the cooker, place an extra pillow of insulation around the pot.

Step 3 Keep The Insulation Dry

Place a moisture barrier between the pot and the insulation. Use materials like plastic, metal or waxy cloth. If the insulation does become damp after cooking, be sure to dry it out between uses.

Preparing food with a retained heat cooker

Place food (pre-soaked if applicable) in a pot with approximately 1/3 less water than you would use for conventional cooking. Put the pot on a stove and bring to a rolling boil. Boil the food for a short time (usually between 5 - 10 minutes). Secure a tight fitting lid on the pot, quickly remove it from the stove, and place it in the retained heat cooker (see illustration at bottom of page).

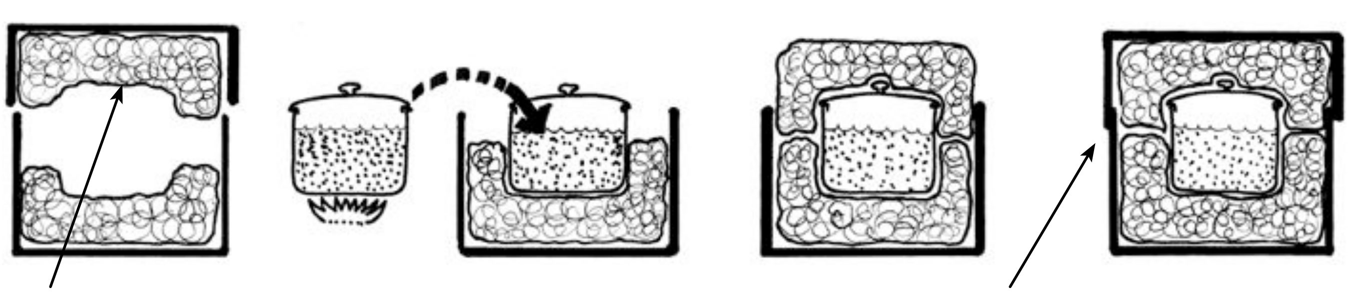
Do not open the cooker during the cooking period. Depending on the density of the food, retained heat cookers usually require 1.5 - 3 times as long as conventional stove top simmering to finish cooking.

After bringing food to a boil for a short time, the pot is placed in an insulated enclosed box to continue cooking with it's own retained heat.

Suggested Cooking Times:

	Time at Boil	Time in cooker
Rice	5 min.	1- 1.5 hours
Potatoes	5 min.	1- 2 hours
Soup stock	10 min.	2- 3 hours
Lentils	10 min.	3- 4 hours
Beans	10 min.	3 hours
Split peas	10 min.	2 hours
Quinoa	5 min.	1.5 hours
Millet	5 min.	1 hour
Polenta	5 min.	1 hour

Note: Soak beans overnight. Pre-soaking saves considerable time and fuel.



Insulation keeps the heat from leaving the pot too quickly.

A tight fitting lid and an enclosed box will reduce the amount of heat lost from convection

Chapter 5

Testing Your Stove

Dr. Samuel Baldwin, in his book *Biomass Stoves: Engineering Design, Development, and Dissemination,* points out that the testing of prototypes is necessary while the stove is being developed. Testing stoves also helps to determine if the model is marketable, whether production costs are as low as possible, and if improvements are needed. This information can be very useful to project partners and organizations who are involved in funding stove projects. Testing gives organizers necessary information during the entire life of a stove project.

Careful testing of stoves over the years has resulted in a more accurate understanding of how to make better stoves. Without experimentation and testing, the development of a stove can take a lot longer. Careful analysis quickly separates truth from opinion. Testing has a twofold function: to identify problems and to point out solutions. It is an essential ingredient for progress.

A simple water boiling test is included in the following pages. This test has been used to determine if stove prototypes are improved compared to traditional cooking technologies.

An In Field Water Boiling Test

This test provides the stove designer with reliable information about the performance of wood burning stove models. The test consists of three phases that determine the stove's ability to:

1. Bring water to a boil from a cold start;
2. Bring water to a boil when the stove is hot; and,
3. Maintain the water at simmering temperatures.

It is used to evaluate a series of stoves as they are being developed. The test cannot be used to compare stoves from different places because the different pots and wood used change the results.

The test is a simplified version of the University of California Berkeley (UCB)/Shell Foundation revision of the 1985 Baldwin International Standard Water Boiling Test. The wood used for boiling and simmering, and the time to boil are found by simple subtraction. All calculation can be done by hand in the field.

By using a standard pot, and taking into account the moisture content of the wood, steam generated, and other factors, the complete UCB/Shell Foundation Water Boiling Test (WBT) makes comparison of stoves from different places possible.

Before starting the tests:

1. Collect at least 30 kg of air-dried fuel for each stove to be tested in order to ensure that there is enough fuel to complete three tests for each stove. Massive multi-pot stoves may require more fuel. Use equally dry wood that is the same size. Do not use green wood.
2. Put 5 liters of water in the testing pot and bring it to a rolling boil. Make sure that the fire is very powerful, and the water is furiously boiling. Use an accurate digital thermometer, accurate to 1/10 of a degree, to measure the local boiling temperature. Put the thermometer probe in the center of the testing pot, 5 cm above the pot bottom. RECORD the local boiling point on the data sheet.
3. Do the tests in a place that is completely protected from the wind.
4. Record all results on the data sheet

Equipment used for the In Field Water Boiling Test:

- Scale of at least 6 kg capacity and 1 gram accuracy
- Heat resistant pad to protect scale
- Digital thermometer, accurate to 1/10 of a degree, with thermocouple probes that can be in liquids
- Timer
- Testing pot(s)
- Wood fixture for holding thermometer probe in water
- Small shovel/spatula to remove charcoal from stove

Beginning of Test

a. RECORD the air temperature.

b. RECORD weight of commonly used pot without lid. If more than one pot is used, record the weight of each pot. If the weights differ, be sure not to confuse the pots as the test proceeds. Do not use pot lids for this, or for any other phase of the WBT.

c. RECORD weight of container for charcoal.

d. Prepare 2 bundles of fuel wood that weigh about 2 kilos each for the cold and hot start high power tests. Prepare 1 bundle of fuel wood that weighs about 5 kilos to be used in the simmering test. Use sticks of wood roughly the same size for all tests. Weigh and RECORD weights. Identify each bundle and keep them separate.

High Power (Cold Start) Phase:

1. Fill each pot with 5 liters of cold clean water. RECORD the weight of pot(s) and water.
2. RECORD the water temperature.
3. Using the wooden fixtures, place a thermometer probe in each pot so that water temperature may be measured in the center, 5 cm from the bottom. Make sure a digital thermometer is used.
4. The stove should be at room temperature. Start the fire. RECORD the weight of the starting materials. Always use the same amount and material.
5. Use the wood from the first 2 kilo bundle.
6. Once the fire has caught, start the timer. RECORD the starting time. Bring the first pot rapidly to a boil without being excessively wasteful of fuel.
7. When the water in the first pot reaches the local boiling temperature as shown by the digital thermometer, rapidly do the following:

   a. RECORD the time at which the water in the primary pot (Pot # 1) reaches the local boiling point of water. RECORD this temperature for other pots as well.

   b. Remove all wood from the stove and put out the flames. Knock all loose charcoal from the ends of the wood into the tray for weighing charcoal.

   c. Weigh the unburned wood from the stove together with the remaining wood from the preweighed bundle. RECORD the result.

d. For multi-pot stoves, measure the water temperature from each pot (the primary pot should be at the boiling point). RECORD the temperatures.

e. Weigh each pot, with its water. RECORD weight.

f. Remove all the charcoal from the stove, place it with the charcoal that was knocked off the sticks and weigh it. RECORD the weight of the charcoal and container.

This completes the high power (cold start) phase. Continue without pause to the high power (hot start) portion of the test. Do not allow the stove to cool.

High Power (Hot Start) Phase:

1. Refill the pot with 5 liters of fresh cold water. Weigh pot (with water) and measure the initial water temperature; RECORD both measurements. For multi-pot stoves, fill the additional pots, weigh them and record their weights.

2. Rekindle the fire using kindling and wood from the second 2 kilo bundle. RECORD weight of any additional starting materials.

3. RECORD the time when the fire starts and bring the first pot rapidly to a boil without being excessively wasteful of fuel.

4. RECORD the time at which the first pot reaches the local boiling point. RECORD the temperature of any other pots.

5. After reaching the boiling temperature, rapidly do the following:

   a. Remove all wood from the stove and knock off any loose charcoal into the charcoal container. Weigh the wood removed from the stove, together with the unused wood from the bundle. RECORD the result.

   b. Weigh each pot, with its water and RECORD the weights.

   c. RECORD the water temperature at boiling.

6. Remove all remaining charcoal from the stove and weigh it (including charcoal which was knocked off the sticks). RECORD the weight of the charcoal plus container.

Without pause, proceed directly with the simmering test.

Low Power (Simmering) Test

This portion of the test is designed to test the ability of the stove to simmer water using as little wood as possible. Use the 5 kilo bundle of wood to bring the water to boil. Then record the weight of the remaining wood and simmer the water for an additional 45 minutes.

Only the primary pot will be tested for simmering performance.

Start of Low Power Test

1. RECORD the weight of the 5 kilo bundle of fuel.
2. Refill the pot with 5 liters of cold water. Weigh the pot (with water). RECORD weight. RECORD temperature.
3. Rekindle the fire using kindling and wood from the weighed bundle. RECORD the weight of any additional starting materials. Replace the pot on the stove and RECORD the start time when the fire starts.
4. Bring the pot rapidly to a boil without being excessively wasteful of fuel. As soon as local boiling temperature is reached, do the following steps quickly and carefully:
5. RECORD the boiling time. Quickly weigh the water in the primary pot and return it to the stove. RECORD the weight of the pot with water. RECORD the weight of remaining in 5 kilo bundle. Replace the thermometer in the pot and continue with the simmer test by reducing the fire. Keep the water as close to 3 degrees below the boiling point as possible.

It is OK if the temperatures vary up and down, however;

- The tester must try to keep the simmering water as close as possible to 3° C below the local boiling point.
- The test is invalid if the temperature in the pot drops more than 6° C below the boiling temperature.
- The tester should not further split the fuel wood into smaller pieces to try to reduce power.

1. For the next 45 minutes maintain the fire at a level that keeps the water temperature as close as possible to 3 degrees C below the boiling point.
2. After 45 minutes rapidly do the following:
    a. RECORD the finish time of the test (this should be 45 minutes).
    b. Remove all wood from the stove and knock any loose charcoal into the charcoal weighing pan. Weigh the remaining wood, including the unused wood from the preweighed bundle. RECORD the weight of wood.
    c. Weigh the pot with the remaining water. RECORD the weight.
    d. Extract all remaining charcoal from the stove and weigh it (including charcoal which was knocked off the sticks). RECORD the weight of pan plus charcoal.

Data Sheet

DATE ☐ TEST NUMBER ☐ STOVE ☐

local boiling point	
air temperature	
wood dimensions	
weight pot one	
weight pot two	
weight charcoal container	Y

notes: IN FIELD WBT DATA AND CALCULATION SHEET
All spaces should be filled in.
Results from TWO and THREE should be similar.
Better stoves use less wood and make less charcoal.
Rapid boiling is usually appreciated by cooks.

BUNDLE 1 - 2kg	cold start hi power		**2 - 2kg** hot start hi power		**3 - 5kg** bring to boil		**4** simmer 45 minutes	
	begin	end	begin	end	begin	end end	begin	end
time	A	B	C	D	E	F		
weight wood	#G	H	#I	J	#K	L		M
water temp pot one								
water temp pot two								
weight pot one plus water	N	O	P	Q	R	S		T
weight pot two plus water								
weight fire starter								
weight charcoal and container		U		V				W

Calculation Sheet

Time to Boil:

_________ = B – A = Time to boil for cold start high power phase

_________ = D – C = Time to boil for hot start high power phase

_________ = F – E = Time to boil for boiling phase of simmering

Wood Use:

_________ = G – H = Wood use for cold start high power phase

_________ = I – J = Wood use for hot start high power phase

_________ = K – L = Wood use for boiling phase of simmering

_________ = L – M = Wood use for simmering phase

Water Converted to Steam:

_________ = N – O = Water lost to steam for cold start high power phase

_________ = P – Q = Water lost to steam for hot start high power phase

_________ = R – S = Water lost to steam for boiling phase of simmering

_________ = S – T = Water lost to steam during simmering phase

Charcoal Created:

_________ = U – Y = Charcoal made in cold start high power phase

_________ = V – Y = Charcoal made in hot start high power phase

_________ = W – V = Charcoal either made or consumed during the simmering phase. (If this number is positive, then additional charcoal was created during simmering, and if negative, then charcoal was consumed during the simmering phase.)

Chapter 6

Options for Combustion Chambers

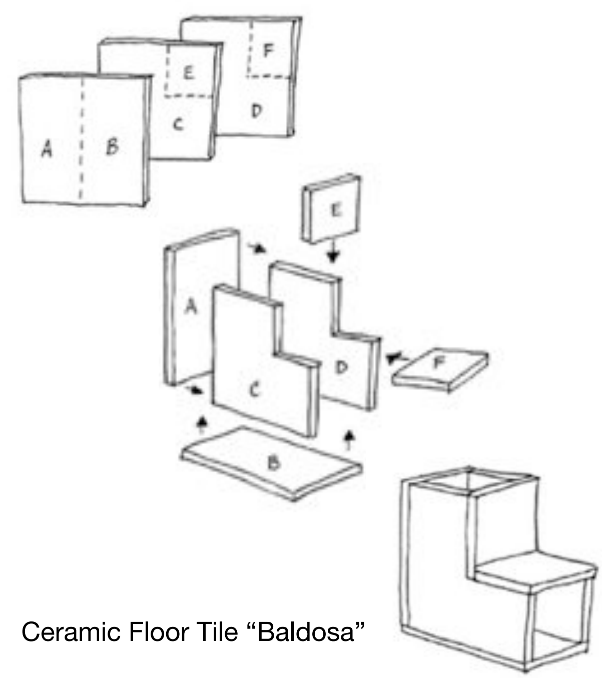
Multiple tests of the sand and clay Lorena stove, beginning in 1983, showed that placing materials with high thermal mass near the fire can have a negative effect on the responsiveness, fuel efficiency, and emissions of a cooking stove because they absorb the heat from the fire. Examples of high thermal mass materials are mud, sand, and clay. When stoves are built from high thermal mass materials, their efficiency (when tested in the laboratory) can be worse than that of the three-stone fire.

So what other materials can be used? Cleaner burning stoves can produce such high temperatures in the combustion chamber (where the fire burns) that metal, even stainless steel, can be destroyed. Cast iron combustion chambers, though longer lasting, are expensive.

While mud, sand, and clay are high in thermal mass, they do have certain benefits. They are locally available, cheap, easy to work with, and are often long lasting because they don't burn out under the intense heat produced by a fire. Creativity and good engineering allow a stove designer to use these materials advantageously without allowing their high thermal mass to degrade the quality of the stove.

Stove makers have been using ceramic parts for many years. The Thai Bucket Stove uses a ceramic combustion chamber. The Kenyan Jiko Stove also uses a ceramic liner to protect the sheet metal stove body. Books have been written describing how to make clay combustion chambers that will last for several years.** A women's co-operative in Honduras called Nueva Esperansa makes long-lasting refractory ceramic stove parts from a mixture of clay, sand, horse manure, and tree gum. These combustion chambers are used in the Doña Justa and Eco Stoves now popular in Central America.

The benefit to using ceramic combustion chambers in these instances is their longevity. As we shall see in the example



Ceramic Floor Tile "Baldosa"

* First published in Boiling Point #49

**A good book on the subject is *The Kenya Ceramic Jiko: A Manual for Stovemakers* (Hugh Allen, 1991).

below, the key to minimizing the drawback of ceramic material, which is its high thermal mass, is to use the least amount possible without compromising its strength and by surrounding it with an insulative material.

Option #1: Floor Tiles

Don O'Neal (HELPS International) and Dr. Winiarski located an alternative material in Guatemala, an inexpensive ceramic floor tile called a baldosa. The baldosa is about an inch thick and can be cut or molded into appropriate shapes to make a combustion chamber. Loose insulation fills in between the combustion chamber and the inside of the stove body. Wood ash, pumice rock, vermiculite, and perlite are all good natural heat resistant sources of loose insulation. The baldosa is inexpensive and has lasted four years in the insulated HELPS and Trees, Water and People stoves built in Central America.

The baldosa floor tile is tested by placing it in a fire until it is red hot. Then the tile is removed and quickly dipped into a bucket of cold water. If the tile doesn't crack, it will probably last in the combustion chamber. Baldosa are usually made with red clay and are fired in a kiln at around 900^0 - 1000^0C. They are somewhat porous and ring when struck with a knuckle. Using baldosa in a combustion chamber surrounded by loose insulation adds one more material option for the stove designer.

Option #2: Insulative Ceramics

These recipes are intended to assist stove promoters in making insulative ceramics for use in improved wood burning cook stoves. Each of these materials incorporates clay, which acts as a binder. The clay forms a matrix around a filler, which provides insulation. The filler can be a lightweight fireproof material (such as pumice, perlite, or vermiculite), or an organic material (charcoal or sawdust). The organic material burns away, leaving insulative air spaces in the clay matrix. In all cases, the clay and filler are mixed with a predetermined amount of water and pressed into forms (molds) to create

Table 1 - Insulative Ceramics

Type	Filler Wt. (Grams)	Clay (damp) Wt. (Grams)	Water Wt. (Grams)	Fired at (degrees C)	Density gr/cc
Sawdust	490	900	1300	1050	0.426
Charcoal	500	900	800	1050	0.671
Vermiculite	300	900	740	1050	0.732
Perlite Mix	807	900	1833	1050	0.612
Pumice Mix	1013	480	750	950	0.770

bricks. The damp bricks are allowed to dry, which may take several weeks, and then fired at temperatures commonly obtained in pottery or brick kilns in Central America.

Our test samples were made using low-fired "raku" clay obtained from a local potter's supply store. In other countries, the best source of clay would be the kind used by local potters or brick makers. Almost everywhere, people have discovered clay mixes and firing techniques, which create sturdy ceramics. Insulative ceramics need to be lightweight (low density) to provide insulation and low thermal mass. At the same time, they need to be physically durable to resist breakage and abrasion due to wood being forced into the back of the stove. These two requirements are in opposition; adding more filler to the mix will make the brick lighter and more insulative, but will also make it weaker. Adding clay will usually increase strength but makes the brick heavier. We feel that a good compromise is achieved in a brick having a density between 0.8 gm/cc and 0.4 gm/cc.

The recipes in Table 1 indicate the proportions, by weight, of various materials. We recommend these recipes as a starting point for making insulative ceramics. Variations in locally available clays and fillers will probably require adjusting these proportions to obtain the most desirable results.

Insulative ceramics used in stoves undergo repeated heating and cooling (thermal cycling), which may eventually produce tiny cracks that cause the material to crumble or break. All of these recipes seem to hold up well to thermal cycling. The only true test, however, is to install them in a stove and use them for a long period of time under actual cooking conditions.

Sawdust/Clay:
In this formulation, fine sawdust was obtained by running coarse sawdust (from a construction site) through a #8 (2.36-mm) screen. Clay was added to the water and mixed by hand to form thick mud. Sawdust was then added, and the resulting material was pressed into rectangular molds. Excellent insulative ceramics can be made using sawdust or other fine organic materials such as ground coconut husks or horse manure. The problem with this method is obtaining large volumes of suitable material for a commercial operation. Crop residues can be very difficult to break down into particles small enough to use in brick making.

This method would be a good approach in locations where there are sawmills or woodworking shops that produce large amounts of waste sawdust.

Charcoal/Clay:

In this formulation, raw charcoal (not briquettes) was reduced to a fine powder using a hammer and grinder. The resulting powder was passed through a #8 screen. Clay was hand mixed into water and the charcoal was added last. A rather runny slurry was poured into molds and allowed to dry. It was necessary to wait several days before the material dried enough that the mold could be removed. Dried bricks were fired at 1050^0C. Charcoal can be found virtually everywhere, and can be used when and where other filler materials are not available. Charcoal is much easier to reduce in size than other organic materials. Most of the charcoal will burn out of the matrix of the brick. Any charcoal that remains is both lightweight and insulative.

Charcoal/clay bricks tend to shrink more than other materials during both drying and firing. The final product seems to be lightweight and fairly durable, although full tests have not yet been run on this material.

Aprovecho Research Center
Advanced Studies in Appropriate Technology
WFP
World Food Programme
Shell Foundation
EPA United States Environmental Protection Agency
Office of Air & Radiation (6609J)
EPA-402-K-05-004