Cooking with Less Fuel: Breathing Less Smoke

Aprovecho Research Center
World Food Program, School Feeding Service (PDPF)
Environmental Protection Agency
Shell Foundation

Introduction

This manual was initially designed to help school feeding programmes use cleaner (reduced smoke emissions) and more efficient (less consumption of fuel wood) cooking stoves. Then, we realized that its contents can also be adapted and used in other settings. We encourage anyone interested and willing to improve their cooking stoves to read and use this manual. It can be used by Non Governmental Organizations (NGOs), local stove builders, School Directors and teachers, heads of households among others, to design and develop better cooking stoves; train new local stove producers; and train cooks (or regular users) on the use and maintenance of their new improved stoves. Teachers can also use this manual to teach their students, not only about the importance of eliminating indoor smoke emissions, reducing negative social and environmental impacts of fuel wood consumption and using healthier cooking practices; but most importantly, they can teach them how to make these recommendations real in their every day life.

We hope you find this publication useful and encouraging. We will be looking forward to hearing your comments and suggestions on how to make this publication even better next time.

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Chapter 1

Improved Cook Stoves

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

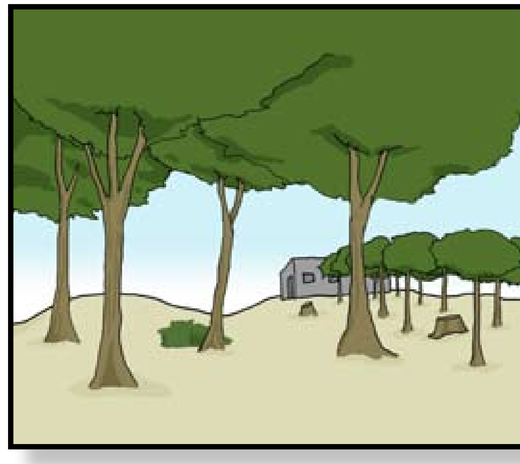
Fuel wood is wasted: If you are using a three stone open fire, or if your stove is old and has cracks, the wind can blow away most of the energy produced. This makes your stove inefficient. Cooking will take more time and it will use more fuel wood.

Local forests are under threat: Using too much fuel wood to cook contributes to forest degradation and loss of forest cover. Soils are left unprotected and are affected by wind and water erosion. Forest degradation also affects natural flora, fauna, and water cycles. As fuel wood resources disappear, women and children have to walk longer distances to find fuel wood and carry it to school.

Cooks suffer health problems: Unimproved stoves emit large amounts of smoke that is inhaled by cooks. Smoke is harmful, causing health problems such as: coughing, eye irritation, asthma, headaches, lung problems, etc. Inhaling smoke emissions from a household stove is equivalent to inhaling as many as 20 cigarettes every day. Worldwide 1.6 million people die each year from breathing wood smoke.

The advantages of an improved cook stove

- Consumes less fuel wood.
- Produces less smoke, and excess smoke is removed from the kitchen
- Facilitates better hygiene and cooking practices.
- Cooks are more comfortable and happier when cooking
- Optimizes cooking time so cooks can take care of other activities



Improved cook stoves save fuel wood (average 60%) so local forests may be conserved.

Wood is the main source of energy for families and schools in rural areas.

Women and children gather less wood from local forests.

Cooks can choose the type of stove that best suits their needs.

What constitutes 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 in terms of less smoke production), and more pleasant to the cook. Obviously, 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 improved stove can please the cook while using less fuel and reducing smoke 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 old stove.
- Uses 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. The ideal situation is to first design and develop a prototype model stove which can be field tested in one or two pilot schools, homes, or wherever the stove will be used. The stoves can be tested to make sure they meet all the required criteria before building and installing them in more schools/homes, or other places within the country.

Who should participate?

It is a good idea to form a stove design committee consisting of the people who will be using the stove. The committee should at least 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 should then work with local crafts people together creating the experimental stoves. These experimental stoves will then need to be used and evaluated. The last chapter "Testing Your Stove" contains simple tests the stove design committee can use to evaluate stove performance. Eventually a suitable stove will be created that meets their needs. Once the final stove has been selected, the manufacturer can build as many as required to be distributed to schools or homes.

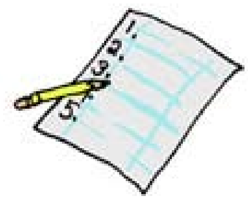
Training should be provided to cooks on how to use and maintain the improved stoves. The stoves should be checked at least four times per year. Chimneys and all parts of the stove need to be cleaned and inspected. Worn out parts will have to be replaced. If possible, the committee continues to manage 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.

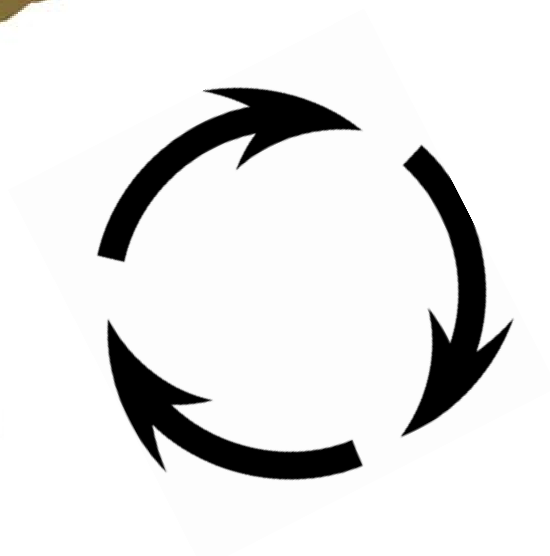
The cycle of designing and implementing improved cook stoves

1.) Identification of pilot schools

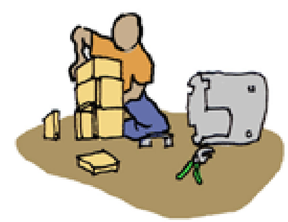
2.) Form stove design committee

3.) Development of a plan of action in pilot schools

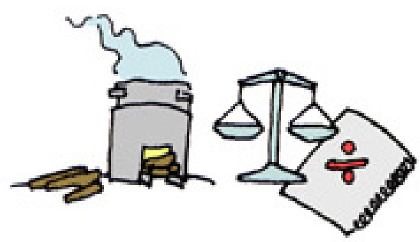




4.) Construction and/or rehabilitation of pilot stoves



5.) Field-testing of pilot stoves



6.) Improvement of prototype stove, construction and dissemination of final stoves to other participating schools/ homes

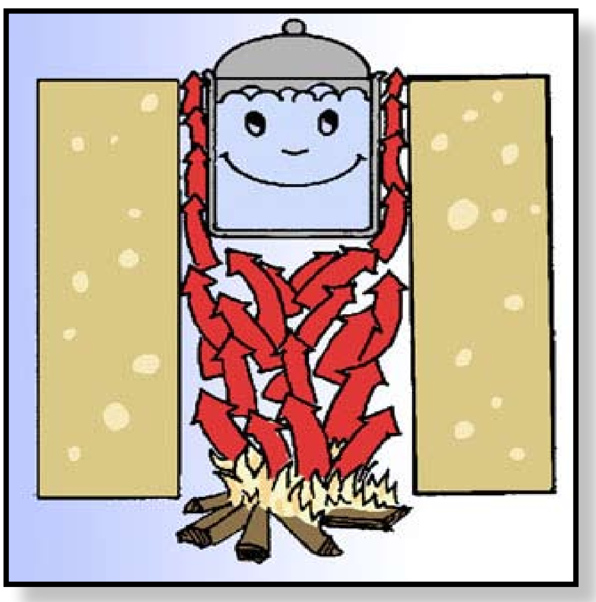
7.) School cooks are trained on how to use efficient stoves, how to provide regular maintenance, and how to use energy saving cooking practices

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

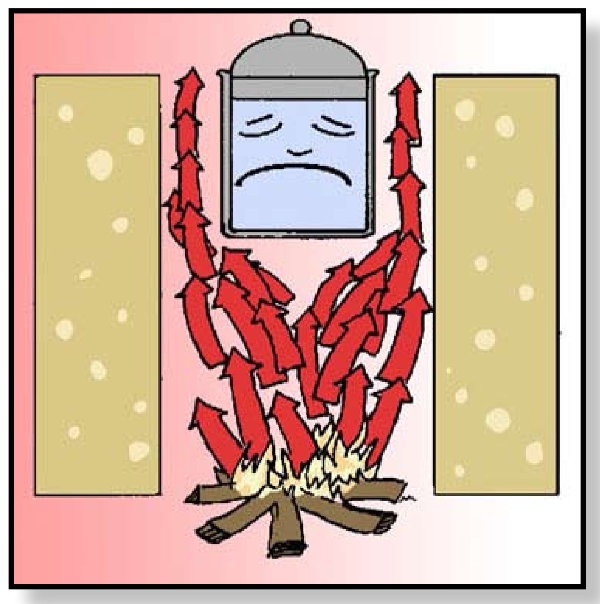
What makes a stove consume less wood?

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 scrape against the pot is the most important technique to reduce the fuel used when cooking.

Many stoves do not force all of the heat to scrape against the pot. Most stoves throw away a lot of heat into the air.



When the hot flue gasses are forced to scrape against the 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 gasses 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, 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 (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 heat to scrape against the pot so that cooking uses less wood. The design committee should consider using this information as they develop their experimental stoves.

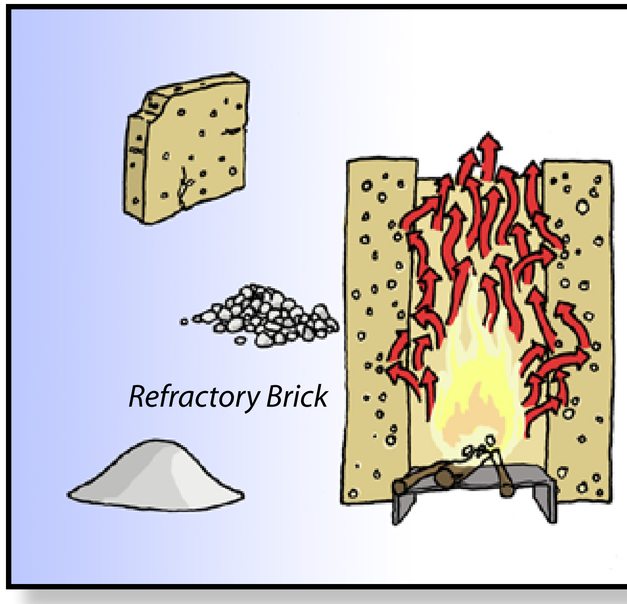
Smoke is harmful, causing health problems, like coughing, eye irritations, asthma, and respiratory infections. Worldwide 1.6 million people, mostly women and children, die each year from breathing wood smoke!

Chapter 2
Ten Design Principles

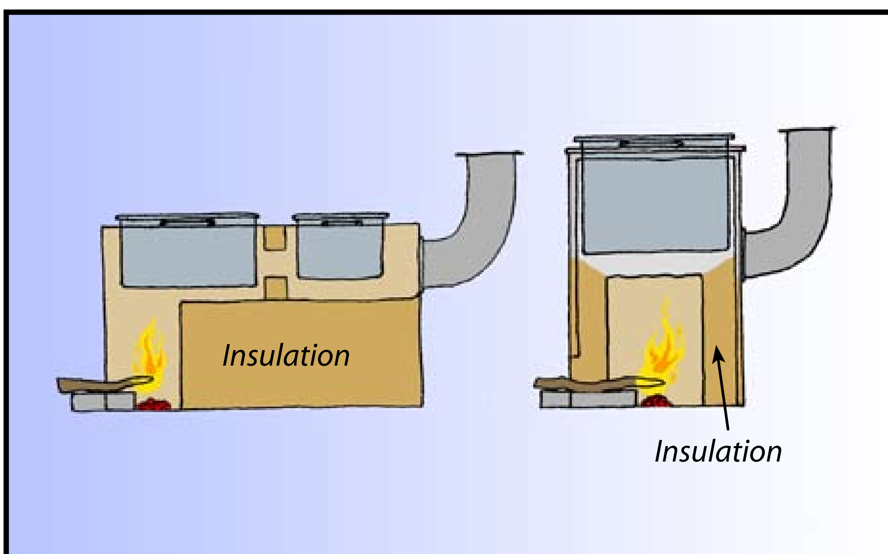
Principle One

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

Insulation is light and full of small pockets of air. Fire resistant examples of 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 the appendix. 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.



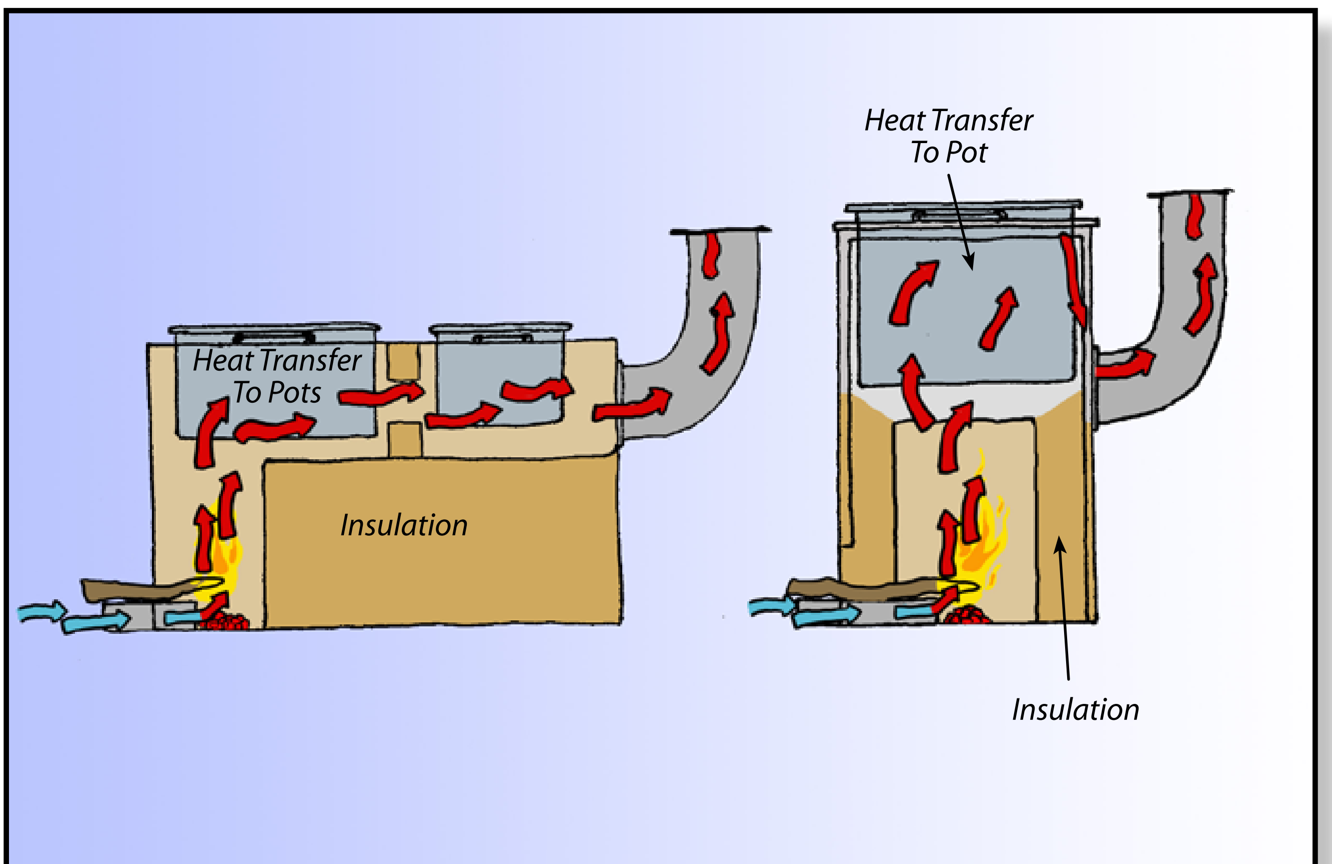
Important: Avoid using heavy materials like sand or clay or cement around the fire. Heavy materials cool the fire robbing heat from the pot. When starting a cold stove the heavy materials slowly warm up. It does not make sense to heat up 100 kilos of stove when the cook wants to cook 10 kilos of food.

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 heat is scraping against the pot(s) or griddle. Insulation reduces the heat that passes into the stove body so in an insulated stove 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 holes of air.

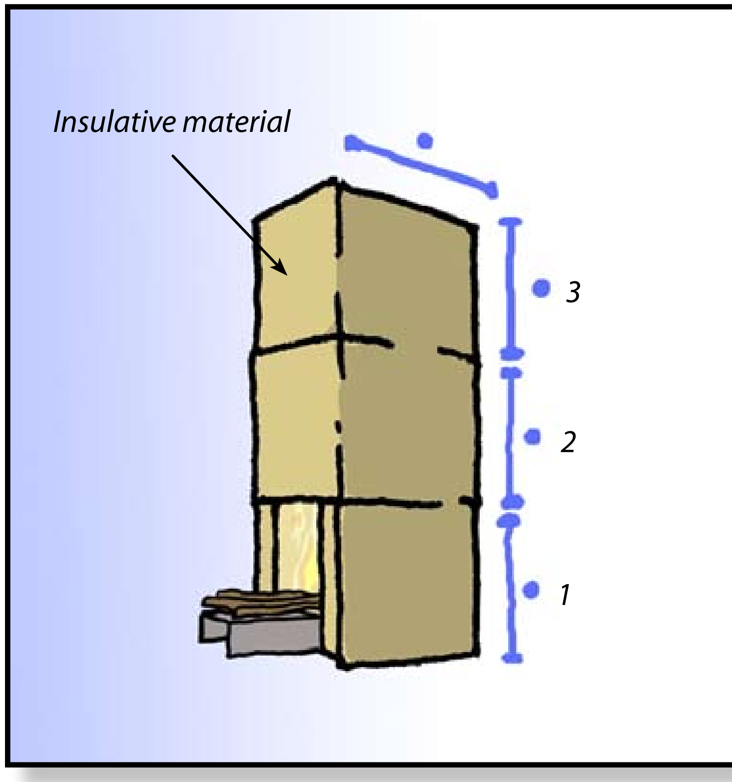


The path of the heat from the combustion chamber to the chimney is insulated everywhere except where the hot gasses rub against the cooking surfaces.

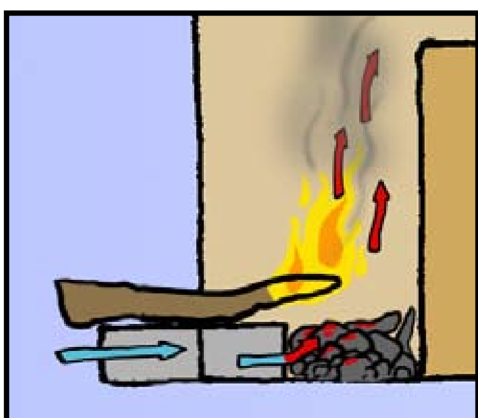
Principle Three

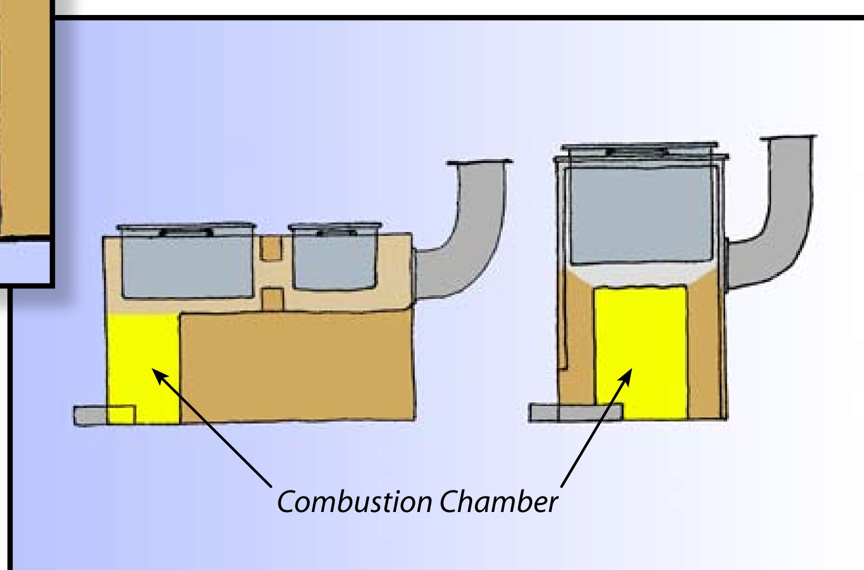
Include an insulated enclosed space (like a short internal chimney) above the fire in the combustion chamber.

If the fire is made under a short insulated chimney that is 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 hotter. The pot should be placed above the short chimney so that very hot gases hit its bottom and sides. Forcing the hot gases to scrape past the pot at a high 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 three times higher than it is wide and should be made from heat resistant insulative materials.



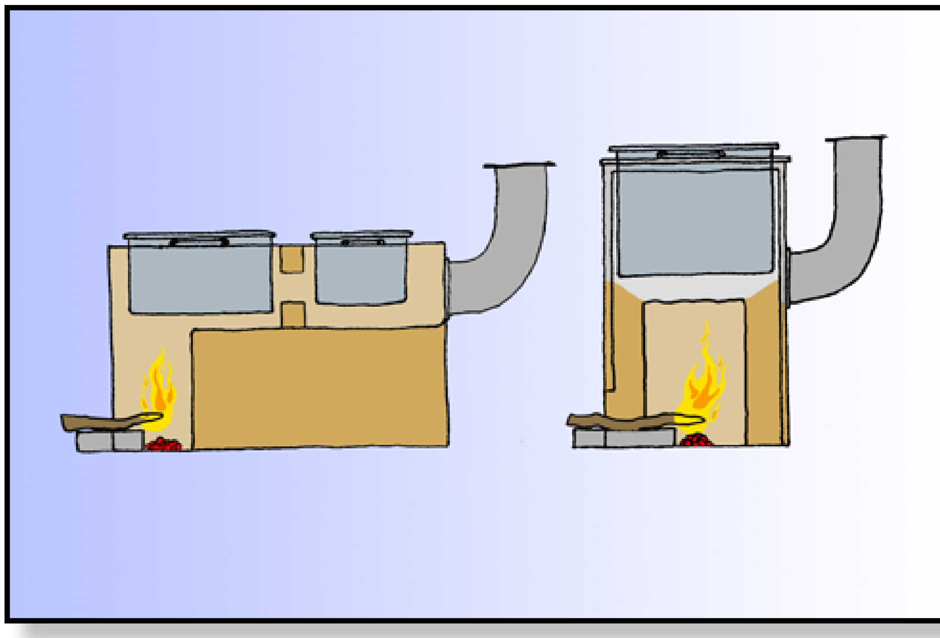


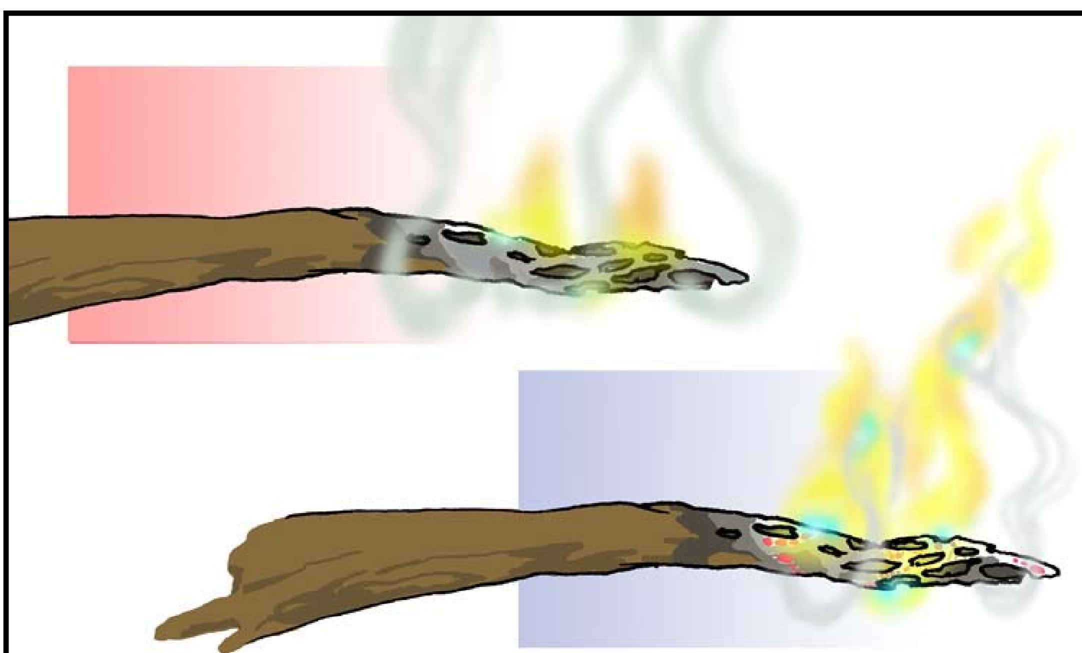
Principle Four

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 that will be burned up if it enters the flame (if smoke passes into a flame it will burn up). Excess smoke is made from the wood gases that have not been burnt by the flame.

Try to keep the rest of the wood sticks 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 without making smoke.



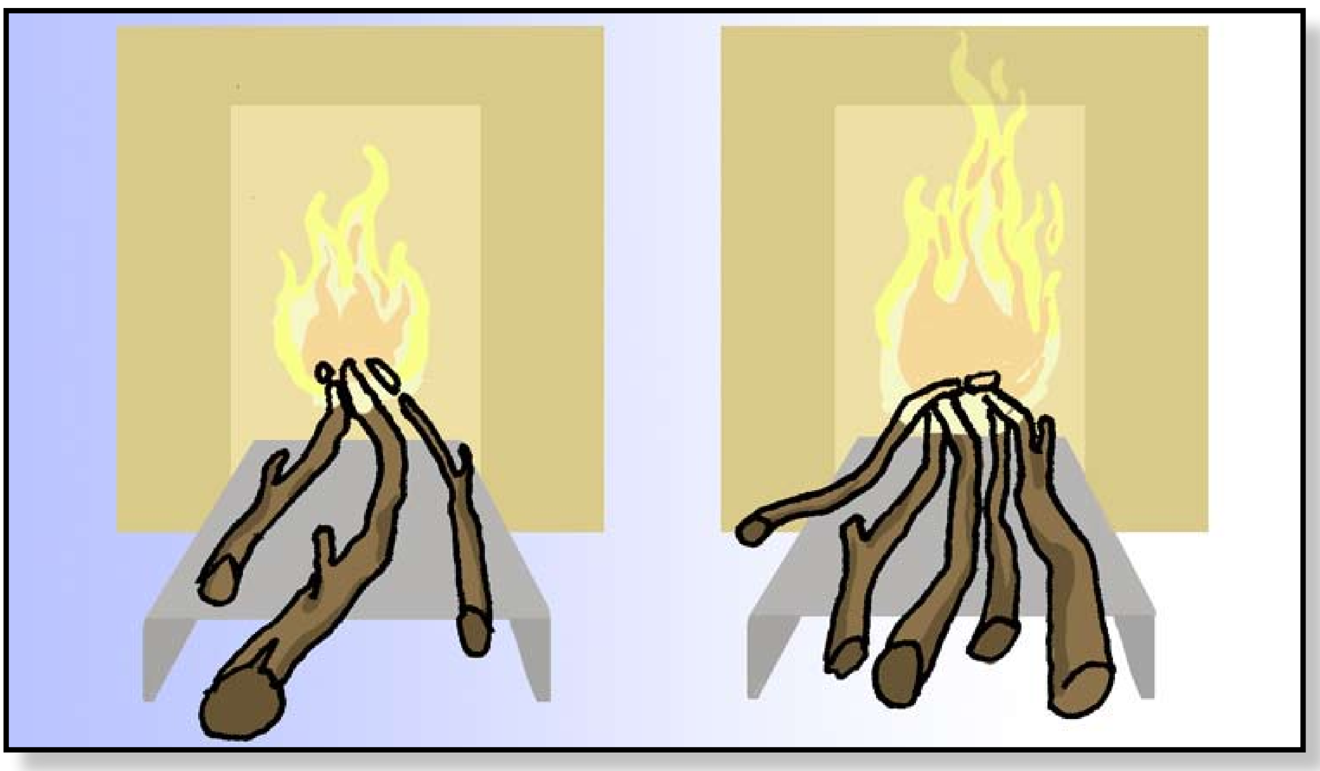


Smoke is unburned wood gas

Principle Five

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

When wood gets hot enough it makes 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, then the fire gets bigger. The amount of heat is controlled by the amount of wood pushed into the fire, not by reducing the air entering the fire (wood gets hot and releases gas which catches fires and makes heat). Reducing the air needed for burning makes a lot more smoke.

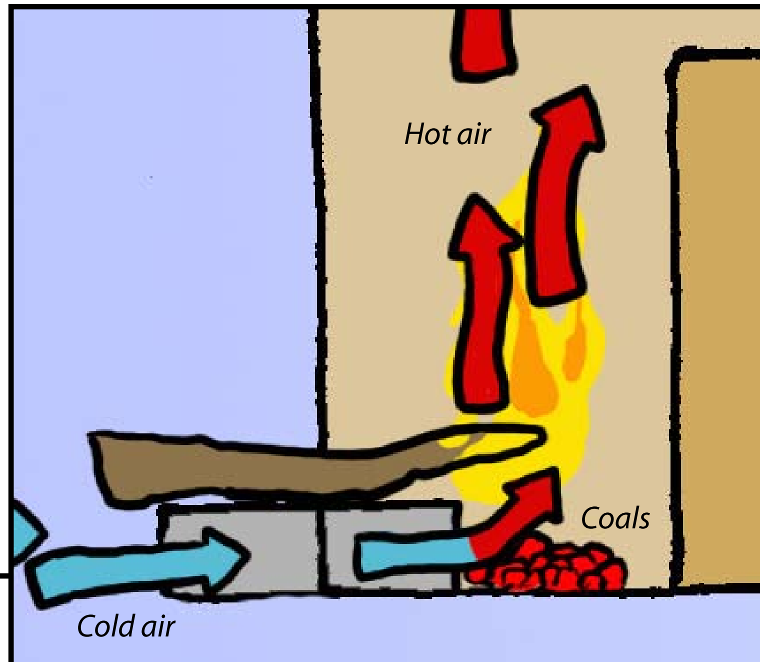


The amount of heat is controlled by the number of sticks pushed into in the combustion chamber.

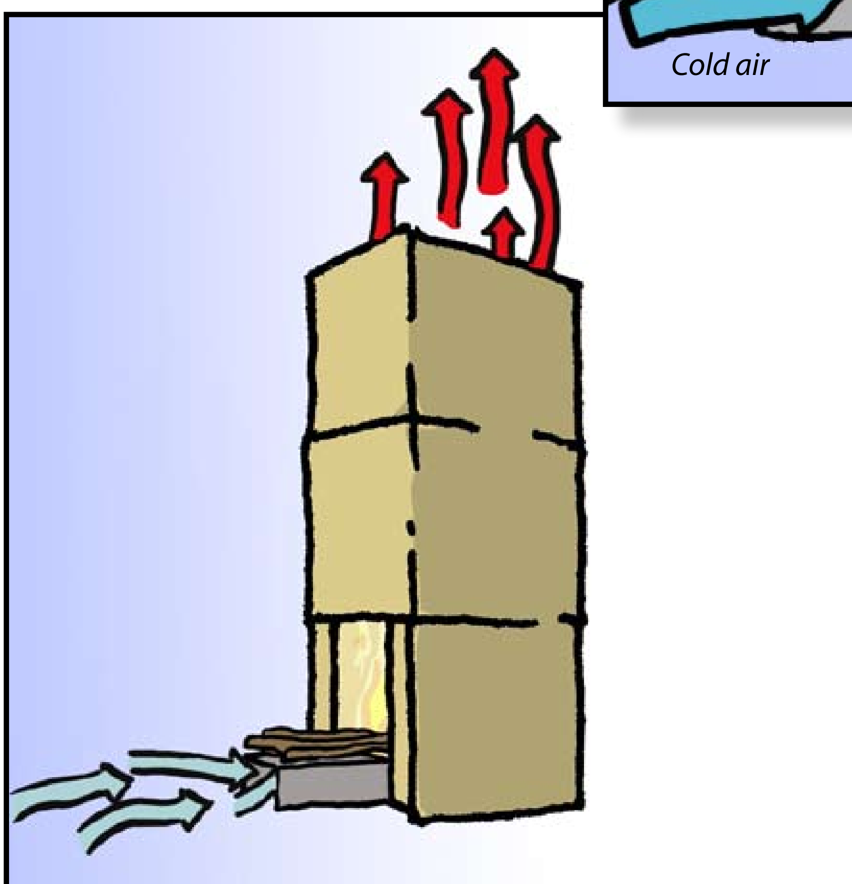
Principle Six

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

Blowing 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 your stove. The air passing through the coals helps to raise the temperature of the fire so that all the gases become flame.



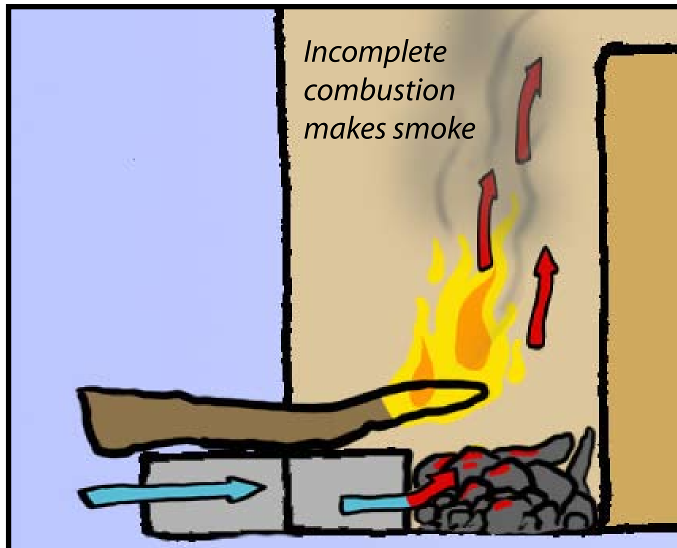
The air should be aimed at the coals and not above the sticks into the flame. The wind that is drawn into the coals heats up the fire. Blowing air into the flames can do the opposite and cool the fire.



Principle Seven

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

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. This is an indication of incomplete combustion. A fire that makes a lot of charcoal is producing too much harmful Carbon monoxide.



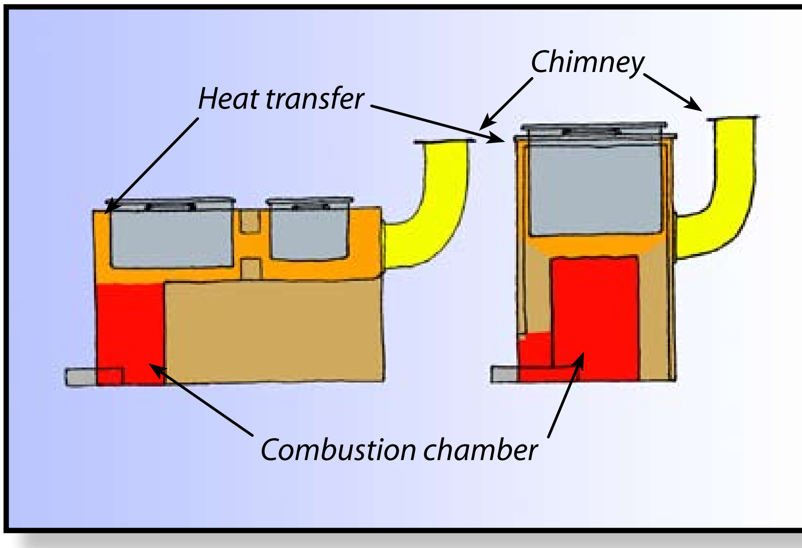
Charcoal build up from incomplete combustion

A hot clean burning fire will not make much 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.

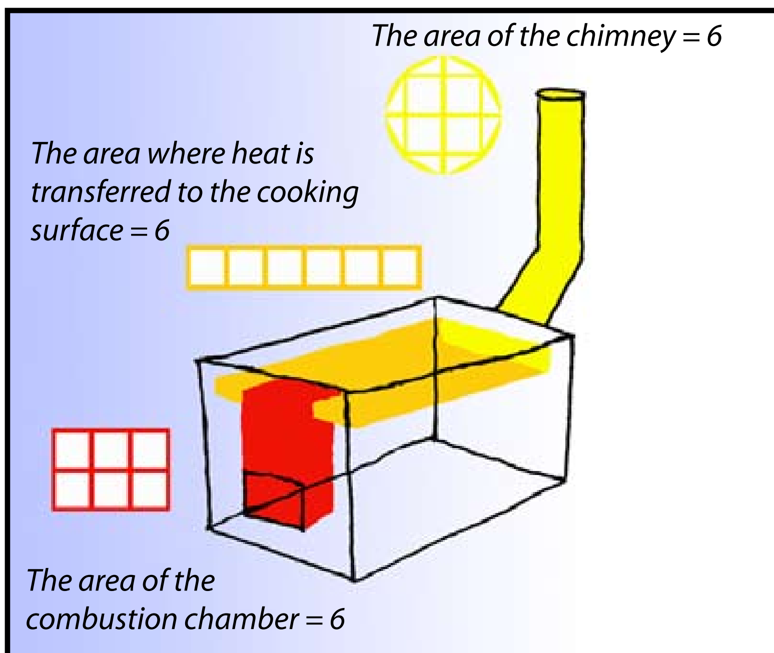
Principle Eight

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



The door through which wood is pushed into the fire, the spaces in the stove through which the hot gases flow, and the chimney should all have about the same volume so that air can flow well through the stove. Make all the spaces in the stove so that the same amount of gases can flow through the stove and up the chimney.

Air blowing 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 scrape against the pot to effectively cook the food. Slowing down the gases reduces the amount of heat that enters the pot. If less heat enters the pot then more wood is used for cooking.



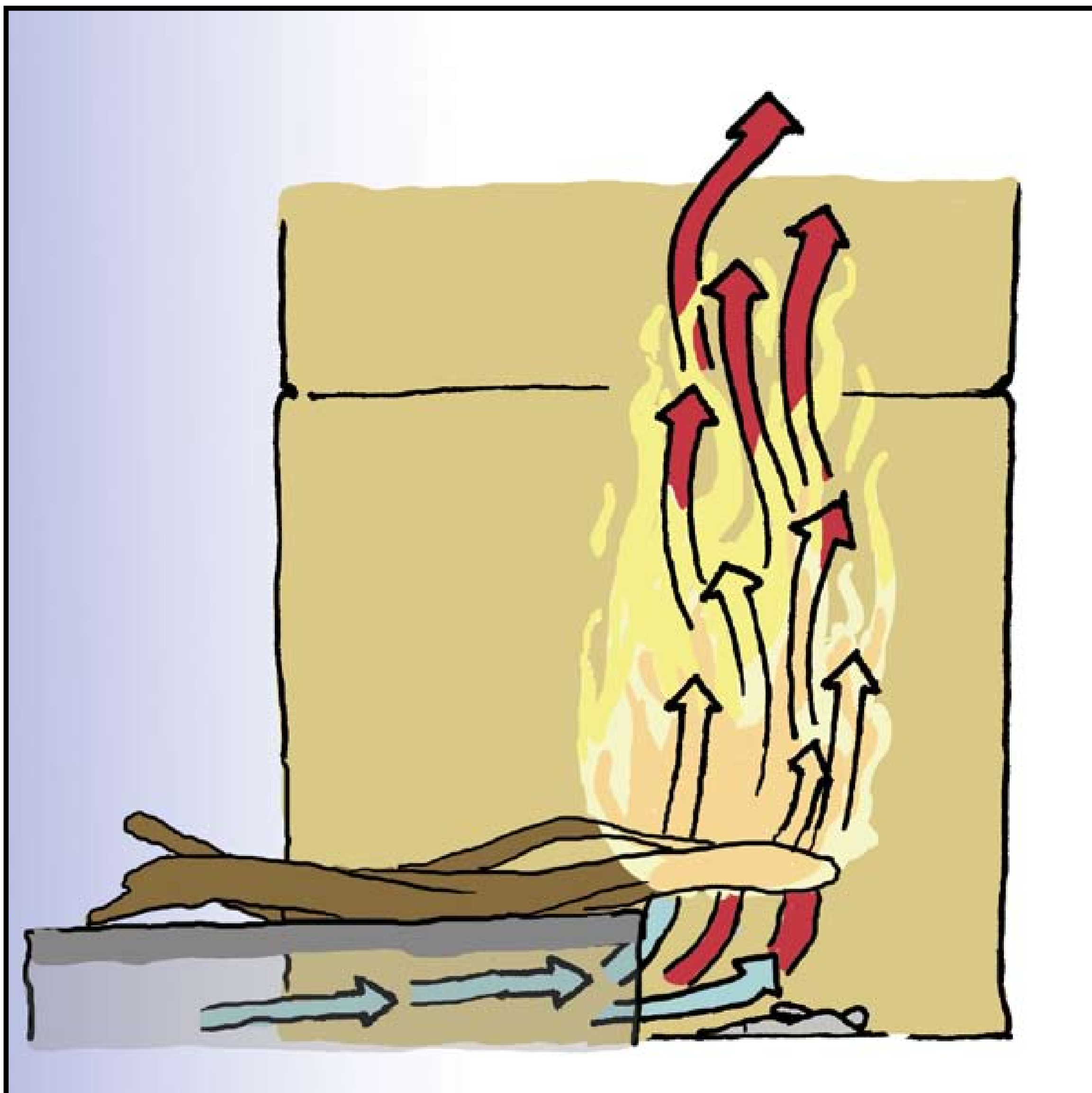
Throughout the entire stove, the cross sectional area that the hot exhaust gasses must travel through remains constant

In bigger stoves more wood is burned per hour and the spaces within the stove have to be bigger as well. As a general rule, the fuel entrance into the fire in a family sized stove should be about 12 cm by 12 cm. Institutional stoves need bigger fuel entrances, larger tunnels through the stoves, and larger chimneys. The next chapter shows the sizes needed for institutional sized stoves.

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 a space in between each stick. In this way, each stick helps to keep the next stick burning. This kind of fire is hotter which helps to reduce smoke.

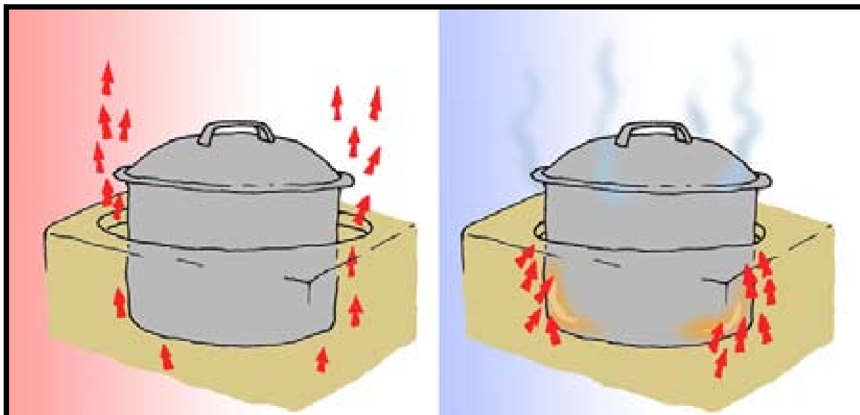


Air entering the stove must pass under the fuel shelf and through the fire

Principle Ten

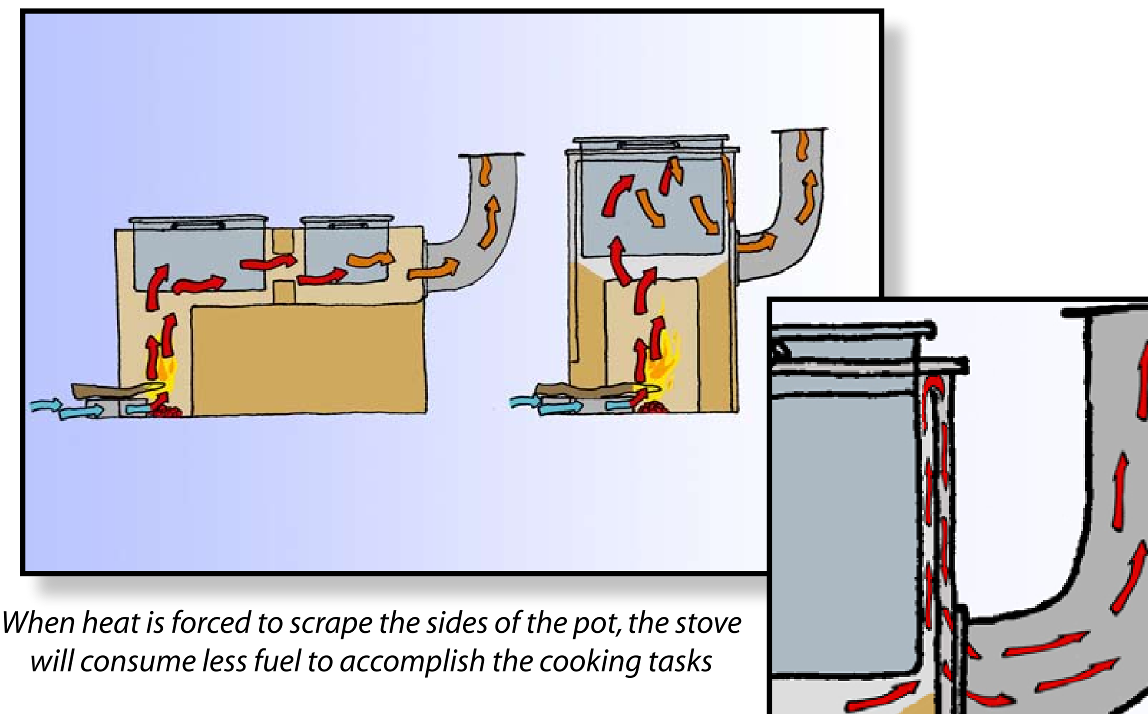
Force as much heat as possible into the pot(s) or griddle by using properly sized channels around the pot(s) or griddle.

It is necessary to force the heat to scrape against the pot(s) or griddle by making the spaces around them much smaller. However, 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. It is necessary to use the right sized spaces around the pot(s) or griddle. If the hot gases flow through big spaces next to the pot(s) or griddle the gases flow up the middle of the space avoiding the pot or griddle. If the hot gases do not scrape against the pot or griddle, more wood is used when cooking. Make all the spaces in the stove the right size so that the same amount of gases can flow through the stove and up the chimney.



A channel that is too wide allows heat to escape

A properly sized channel forces heat into the pot



When heat is forced to scrape the sides of the pot, the stove will consume less fuel to accomplish the cooking tasks

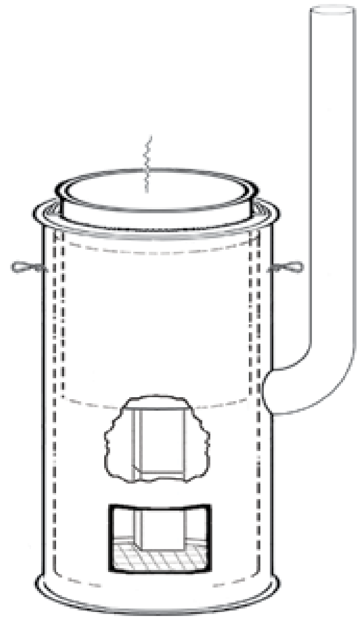
Chapter 3

How To Design Institutional Stoves for School Feeding

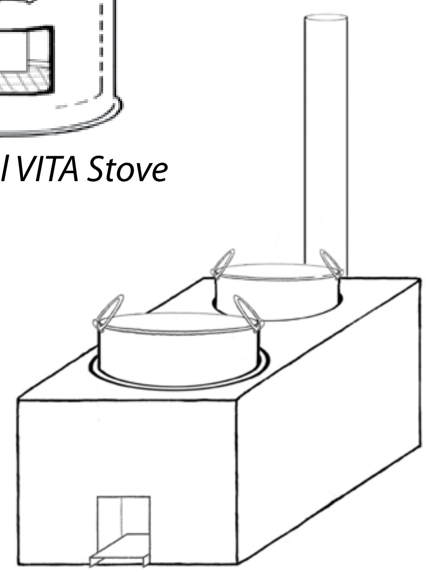
As explained in the Design Principles chapter, both combustion efficiency and heat transfer efficiency can be optimized in cooking stoves. Getting more of the heat into the pot(s) reduces the fuel needed for cooking. Burning the wood more completely helps to reduce the harmful emissions that damage human 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 VITA stove has improved heat transfer efficiency but does not have an insulated combustion chamber . The other two stoves are Rocket stoves that have improved heat transfer and insulated combustion chambers. The Rocket stoves produce less smoke than the VITA stove, but are more difficult to make.

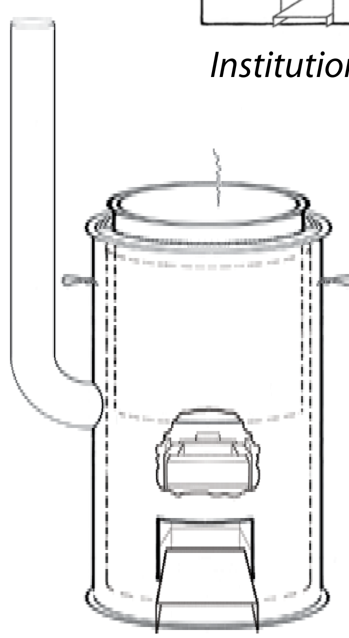
Reviewing these stove suggestions gives the stove committee a better idea of the options and strategies available to them. The simpler stove (VITA) without an insulated combustion chamber is easier to build. However, it is not as clean burning as the Rocket stoves. All improved cook stoves should either have a chimney or a hood to be used indoors or they should be used outside to reduce exposure to dangerous emissions.



Institutional VITA Stove



Institutional 2-pot Stove



Institutional Rocket Stove

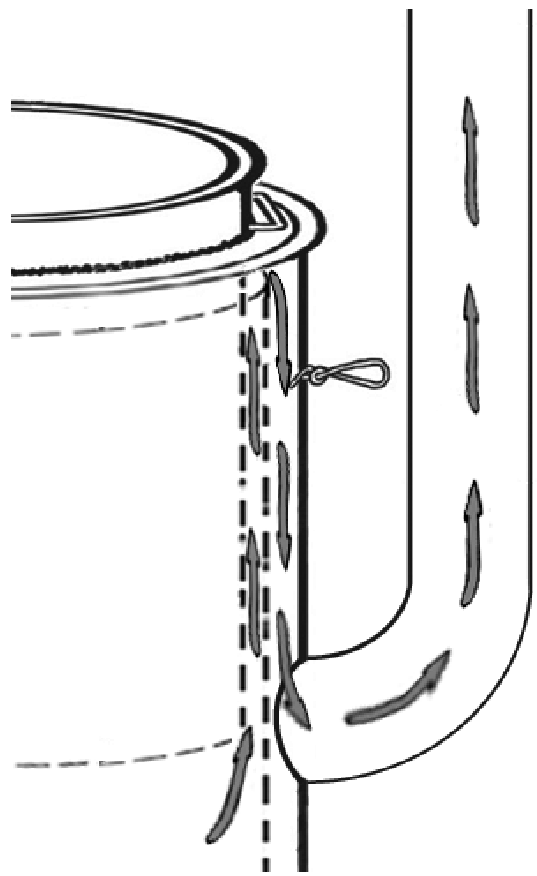
The Institutional VITA Stove

Large pots have greater surface area compared to smaller pots. Using a larger pot 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 larger version of the VITA stove can be made with or without a chimney. If a chimney is not attached to the stove the hot gases from the fire scrape against the sides of the pot and then rush up into the room. Because the VITA stove does not have an insulated combustion chamber around the fire a lot of smoke is made. For this reason, this type of stove should only be used with a chimney or out of doors or perhaps under a veranda in a windy area.

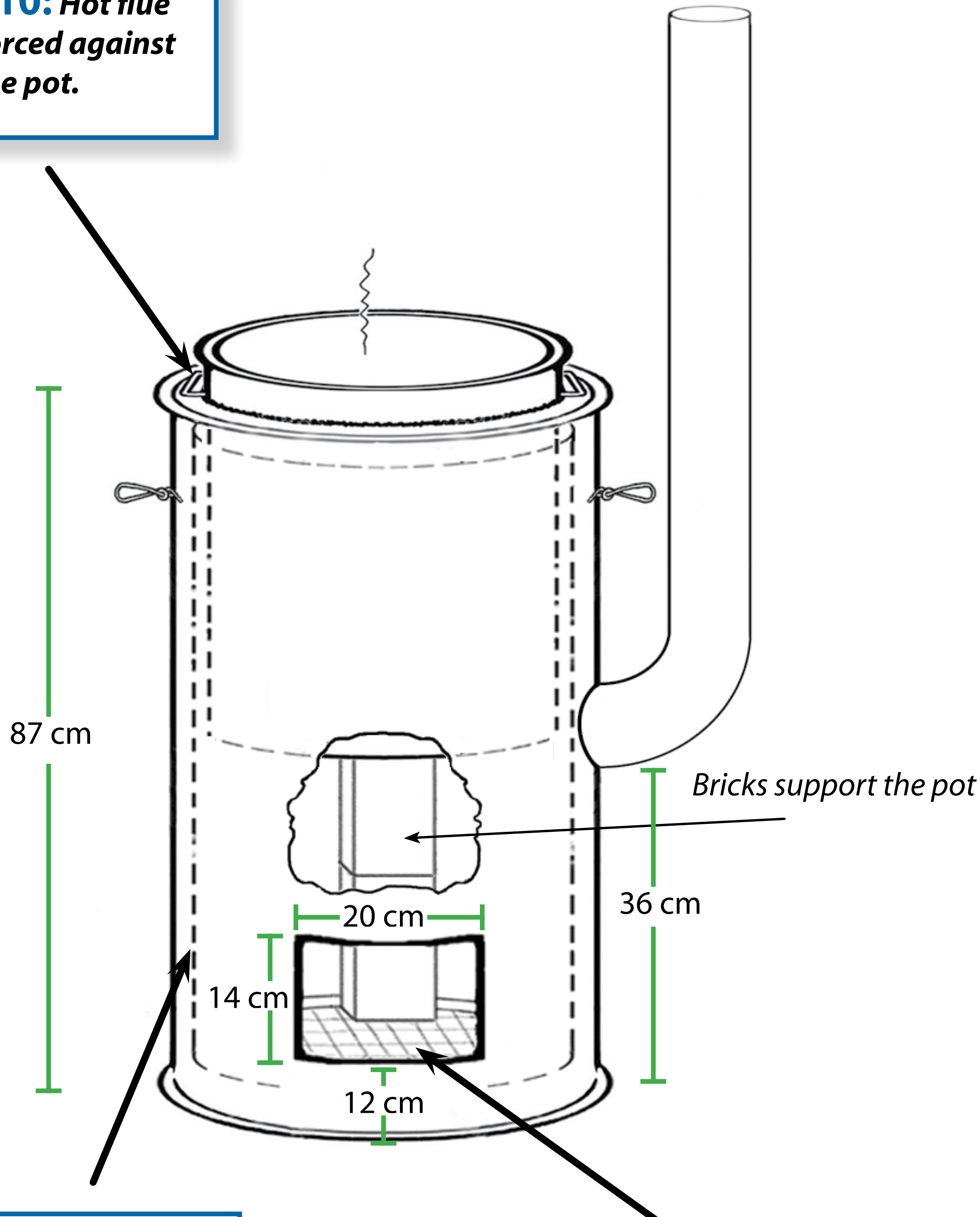
The chimney is attached to the VITA stove using a technique that forces the heat to scrape against the sides of the pot. Then the heat passes down in another channel that leads to the chimney. In this way, adding a chimney does not affect the heat transfer to the pot. It is highly recommended that the VITA 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 air cannot pass up and out of the kitchen. Then dirty, dangerous air is breathed in by the family causing disease and possibly shortening life.



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

Principle 10: ***Hot flue gasses are forced against the side of the pot.***



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

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

The Institutional VITA Stove

Instructions for Building

Materials Needed:

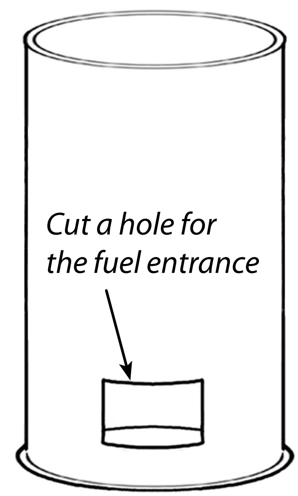
Tools - tin snips to cut the metal, a drill or punch to start holes.

Stove Body - Two large pieces of sheet metal or a metal drum.

Step 1

Make the outer cylinder from a large piece of sheet metal or a metal drum.

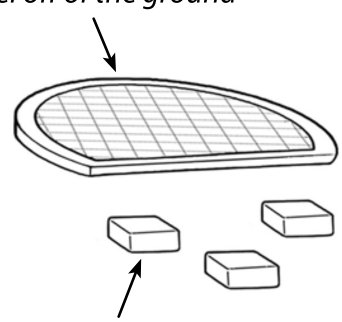
A hole, the fuel entrance, is cut in the outer cylinder. The fuel entrance is 20 cm by 14 cm. It is 12 cm above the bottom.



Step 2

A grate is made from any 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.

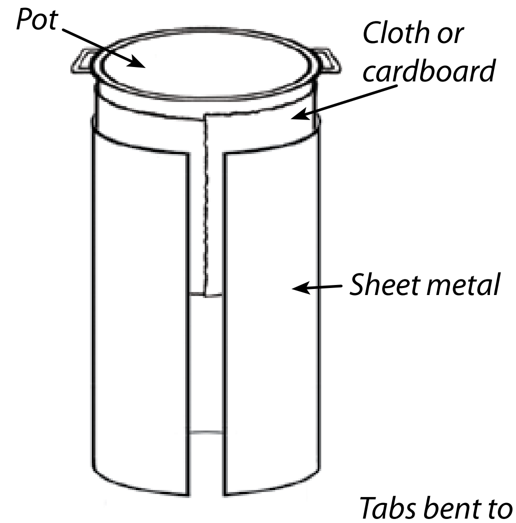
Stones or bricks can hold the grate up, just below the bottom of the fuel entrance.



Step 3

Wrap 16mm of cloth or cardboard around the pot to be used.

Make an open cylinder of sheet metal the right size by wrapping it around the pot. The cylinder is not closed. Leave a space from top to bottom which is 18cm.

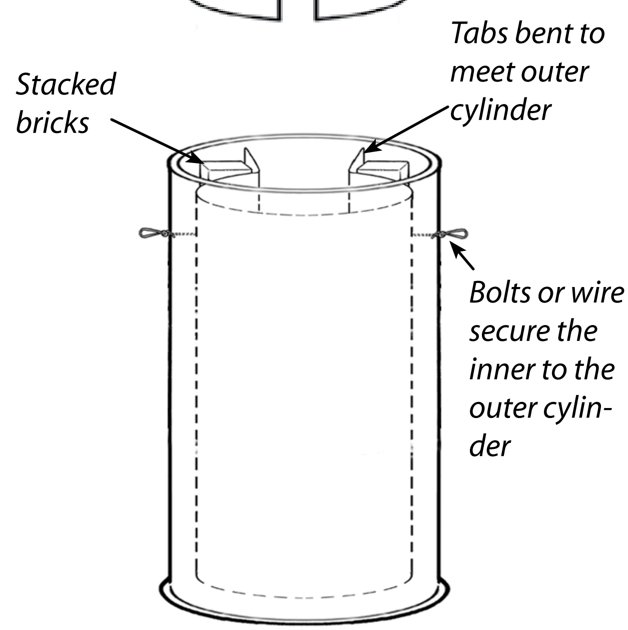


Step 4

You are looking at the back of the stove.

There are tabs in the inner cylinder. These tabs are bent to meet the inner wall of the outside cylinder. Bricks are stacked up to help make these walls solid.

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

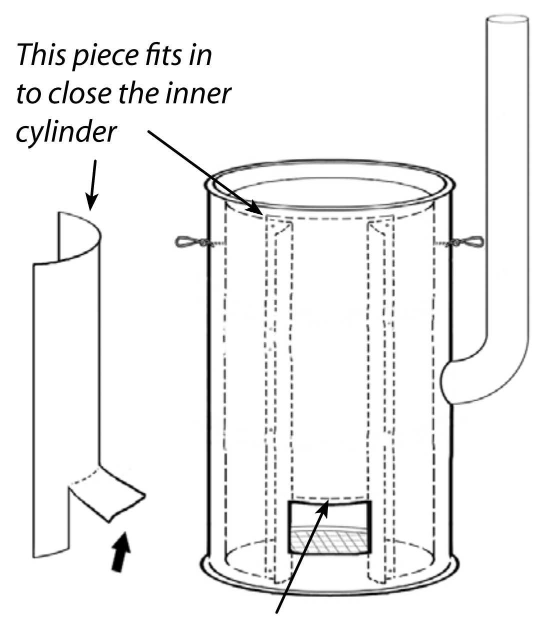


Step 5

The inner cylinder is now placed inside the outer cylinder

A piece of sheet metal is cut to fill the open space in the inner cylinder and to seal the space above the fuel entrance. Screw the piece in place.

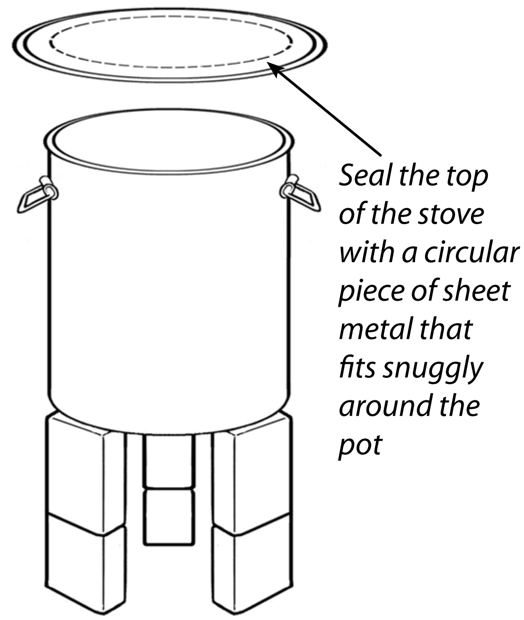
The chimney is attached to the outer body of the stove. The fire and hot gases are forced to scrape against the pot in the 16 mm gap between the pot and the inner cylinder. Then the hot gases flow down the outer 16 mm gap to the chimney. In this way only 'waste heat' leaves the stove.



Step 6

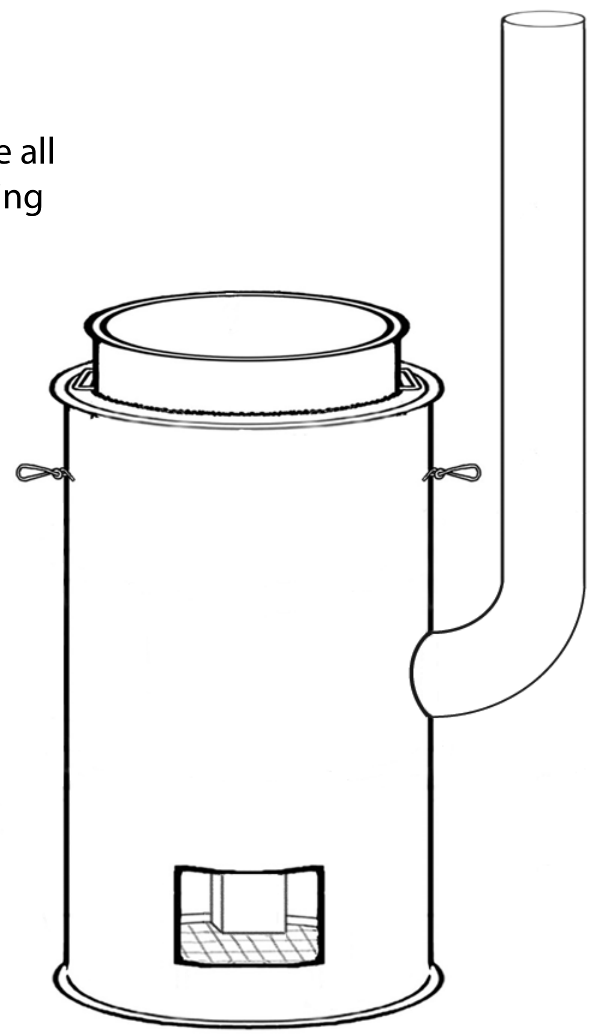
The pot is held up on bricks. The pot should be 25 cm above the grate.

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.



The large VITA stove demonstrates how the heat from a fire can be forced to enter the pot. Using very large pots increases the fuel efficiency of stoves.

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 house without increasing wood use.



The Institutional 2-Pot Stove

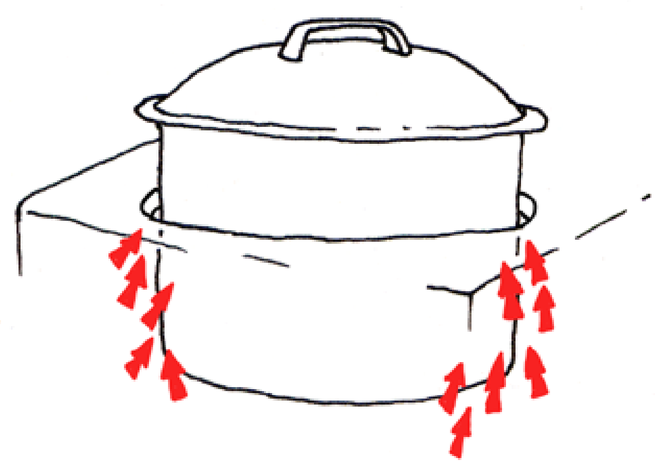
Adding a second pot to a stove is helpful because the "waste" heat that passes the first pot can be used to warm food in a second pot. However, if the first pot uses up a lot of the heat then not enough is left over to boil a lot of water in the second pot. A helpful rule of thumb is to make the second pot only half as big as the first pot.

It is important to improve the entire system in a cooking stove follow 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 'waste' heat then travels through an insulated tunnel or passageway that maintains a 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 pot, not from reducing the size of the spaces that brings the hot gases to the chimney.

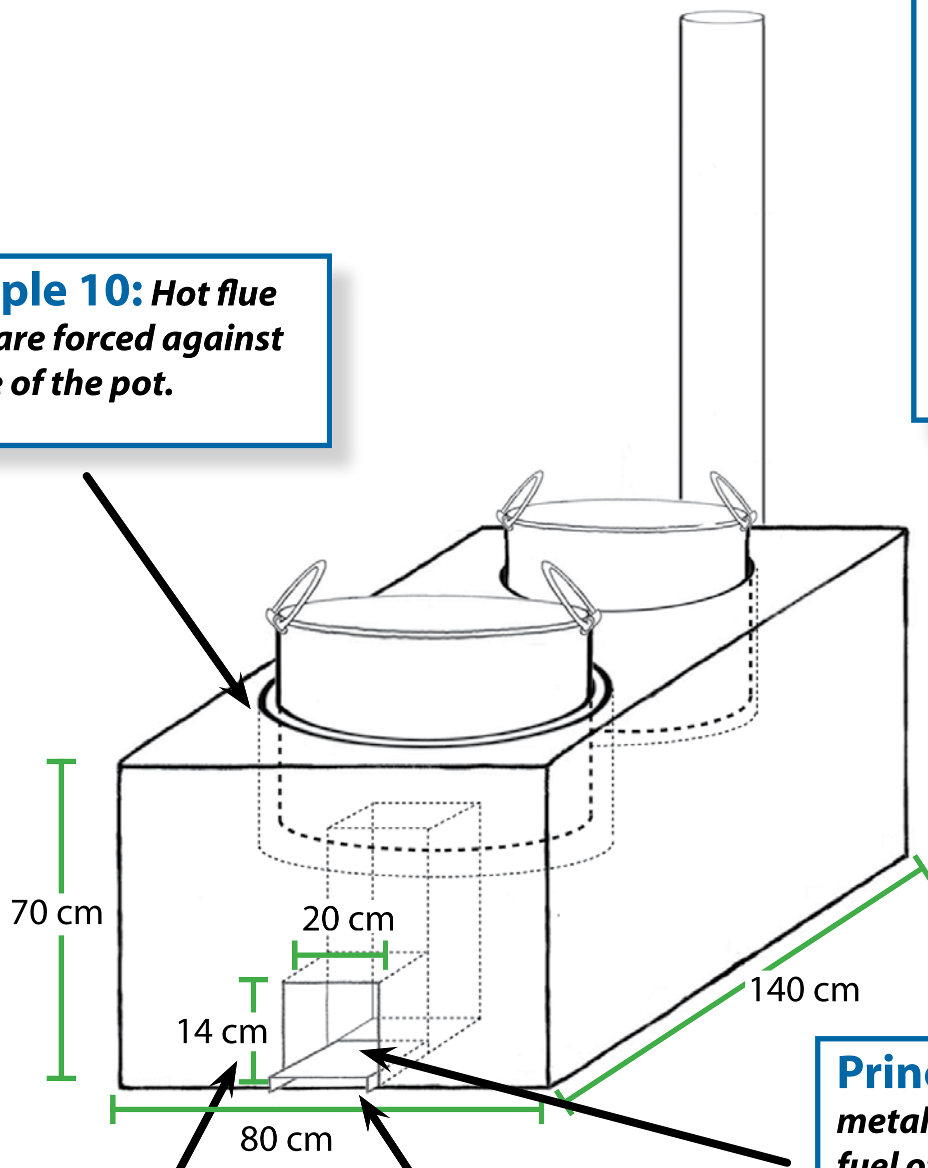
Stoves with chimneys can draw essentially all of the pollution through the stove and out of the chimney. Wood burning heating stoves in the U.S. and other countries burn large amounts of wood without adding to indoor air pollution. It is only necessary to remove all incomplete products of combustion 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. Luckily, this can be remedied by installing an insulated combustion chamber including a short 'chimney' above the fire and forcing heat to scrape against the pots in a narrow channel that maintains the cross sectional area found in the short 'chimney' above the fire. Following these design principles the pots are heated using less wood while the poisons in the wood smoke exit out of the kitchen.



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

Principle 10: ***Hot flue gasses are forced against the side 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 Institutional 2-Pot Stove

Instructions for Building

This two pot stove has an insulated combustion chamber that includes a short chimney above the fire. The hot flue gases scrape against the bottom and sides of the first pot before going through an insulated tunnel. This "waste" heat then warms a smaller 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.

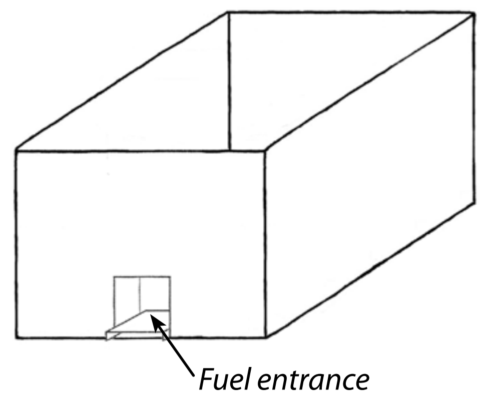
Materials Needed:

Tools - Saw, brick laying tools, tin snips

Stove Body - Regular clay bricks, cement mortar, insulative refractory bricks, chimney, sheet metal

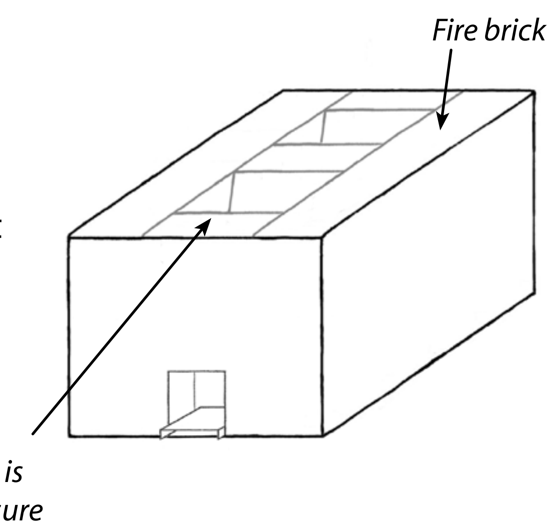
Step 1

A box is made, usually from bricks. A fuel entrance in the front of the stove is made to fit the combustion chamber. The height of the box is determined by adding together the dimensions of the submerged pot, the combustion chamber and the space between the two through which hot gases must flow.



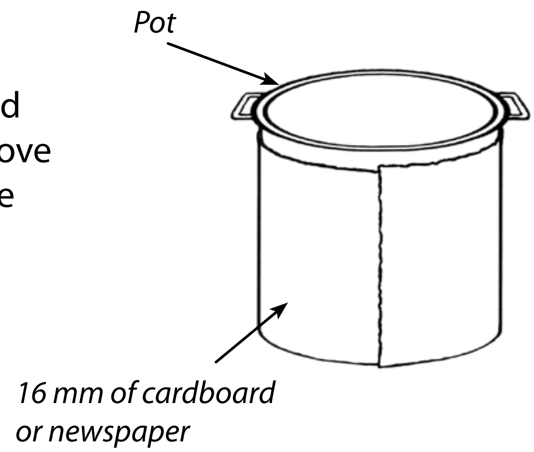
Step 2

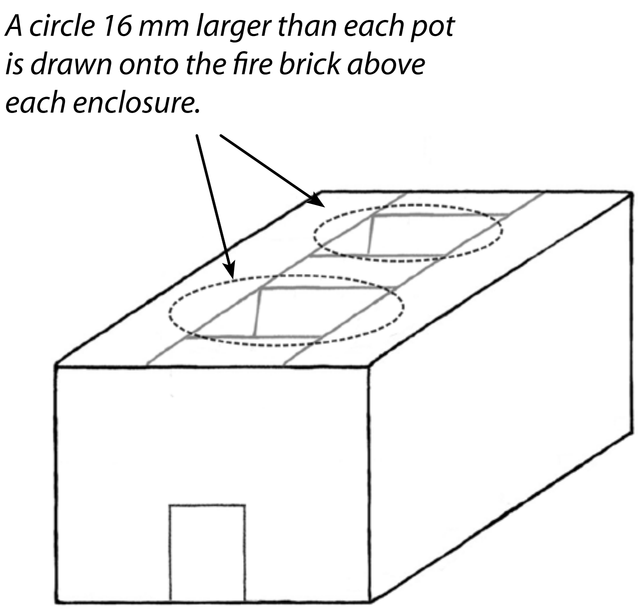
The box is partially filled with locally made lightweight fire brick made from clay and sawdust. The fire brick insulates around the fire and throughout the stove. The insulated combustion chamber is centered in the first enclosure nearest the fuel entrance.

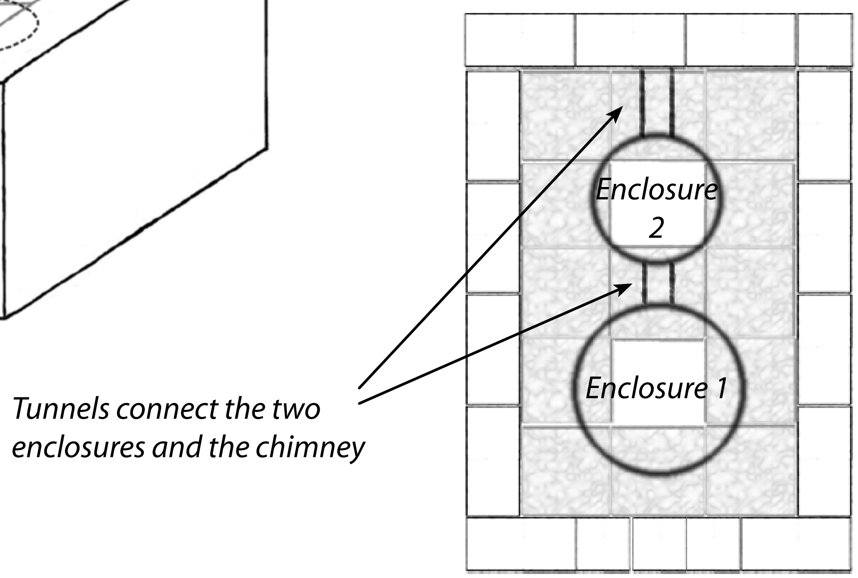


Step 3

16 mm of cardboard or newspaper is wrapped around the pots. The pots are then placed above the enclosures in the stove and two circles are drawn onto the top of the fire brick.





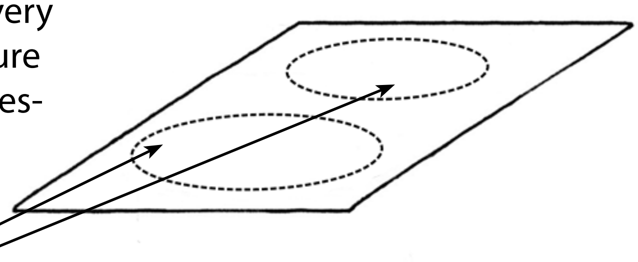


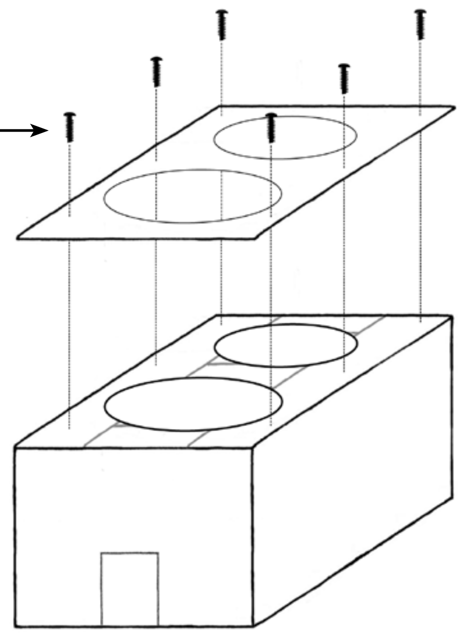
Step 4

Two cylindrical holes are carved into the soft firebrick. The holes are 16 mm larger than the pots and 16 mm deeper than the pots. A tunnel is cut through the fire brick to connect the 1st and 2nd enclosures. Another 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.





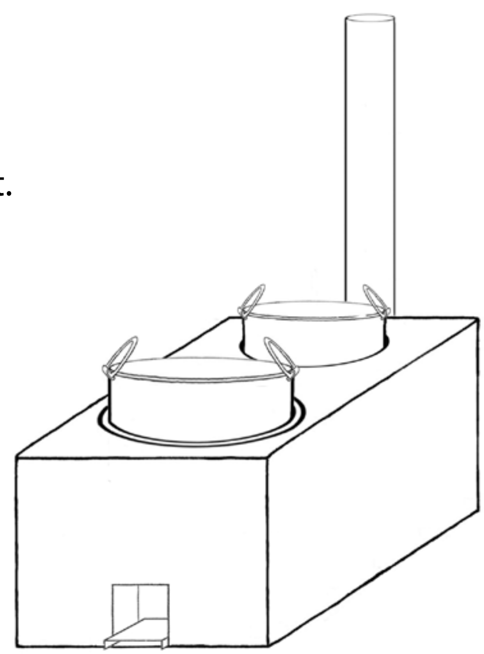
Step 6

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 35mm between the top of the combustion chamber and the first pot.



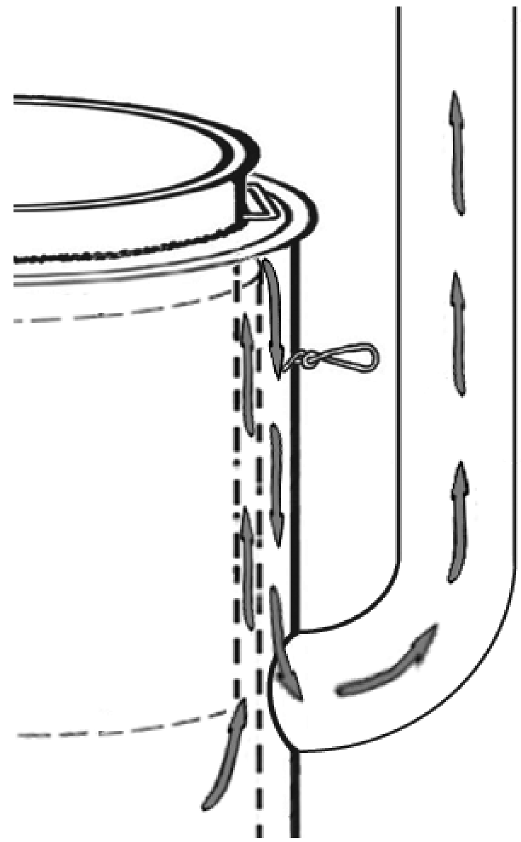
The Institutional Rocket Stove

Designed by Dr. Larry Winiarski

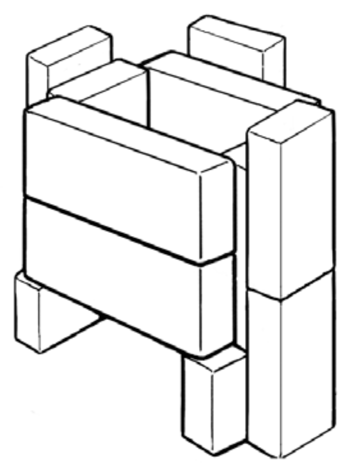
The institutional Rocket stove combines the same strategies that are in VITA stove while adding an insulated combustion chamber for cleaner burning. A cylinder surrounds the larger pot creating a 16mm gap which is especially effective in transferring heat because the pot is larger. Larger pots have more surface area so greater amounts of heat pass into the food. In fact, using larger pots decreases the amount of fuel used and helps to reduce the emissions made when cooking.

Because a chimney is attached to the stove, the hot gases are forced to flow down another gap on the outside of the inner cylinder (as in the Institutional VITA stove). In this way having a chimney on the stove does not diminish the fuel efficiency. All of the heat has already scraped against the pot before it exits out of the chimney.

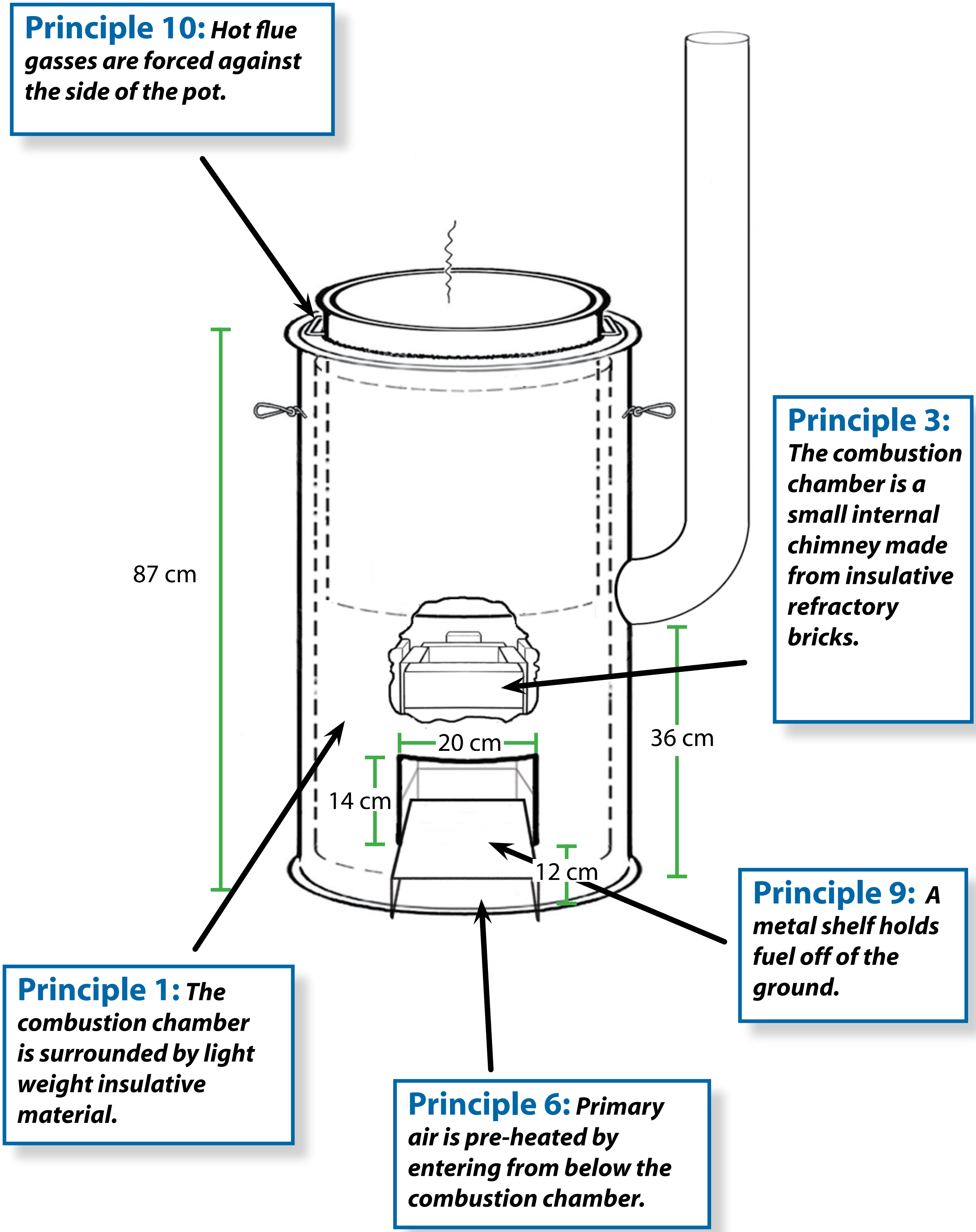
The light weight bricks used in the institutional rocket stove insulate the area directly around the fire. This allows for the fuel wood to burn more completely, reducing harmful emissions. The Institutional Stove in the following drawings can handle pots from 100 to 300 liters.



As with the VITA stove, heat is forced to scrape against the 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 gasses are forced against the side of the pot.
Principle 3: The combustion chamber is a small internal chimney made from insulative refractory bricks.
87 cm
36 cm
20 cm
14 cm
12 cm
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 Institutional Rocket Stove

Instructions for Building

Materials Needed:

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

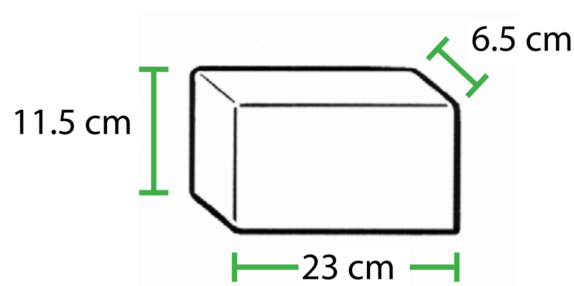
Stove Body - Two large pieces of sheet metal or a metal drum.

Combustion Chamber - high fire clay, low fire clay, cement, water, sawdust, and wood or metal for making a mould.

The Combustion Chamber

Step 1

The 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 used in construction. A heavy brick will not be damaged by sticks hitting the surface.



Insulative "lightweight" ceramic bricks

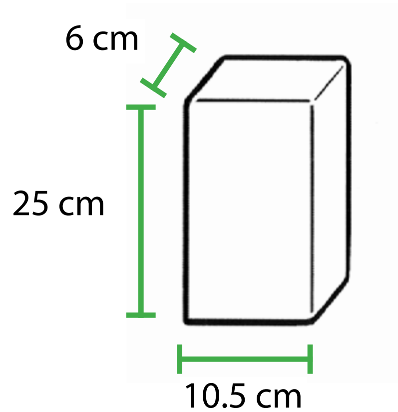
Step 2

All of the bricks used in this larger combustion chamber are lightweight insulative ceramic bricks. The inside of the combustion chamber is 34.5 cm tall, 23 cm wide, and 11.5 cm deep.

Step 3

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 such a heavy pot full of water and food.

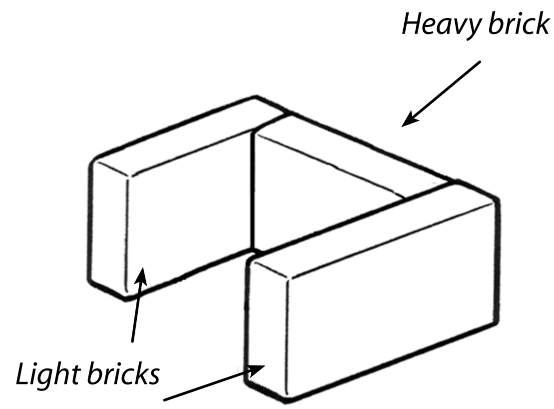
The pot supports are 50 cm high. This makes them 15.5 cm taller than the combustion chamber.



Regular "heavy" ceramic bricks

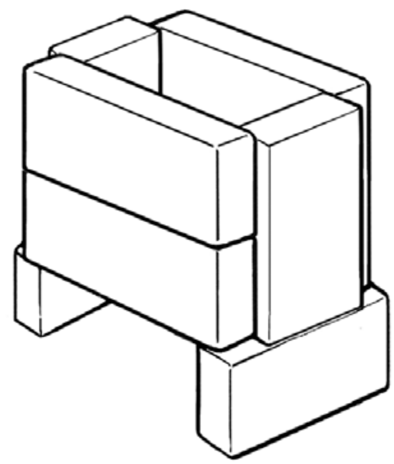
Step 3

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



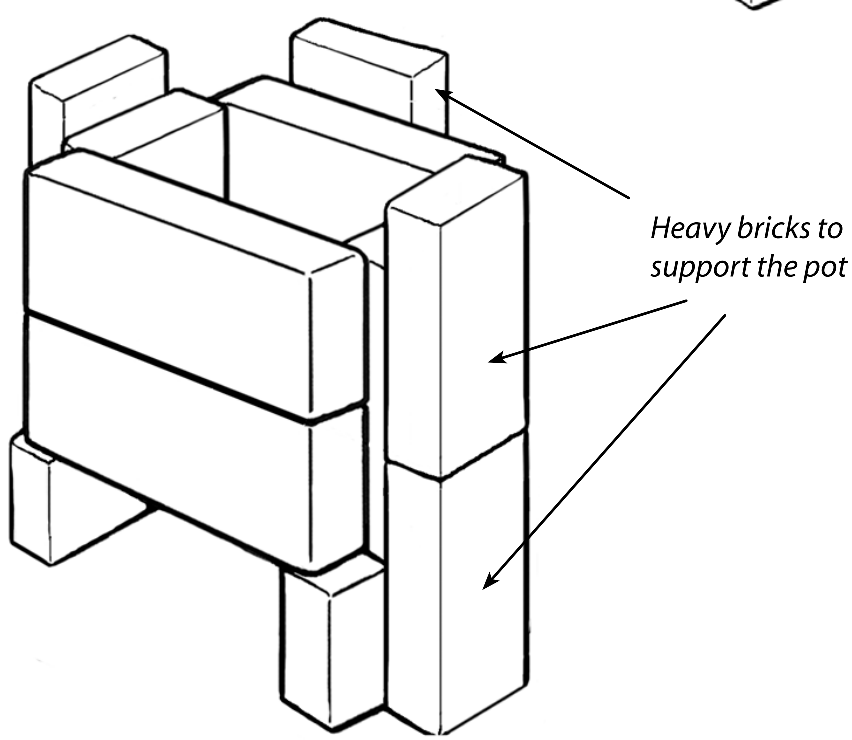
Step 4

Place one shorter and one longer light weight insulative bricks as shown on top of the three bricks below them.



Step 5

Finish the combustion chamber as shown using all the remaining bricks.



Finished combustion chamber using all 11 bricks

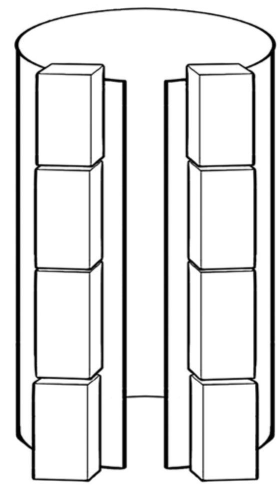
The Stove Body

Step 6

The combustion chamber with pot supports is 50 cm high. The pot should be submerged at least 40 cm into the open cylinder which forces the fire and heat scrape against it.

In this case the cylinder is 87 cm high. The open cylinder creates a 16 mm gap all around the pot.

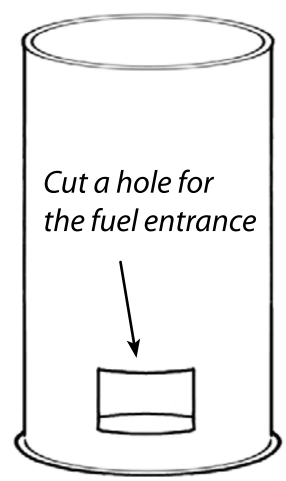
Stacks of bricks are used to fill the space between the outside of the open cylinder and the inside of the stove body as shown.



Step 7

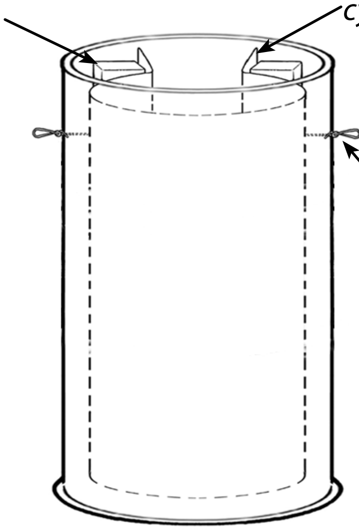
An opening is cut into the outer body of the stove. The outer body of the stove creates another 16mm gap all around the inner cylinder surrounding the pot.

The fuel entrance is 20 cm by 14 cm. It is 12 cm above the bottom.



Step 8

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

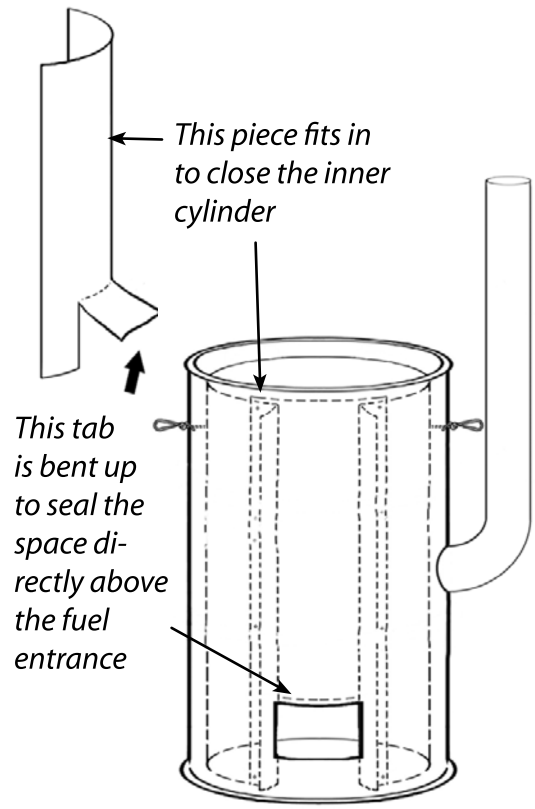


Step 9

The inner cylinder is now secured inside the stove body.

A piece of sheet metal is cut to fill the open space in the inner cylinder and to seal the space above the fuel entrance. Screw the piece in place.

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 16mm gap between the pot and the inner cylinder. Then the hot gases flow down the outer mm gap to the chimney. In this way only 'waste heat' leaves the stove.



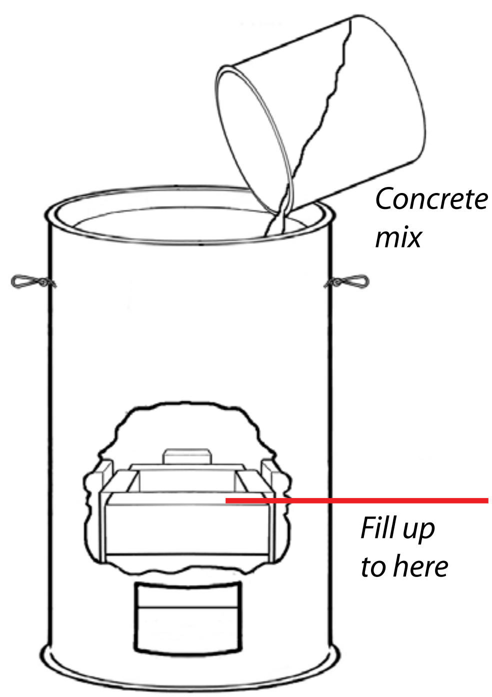
Step 10

Mix together enough concrete to fill between the outside of the combustion chamber and the inside of the open cylinder. 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".

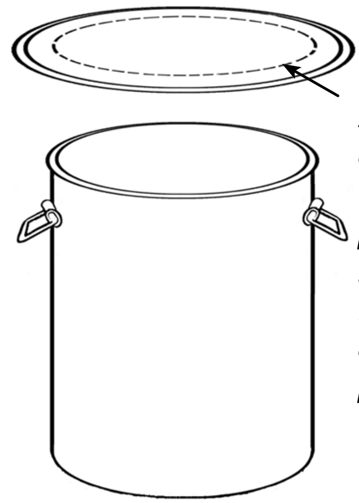
Fill up to the top of the combustion chamber made from lightweight bricks. The tops of the pot supports, made from heavy brick are 15.5 cm higher than the cement. A space is needed so fire and hot gases can flow under the pot and up the sides of the pot as well.



Step 6

If the stove will be used without a chimney fill between the inner cylinder and the stove body with insulation. Use wood ash, pumice rock, vermiculite of perlite. Insulation needs to be as light as possible.

If a chimney will be used 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 leave out of the top of the stove it is forced down the gap between the inner cylinder and the stove body where it exits out of the chimney.

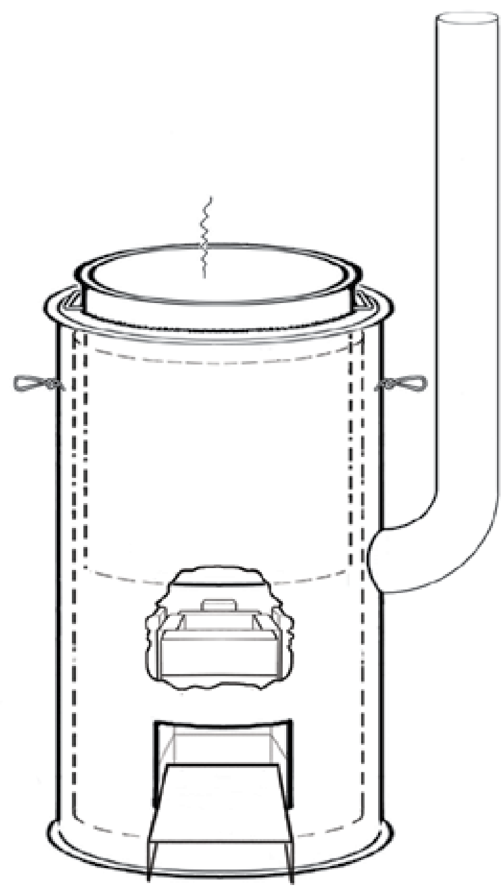


Seal the top of the stove with a circular piece of sheet metal that fits snuggly around the pot

Step 7

Using this type of stove usually surprises cooks who have used a lot of wood in open fires. This type of stove uses less wood and is quicker to boil. Also the insulation in the combustion chamber helps to burn up smoke that used to escape.

A shelf in the fuel entrance helps as well to feed wood at a controlled rate into the fire. In this stove the shelf was wide, high, deep.



Chapter 4

Retained Heat Cookers

A retained heat cooker ("haybox") is basically an insulated enclosure that a pot of food can be placed into after being brought to a boil. The food in the pot will remain at cooking temperature and will complete cooking inside of the haybox. The entire 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. They rely on insulation to trap heat inside of the pot, thus using significantly less fuel to cook the food.

Retained heat cookers are:

- **Efficient-** They can reduce fuel consumption by up to 70%.
- **Safe-** They reduce the risk of burns and exposure to smoke due to shortened cooking time on the stove,
- **Convenient-** Food never burns, sticks, or boils over. The food can even have more flavor from the slow cooking process.
- **Simple-** They 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 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. Open cell insulators like straw, wood ash, charcoal, feathers, pumice, raw cotton, or wood shavings work well as long as they are kept dry.

Even better are closed-cell materials such as: wool or polyester blankets, fur, rigid foam, and foam peanuts.

Step 2 Stop Air Leaks

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. For the best results, do not place the cooker in the wind or in the ground. Try to isolate the insulation from the external environment by placing it inside of a plastic bag, a cardboard box, a wooden box, or a cloth sack. If these materials are not available, it is possible to build an earthen structure from sand and clay to hold the insulation. Remember that earth, sand, and clay cannot act as insulation.

Step 3 Keep it Dry

Place a moisture barrier between the pot and the insulation, especially if you are using an open-cell insulator. 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. Place 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 and quickly remove it from the stove and place it in the retained heat cooker.

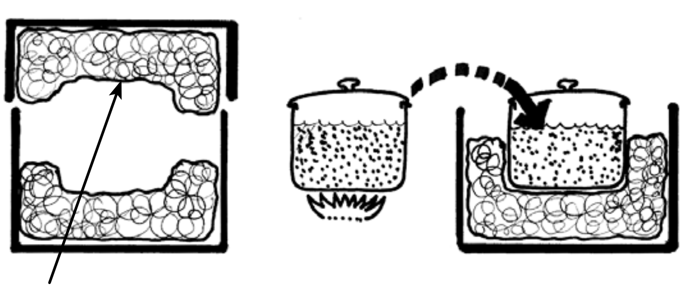
Do not open the cooker during the cooking period. Depending on the density of the food, retained heat cookers usually require 1.5 - 3 times as long as conventional stove top simmering to finish cooking.

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.

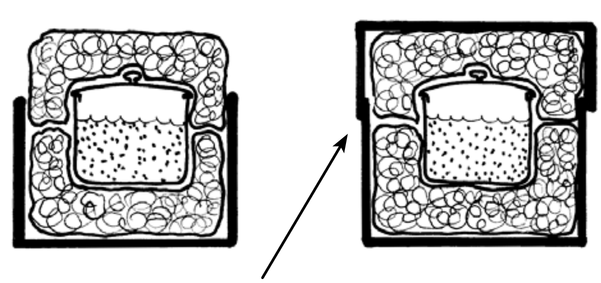
Suggested Cooking Times:

	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, the inventor of the VITA stove, points out that the testing of prototypes is necessary while the stove is being developed. Testing stoves also helps 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 should happen during the entire life of a stove project.

Baldwin includes tests to determine whether consumers are happy with the product, if firewood is being saved, and how lifestyle issues are affected. Without continual testing, a stove project operates in the dark; it lacks essential technological, sociological, and business information. Reading the stove testing chapter in Biomass Cookstoves is highly recommended.

Careful testing of stoves has resulted in a more accurate understanding of how to make better stoves. Without experimentation and testing, the development of a stove is based on conjecture. Careful investigation can quickly separate 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 on the following pages.

An In Field Water Boiling Test (WBT)

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 VITA 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, taking into account the moisture content of the wood, steam generated and other factors the complete UCB/Shell Foundation Water Boiling Test 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 that 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 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 pre-weighed 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 hi power phase

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

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

Wood Use:

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

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

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

_________ = V – Y = Charcoal made in hot start hi 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.)

Appendix

Options for Combustion Chambers

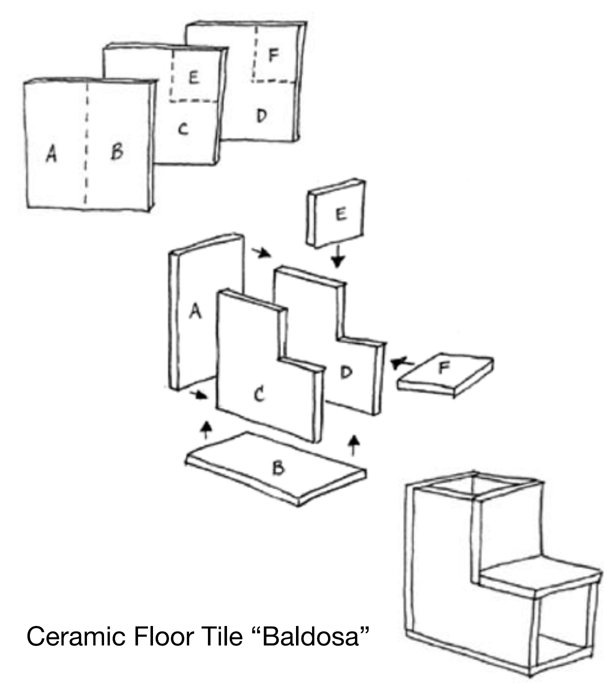
Multiple tests of the sand and clay Lorena stove, beginning in 1983, showed that placing materials with high thermal mass near the fire can have a negative effect on the responsiveness, fuel efficiency, and emissions of a cooking stove because they absorb the heat from the fire. Examples of high thermal 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^{0}C. 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.

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