WOOD HEATING STOVES IN RURAL GEORGIA

MAY 2008

May 30, 2008

This publication was produced for review by the United States Agency for International Development. It was prepared by Winrock International Georgia.

Wood Heating Stoves in Rural Georgia

Grant Agreement No. LOA – 5596 – 07 - 11

May 2008

Prepared for: USAID/Caucasus
25 Atoneli Street
0105 Tbilisi, Georgia

.

WINROCK INTERNATIOAL GEORGIA
RURAL ENERGY PROGRAM
26 DZMEBI KAKABADZEEBI STR.
TBILISI,0108, GEORGIA
Tel: +995 32 506 343
Fax: +995 32 935 352
www.ruralenergyprogram.ge

Wood Heating Stoves in Georgia

Summary

Georgia's energy needs are like those of many countries. To effectively address increasing energy needs, rising energy costs, environmental concerns, and global warming; Georgia needs a broad spectrum of energy resources. Within this mix of energy resources, wood is widely used in rural Georgia for household heating. However, wood is a limited resource that is being rapidly depleted. Because it is becoming scarce, wood is costly and needs to be shipped to communities from greater and greater distances. The problem is twofold: The homes that are being heated are poorly insulated and sealed. And the woodstoves used for heating are inefficient and poorly made. This study reviews wood heating stoves in rural Georgia and provides a road map for improving stove performance. This road map provides short term recommendations for improving and measuring stove performance, intermediate term recommendations for the development of a certification and measurement program, and long term recommendations for a sustainable wood energy heating program with high efficiency, clean, safe stoves based on consumer desires and demand.

The current stoves available in Georgia are inefficient, poorly made, do not meet consumer desires, require continuous tending, and do not meet basic safety requirements. Moreover, because there are no other options, there is a significant amount of wood use in rural Georgia. Nearly every rural home has a woodpile, and one can see many people gathering wood at the roadside and wood being transported by cart and truck. In addition, wood is relatively expensive. Homeowners reported using five to eight cubic meters of wood each year at a cost of 40 to 60 GEL per cubic meter. Several homeowners stated that their heating costs were approximately 200 to 300 GEL per year to heat a two to three room home with an area of 50 square meters. All heating stoves we observed in rural Georgia were of the same basic design, and the estimated efficiency of these stoves is 30 to 50%. Because of these relatively high costs for heating, there should be significant consumer interest in higher efficiency stoves. However all manufacturers state that their stoves are high efficiency stoves with greater than 75% efficiency. There is no basis for this claim, and the consumer does not know what the attributes of high efficiency stove are. In addition, the stove manufacturers are small craft shops with limited technical ability and do not know how to improve the efficiency of their stoves. Moreover, there is no testing lab, stoves group, university research program or other capability in Georgia to determine what stove efficiency is.

Based on these observations, there are several recommendations. To guide the implementation of these changes, they have been grouped into short term, intermediate term, and long term changes. In the short term (immediately) it is recommended that:

- Stove efficiency should be improved by including 1) an airtight combustion chamber, inlet air control, flue air control, and additional heat transfer area (smoke chambers). These changes should improve efficiency by 10 to 20% depending on application and how the stove is used. The cost of these changes is estimated to be less than 5% of the cost of the stove.
- Stove safety should be improved by 1) providing fire proof floor covering under the stove, 2) providing a larger tray to catch falling embers from the combustion chamber when the door is open, 3) promoting good craftsmanship (no sharp edges, not tippy), and 4) securing the stove pipe so that it is not loose and is out of the way so it will not burn people. The cost of these changes is small and should

not increase the cost of the stove by more than 5%. The floor covering can be installed by the user, and the cost will vary depending on consumer preference.

- A program should be developed to address household energy efficiency. Rural Georgian homes are poorly insulated and drafty. It is likely that helping the consumer improve household efficiency would save as much or more wood as improving woodstove efficiency.
- The Energy Bus Project provides an excellent forum to educate people on these issues. The Energy Bus should have an improved stove available. This will enable consumers to see the changes and know what to look for in an improved heating stove. The reduced heating costs, improved comfort, and safer operation should be highlighted.
- To provide consumers an opportunity to buy an improved stove, a program should be implemented in which the efficiency of small stove manufacturers' stoves is measured simply, the manufacturers are taught how to build improved stoves, and the efficiency of the improved stoves is verified.
- Flue gas heaters that attach to stove pipes are relatively simple to make and could immediately improve the performance of Georgian woodstoves. This should be introduced to stove manufacturers as an additional product that could be offered to consumers.

These steps can be implemented almost immediately at low cost and are a starting place that will help build consumer understanding that heating costs can be reduced, their homes can be more comfortably heated, and that stove safety is a key concern in the home.

In the intermediate term (0-2 years) it is recommended that

- Additional stove efficiency improvements should be implemented. These would include increasing the thermal mass of the stove to provide for better efficiency and increased consumer comfort. In addition stoves should be designed to include a secondary combustion chamber.
- A more detailed and complete stove testing program should be developed. Two laboratories have been identified that have the capability to perform this testing in their facility. On site testing would be a better solution. The cost for portable equipment for testing of simple efficiency is estimated to be approximately $4,000 USD. In either case stove testing procedures would need to be developed, and a local laboratory taught how to perform the testing.
- A stove certification program should be developed in which vendors of improved stoves can be verified to be meet an efficiency standard, perhaps 50% efficiency, and to be safe.
- These certified stoves would then be eligible for micro credits and subsidies. This would encourage consumers to buy the improved stoves and manufacturers to build them.

In the long term (3-10 years) Georgian stoves need to evolve to become high efficiency (70%+ efficiency) consumer preferred devices, similar to those in Europe and the United States. To achieve this will require Georgian testing and certification of stove designs, more advanced stove designs, and consideration of separating the heating and cooking functions of the stove. It is recommended that

- A market based approach involving several stoves manufacturers and based on an understanding of consumer preferences and desires should be developed.

- One or more testing laboratories that can certify stoves using a common stove testing protocol should be developed. This protocol should address heat output, efficiency, and emissions. It should be noted that there are several testing procedures available from various countries and that these vary widely. A Georgian testing procedure should be developed based on these testing procedures.
- A Georgian wood heating stove certification program should be developed. The US EPA woodstove certification program is an example of a similar program.
- High efficiency heating stoves should be designed and manufactured. This should provide a range of stove options meeting consumer resources, needs, and preferences. These designs could be developed in cooperation with manufacturers in other countries.
- Pellet fuel and stoves should be developed as a way to take advantage of crop waste material and other biomaterials and to improve heating stove efficiency.

1. Background

Today in rural Georgia consumers are meeting their household energy needs with a mixed suite of resources. Electricity is available for lighting and household appliances, and wood is used for heating (and cooking in many households). This is a desirable way to meet household energy needs. High cost, carbon intensive electricity is used sparingly, and the bulk of the household energy needs are met using low cost, carbon neutral wood. However, the use of wood heating stoves is not a consumer choice but rather the only practical choice. Electrical heating is expensive and natural gas heating is not available.

Today the woodstoves in use and available on the market are all of the same basic design, a single combustion chamber with fixed above grate air vents, an ash collection chamber, an oven chamber around which the hot combustion gases circulate, and a rear chimney. There are minor variations among manufacturers that are perceived by them to provide higher efficiency or other benefits, but no efficiency testing of stoves is conducted to validate these claims.

While there are many good reasons to maintain wood heating as the primary source of household energy, wood heating stoves in Georgia are inefficient, unsafe, and time consuming. Because of this, it is likely that consumers will quickly move away from woodstoves to other solutions for heating as soon as they become available and affordable. The challenge for wood heating in rural Georgia is three fold:

1. How to increase stove efficiency and reduce wood consumption in the near future,
2. How to improve stove safety in the future, and
3. How to build and maintain consumer preference so that consumers will continue to choose to use wood as the preferred heating choice in their homes.

This report reviews the current wood heating stove design, manufacturing capability of current stove manufacturers, and stove testing capability. Recommendations for short term improvements in stove performance are made, the fundamentals of stove design and testing are discussed, and mid range and long term strategies for stove improvement are provided.

One area that was not reviewed extensively but is worthy of mention is that all Georgian homes and buildings visited were drafty with air leaks around doors and windows. The buildings were poorly insulated. Providing the consumer with education on these types of issues could save as much or more fuel as improving stove efficiency. Because of this, the Energy Bus should provide education on these topics as a part of a complete solution.

2. Review of stoves in Georgia

Figure 1. Typical Georgian Wood Stove

Stoves made by four different manufacturers were reviewed. Three of the manufacturers are small shops with limited production capability. They were located in Ozurgeti, Khoni, and Tbilisi; and stoves were made one-by-one by hand without patterns or modern manufacturing techniques. The stoves were made to order in several sizes. The fourth manufacturer was the Kutaisi Truck Factory operated by the Georgia Industrial Group.

All of the stoves were of the same type and pattern. As shown in Figure 1, the stoves include a simple combustion chamber, a loose fitting door, an ash collection tray, a flat top used for heating water and cooking, and a chimney at the rear. In the household stoves the hot gases can be circulated around an oven compartment for cooking. A bypass is available for temperature control of the oven. In practice the oven temperature is not controlled with the bypass and is used when not baking.

No stove examined included the basic elements of an improved heating stove. These include an inlet air damper, a sealed combustion chamber, a flue damper, or a smoke chamber. None of the stoves had a secondary combustion chamber; the stove produced by Union Bioenergy in Tbilisi had air ports to support secondary combustion, but the chamber was not insulated, and there was no inlet air control. Based on this, it is unlikely that secondary combustion actually occurs. However, an operating stove was not available to examine.

Figure 2. Georgian Industrial Group stoves installed at Sadmeli School

The Georgia Industrial Group

Figure 3. Typical school room wood heating stove configuration.

Figure 4. Creosote leaking from a stove pipe onto a window.

The Georgia Industrial Group based at the Kutaisi Truck Factory provided 35 heating stoves to Winrock International in November 2007 at a cost of 125 GEL. These were unimproved heating stoves that are widely available in Georgia (Figure 2). 32 of the stoves were installed in the Sadmeli Public School. These stoves are similar to the wood heating stoves made by local producers. In discussions with Mr. Merab Chrelashvili, he stated that the stoves are 75% efficient. The physical size of the stove fits well into the classrooms, which are roughly 25 m^3 and have desks for ten to twenty children. The stoves do not have a sealed combustion chamber or inlet air control. Heat output is handled by fuel loading. Room temperature swings are handled by opening and closing windows and doors. They are roughly made with poor quality welds obvious to visual inspection. There are sharp edges and weld splatter. The stoves were installed in November 2007. One stove had rust deposits at the back after less than 4 months in operation. The stoves are installed on wood floors in classrooms adjacent to student desks. The uninsulated sheet metal of stoves is unshielded and becomes very hot, and thus is unsafe for use around children. The stove pipe is a single wall stove pipe that exits through the window and is starting to corrode. The stove is loose and if touched readily moves. Creosote is leaking down the glass window from the piping. There is a 2-5 cm gap between the stove pipe and the window which admits cold outside air to the class room.

Figure 5. Typical air leaks around stove pipe.

We met with Merab Chrelashvili of the Georgian Industrial Group (GIG) to discuss the stoves built by them. GIG is involved in the development and manufacture of several heating products. These include electric room heaters, coal furnaces, and high end woodstoves for sale in Italy. Pictures and reports of these products indicate that they are well made and that the Kutaisi Truck Factory is capable of making very high quality products. There are however a couple of obstacles for them to manufacture wood heating stoves for use in rural Georgia.

Figure 6. Typical welds and sharp edges on Georgia Industrial Group stoves.

- GIG's primary interest is in manufacturing products for export. At the current time they are not involved in developing distribution channels and are not involved in direct sales to the consumer. This may change. An outside consulting group is developing a strategic business plan for GIG. This plan will cover the period from 2008-2015 and may encourage the GIG to develop a marketing group.
- While the GIG is capable of high quality manufacturing, they do not appear to have a product development group that can develop and design new consumer products. In the case of wood heating stoves, they are working with an Italian stove manufacturer to manufacture woodstoves for export. The stoves locally used were manufactured as a special order with limited engineering. This leaves a gap in the consumer market. The stoves for export are too expensive for most rural Georgian families, and the unimproved stoves, while the initial cost is affordable, are expensive to operate and are unsafe.

An improved stove is needed that is affordable, efficient, and safe, and the GIG is very capable of manufacturing this stove. However, they need access to a product design and engineering group to develop improved stoves and a marketing group to sell the improved stove.

<u>Murman Pharstskhaladze</u>

Murman Phartskhaladze is a sole entrepreneur working in the village of Khoni. He operates a shop from which he sells a wide variety of things ranging from groceries to boots. His stoves are hand made in a small shop with limited tooling. Because of the high cost of materials, he works with second hand sheet metal that he makes into wood heating stoves and wood water heaters. Based on a review of his shop and our discussion, it appears that he could produce 2-3 stoves a week or about 100 stoves per year. His stoves are priced at GEL 170.

Figure 7. Loose, poorly hung stove pipe.

We reviewed a stove in operation at his home, which he stated had been in service for 10 years. It was heating three rooms with about 40 square meters of space. He stated that he used about 7 cubic meters of wood each year and that the cost of wood was GEL 40 – 60 per cubic meter. The stove was badly warped and there was a crack between the combustion chamber and the oven. Although the stove was 10 years old, the warping and cracking of the stove appeared to be related to the metal used and not to general wear and tear.

Figure 8. Stove in Khoni.

Vakhtang Berishvili

Vakhtang Berishvili manufactures stoves in Ozurgeti in a workshop in a small portion of a plant formerly used for manufacturing. He has access to standard machine shop tools and has 1-2 employees who make stoves and biodigesters. He has several other businesses including a computer business. We reviewed a stove made by him in operation in the village of Pampaleti. The stove was in good working order, it was well made with no sharp edges, and the overall construction was good. The stoves are manufactured by hand without patterns, but the craftsmanship is good. The welds appeared to be good and the stoves were square. The stoves are priced at GEL 120 with recycled sheet metal and GEL 200 with new metal. He stated that he had sold 100 stoves per year for the past three years and that he could increase output significantly. Based on a review of his shop, these numbers seemed credible.

Figure 9 Vakhtang Berishvili's Shop

Bioenergia

Avtandil Bitsadze is the director of Bioenergia in Tbilisi. The manufacturing facility we visited was the most modern of the shops we have seen. We were not able to review an operating stove. Mr. Bitsadze stated that they were using patterns and stamps to manufacture the stoves. He was able to provide detailed information for his stoves based on studies done by the University of Twente in 1997. It appears that Bioenergia's stove design has changed significantly since 1997 and that this information is out of date. Mr. Bitsadze is conversant on the principles of combustion and stove design. We were told that the stove we reviewed had air ducts to

Figure 10. Stove construction details for Vakhtang Berishvili's stove.

Figure 11. Picture of Bioenergia stove

support secondary combustion; however, the combustion chamber was not insulated and there was no inlet air control. Based on this, it is unlikely that secondary combustion actually occurs. However, without an operating stove this could not be verified.

Stove cost for the Bioenergia stoves is GEL 250. This price is high relative to other manufacturers and may represent a starting offer rather than an actual selling price. Mr. Bitsadze stated that Bioenergia is making and selling approximately 100 stoves per month. However, in the past 2 months 120 stoves were made. Bioenergia has a second shop, and Mr. Bitsadze stated that Bioenergia could manufacture several hundred stoves per month if needed. They are hoping to paint the stoves and add other features in order to meet consumer preferences.

Observations on stove performance

All wood heating stoves reviewed had similar characteristics and designs. They are unimproved stoves with relatively low efficiency, and it is expected that the stoves will have the same efficiency and performance. The Bioenergia stove may be slightly more efficient if secondary combustion does occur. But any ranking based on efficiency should be based on testing of the stoves. Operation of all the stoves is primitive. There is no air control and the stoves burn quickly and hot. This means that the room being heated is subject to large swings in temperature from too hot to too cold. Room temperature is regulated with outside air, significantly lowering the overall efficiency of the heating system. The stove designs as currently installed and used are unsafe and should be reviewed and updated for safety.

Recommendations on stove improvement and working with stove manufacturers

All of the small scale stove manufacturers discussed efficiency and appeared to be interested in innovation and efficiency. In contrast the Georgian Industrial Group is primarily interested in developing high-end, high quality products for mainly export. It appears that this mixed manufacturing capability and interests could serve consumers well. A program could be developed that helps local manufacturers develop and manufacture more efficient woodstoves that better meet consumer need. The BP/USAID/OSCE Energy Bus Project could inform consumers about how to achieve more energy efficient homes and the advantages of improved woodstoves. As consumers reduce energy costs, the export quality stoves from the Georgian Industrial Group can become a desired consumer good that consumers can step into instead of growing into a natural gas or electric heating system.

Based on this, it is recommended that a set of workshops that help local stove manufacturers design and build improved stoves be developed. In addition, talks should be initiated with the Georgian Industrial Group on how to develop a distribution and marketing network in Georgia for high quality wood heating stoves. One approach would be to offer these to local manufacturers as an addition to their current line of stoves. However, there are other approaches that may be more appropriate.

3. Characteristics of Efficient Wood Heating Stoves

For the sake of this discussion, stoves are divided into three groupings based on efficiency. These are unimproved stoves, improved efficiency stoves, and high efficiency stoves. Unimproved stoves are basic fireboxes with chimneys. They lack airtight combustion chambers and do not control inlet air. They are generally unsafe. Efficiency can range in the 25 to 35% range.

Improved efficiency woodstoves have three characteristics in common. These are airtight combustion chambers, air inlet control, and smoke chambers.

- Airtight combustion chambers are essential. Some amount of air is required to support the combustion process within the stove; this is about 6 kg of air for every kg of wood burnt [G. L. Borman and K. W. Ragland, *Combustion Engineering*, New York: McGraw-Hill, 1998, p. 70.]. Woodstoves generally draw 1.5 to 3 times this amount, and stoves that are not tightly sealed can draw as much as 5 times this amount. This air comes from the outside and is heated to room temperature and then leaves through the chimney.
- Inlet air control works in two ways. It limits the amount of excess air moving through the stove, limiting the amount of air that needs to be heated. In addition, it provides a way to limit the burning rate of the wood, enabling the user to match the stove's output to the need for heat. As currently designed, Georgian heating stoves do not have the ability to be turned down; air flow through the stove and the combustion rate are set by the amount of fuel in the chamber. This results in large swings in heat output and large swings in room temperature. The user compensates for these with open windows and doors. In each home we visited, either a door was ajar or a window was open. In the school visited, windows were left open to control room temperature. Simply by providing the user with a means to control stove combustion rate will reduce wood usage.
- Smoke chambers provide additional surface area to transfer additional heat to the room. The goal is to increase the heat transfer surface of the stove relative to the size of the fire. A smoke chamber is separate from the combustion chamber. Simply adding a larger combustion chamber results in less surface area relative to the size of the fire and reduces the efficiency of the stove. Several of the stoves reviewed had some type of smoke chamber, not necessarily designed as a smoke chamber but rather as a heating source for an oven.
- Another relatively simple change that should be initiated is to add thermal mass to the stove. By adding thermal mass to the walls and the floor of the stove, the temperature of the stove would remain more constant and would require less frequent fueling.
- Because electricity is available in nearly all rural Georgian homes, consideration should be given to improving heat transfer from the combustion chamber to the house by using an electric fan.

These types of improvements can be readily made at low cost to the existing Georgian stoves and would likely improve stove performance into the 50+% range. This would be a significant improvement. These changes would not require substantial changes in how the user uses the stove.

High efficiency stoves improve efficiency and reduce emissions by controlling the path of the combustion gases through the stove. This provides more time to burn out undesirable combustion products and to support secondary combustion. These are the types of stoves for sale in the US and Europe. They are able to address both efficiency and emissions. Developing these stoves in Georgia will require the development of national stove standards and testing, partnership with US and European stove designers and developers, and effective market research on consumer preference and need.

Another group of improvements to woodstove efficiency focus not on the woodstove itself but rather on extracting heat from the chimney or stove pipe. These can be as simple as providing additional heat transfer surface area on the stove piping or as complex as providing an electrically powered flue gas heat exchanger. In all cases these are connected to the stove piping or replace a section of stove piping with a small external heat exchanger that provides additional heat transfer surface. They are relatively inexpensive and can be installed by the consumer. These can be provided as a household accessory that could significantly improve the overall efficiency of woodstove heating.

Recommendations

Stove efficiency and emissions are generally inversely proportional to each other. Small hot fires with excess air generally burn cleanly with few emissions. In contrast, smoldering fires can be very efficient but have high emissions. In rural Georgia stoves are generally small stoves with hot fires. A compromise that could be reached that would build on local practice would be to help small scale manufacturers develop small hot stoves with high thermal mass. An ideal solution would be to develop a relatively trouble free, clean, efficient stove that does not require the consumer to change their habits. But it is one that will require some design work and training.

4. Efficiency

While woodstove efficiency is often the first question raised when discussing stove performance, many aspects of stoves other than energy efficiency are important to consumer satisfaction. These include the heat output, the steadiness and duration of heat output between firings, creosote formation, durability, and safety. This section discusses heat output and efficiency. Section 5 discusses wood heating stove safety.

Stove efficiency is usually the first characteristic cited when a manufacturer is discussing their stove. In discussions with Georgian woodstove manufacturers, each manufacturer quickly stated that their stove was a high efficiency heating stove. And if pressed further, the manufacturer will say that the stove is 75% efficient. While the efficiencies cited indicate a desire to manufacture a high efficiency stove, the chances of any locally available stove being a high efficiency stove are slim. There is no efficiency testing done by the manufacturers, there is no equipment available to manufacturers to do even rudimentary testing, and there is no testing labs that could support testing if a manufacturer wished to test a stove. In addition, most manufacturers cannot clearly tell you what they mean by efficiency in engineering terms, but rather have a layman's view of efficiency, i.e. higher efficiency is better but with no clear metrics.

The overall range of US EPA approved wood heating stoves is approximately 65 to 80%. In general the efficiencies of manufactured woodstoves available worldwide is 35 to 80%. The Georgian stoves examined likely fall in the 35 to 50% efficiency range. In general the more airtight the stoves are the more efficient they are. In all Georgian heating stoves examined, the fire box was not airtight, the door did not seal or effectively keep air out, and there was no damper or mechanism for controlling air flow.

Woodstove efficiency is also dependent on the application. Leaky houses, poorly sealed stove piping, and poor temperature control reduce the overall efficiency of the household heating system. When practical use within a home is considered, it is likely that the effective efficiency of the stoves in rural Georgia is in the range of 25% or less.

Fundamentals of wood heating stove efficiency

Efficiency is an often misunderstood concept. Overall woodstove efficiency consists of three parts—combustion efficiency, heat transfer efficiency, and system efficiency. Combustion efficiency accounts for the amount of energy in the wood released during the combustion process and is reported as a fraction or percent. The heat transfer efficiency accounts for the fraction of the heat released by combustion that is used to heat the room and is reported as a percent or fraction. When people speak of woodstove efficiency, they are generally referring to combined combustion and heat transfer efficiency.

This component efficiency is the ratio of energy applied to a particular application divided by the energy consumed. In the case of a heating stove this can be written as

$$\eta = \frac{\text{Energy provided to the home by the stove}}{\text{Wood energy consumed by the stove}} \tag{1}$$

where η is the energy efficiency of the stove. This is a very specific measure of stove performance that provides a measure of its performance under testing conditions, e.g. continuous firing, a given feed rate, and dry wood. Actual stove performance can differ widely depending on how the stove is fired, the turn down ratio, and the fuel used. Stoves that are continuously fired are generally more efficient. Stoves that can be turned down consume less fuel as the consumer matches a stove's heat output to need and works to even out temperature swings. Dry fuel provides more energy and burns more uniformly resulting in more efficient operation. But, all things being equal, more energy efficient woodstoves use less wood than less energy efficient stoves

However, there is a problem when we discuss wood heating stove efficiency. That is, a significant portion of the actual fuel usage is determined by how the stove is used, how it is installed, and the overall energy performance of the home in which it is placed. And our overall goals are the reduction of wood use and reduction of the cost of household heating. Drafty, poorly insulated homes will require significantly more wood than tight, well-insulated homes. Without a more detailed study, specific energy usage numbers cannot be given for rural Georgian homes. But based on the few rural Georgian homes examined, I would estimate one-half to two-thirds of household heating energy is lost due to poorly sealed homes and lack of insulation. This issue of overall system efficiency directly addresses the amount of wood needed to heat a home. Overall system efficiency examines how the energy released by the wood is used to maintain the comfort of the home and is given in kJ/degree days. Overall system efficiency is similar to the efficiency of an automobile in liters of fuel per 100 kilometers.

The larger view of wood heating efficiency, which examines the stove and home together, while important, is beyond the scope of this report. This reports addresses the issue of woodstove efficiency. Generally woodstoves have a 98%+ combustion efficiency. In contrast heat transfer efficiency of woodstoves is generally 35 to 70%. Therefore, efforts focused on improving stove performance are generally focused on improving the heat transfer characteristics of the stove.

Stove performance testing

Stoves performance testing can be divided into three categories based on the purpose of the testing. These categories are 1) detailed testing to guide the design process, 2) testing to validate/certify a particular design, and 3) quality control testing. Testing to guide the design process is an integral part of the detailed design of a stove. Validation testing is used to ensure that a product meets a given set of specifications. In heating stoves validation testing generally includes efficiency, power level, emissions, and safety. Quality control testing ensures that once a stove design has been validated, the manufactured products continue to meet the specifications.

This discussion is focused on validation testing, specifically measuring the efficiency of a particular stove design. The basic procedure is a simple and quick measure of efficiency. Before implementation it will need to be formalized with specific details including wood moisture content, power level, and method of operation.

The efficiency of the furnace is defined as the ratio of the useful heat output to the energy input, and by convention is always based on the higher heating value. This can be written as

$$\eta = \left[\frac{q_{stove}}{m_{wood} HHV_{wood}} \right] \times 100 \tag{2}$$

Where q_{stove} is the heat transfer from the stove to the room, m_{wood} is the mass of the wood consumed, and HHV_{wood} is the energy content of the wood. The furnace efficiency may be determined directly by measuring the useful heat output and the fuel flow rate, or it can be determined indirectly from the products of combustion. Measuring woodstove efficiency directly by measuring the heat output of a woodstove is very difficult and requires measuring heat loss from a room and heat input to a room. It is much easer to measure the chimney losses. To measure the efficiency indirectly we perform an overall balance on the stove. This can be written as

$$E_{in} = E_{out} \tag{3}$$

Where E_{in} is the energy into the stove and E_{out} is the energy leaving the stove. The energy in the wood fuel is the energy in. Energy leaves the stove through heat transfer to the home and losses through the chimney.

$$m_{wood} HHV_{wood} = q_{stove} + q_{loss} \tag{4}$$

Where q_{stove} is the heating energy that the stove provides to the room and q_{loss} is the total energy lost from the chimney. The total energy lost from the stove, q_{loss}, consists of two parts— q_s, the thermal energy in the exhaust gases, and q_L, the energy needed to vaporize the water in the wood fuel. This can be written as

$$q_{loss} = q_s + q_L \tag{5}$$

Substituting into Equation 4

$$m_{wood} HHV_{wood} = q_{stove} + q_s + q_L \tag{6}$$

Rearranging and substituting into Equation 2 yields

$$\eta = \left[1 - \frac{q_s + q_L}{m_{wood} HHV_{wood}} \right] \times 100 \tag{7}$$

This result can be understood by considering that efficiency is 100% if there are no losses. The energy losses are the thermal energy loss from the chimney, q_s, and the heat to vaporize the water in the fuel, q_L. These losses can be written as

$$q_s = m_{exhaust} h_{exhaust} \tag{8}$$

and

$$q_L = m_{wood} LHV_{wood} \tag{9}$$

Where $m_{exhaust}$ is the mass flow rate of the exhaust gases, $h_{exhaust}$ is the enthalpy of the exhaust gases, m_{wood} is the wood consumed, and LHV_{wood} is the heating value of the wood fuel subtracting away the energy lost due to water. Substituting

$$\eta = 1 - \frac{m_{exhaust}}{m_{wood}} \cdot \frac{h_{exhaust}}{HHV_{wood}} - \frac{LHV}{HHV} \tag{10}$$

The mass of the air can be related to the mass of the wood by measuring the composition of the exhaust gases. The reaction balance is

$$C_aH_bO_c + d(O_2 + 3.76N_2) \rightarrow eCO + (a-e)CO_2 + \frac{b}{2}H_2O + \left(c + d + e - 2a - \frac{b}{2}\right)O_2 + d3.76N_2$$

The air fuel ratio is the weight of the air divided by the weight of the fuel. This can be written as

$$\frac{m_{exhaust}}{m_{wood}} = \frac{28e + 44(a-e) + b/2 \cdot 18 + (c + d + e - 2a - b/2)32 + d \cdot 3.76 \cdot 28}{(12a + b + 16c)} = A \tag{11}$$

Sustituting Equation 11 into Equation 10 and rearranging yields

$$\eta = 1 - A \cdot \frac{h_{exhaust}}{HHV_{wood}} - \frac{LHV}{HHV} \tag{12}$$

At first glance this process seems complicated. However this can be realized into a relatively simple spreadsheet program in which the user enters the moisture content of the wood and the measured values of O_2, CO, and CO_2. The chemical composition of wood can be readily known from ultimate analysis. This provides *a*, *b*, and *c*. By measuring CO, CO_2, and O_2 concentrations in the flue gas, *d* and *e* can be determined. With *a*, *b*, *c*, *d*, and *e* known, *A* can be determined from Equation 9. The HHV value of the wood is known from analysis, and the *LHV* can be determined from the moisture content of the wood. With *A*, *HHV*, and the *LHV* known, the efficiency can be determined using Equation 10.

An overview of the proposed testing procedure is given in Appendix 1.

Testing options in Georgia

As proposed the testing procedure requires a laptop computer and approximately $3000 to $5000 USD of testing equipment. There are several options for how testing could be done. Stoves could be brought to a central testing facility and tested, the stoves could be tested in the field by a testing firm, or alternatively, the stoves could be tested in the field at stove design workshops by a trained professional. The better a stove manufacturing firm understands the testing, the more likely they are to be supportive of building more efficient stoves. Based on this, it is recommended that woodstove efficiency testing be done in the field as a part of an overall stove improvement and design program.

5. Safety

In general significant attention is focused on designing and building woodstoves that use less fuel, are more efficient, and cost less. But little effort has been focused on the safety of woodstoves. Georgian household heating stoves are custom made in small production shops and sold directly to the consumer. As a result, stove safety is not subject to significant oversight by the Georgian State. In spite of this lack of oversight, household heating stoves are high temperature combustion devices with significant potential for injury and destruction of property. There was not sufficient time to determine the frequency and severity of stove related mishaps in rural Georgia as a part of this study. But in two cases it was observed that embers fell from a stove onto a wood floor while a woman was tending the fire. The stoves in the school visited were unshielded, with chimneys that were loose, unshielded, and adjacent to grade school student desks. When school officials were asked about safety, they replied that students were sometimes burnt by the stoves, but that the students needed to learn to be more careful. This was the same attitude voiced by manufacturers; however, responsibility for safety falls primarily upon woodstove designers, manufacturers, and providers.

In this safety discussion it is recognized that the primary purpose of these stoves is for household heating. However, in all cases in which stoves were observed, they were being used for heating of hot water, cooking soup, or some other cooking function. Even the stoves at the Sadmeli School were being used for heating water for tea. Because of this, although cooking was not considered in the efficiency discussion it is considered here. Hot water pots on stoves add an additional degree of safety concern. Pots can spill during movement (particularly if they contact raised surfaces on the stoves) and they change the balance of the stove.

Injuries associated with woodstove use are often classified as burns or scalds, whereas cuts and abrasions occur less frequently. Minor burns often occur from slight contact with a hot surface and heal quickly with little or no scaring. Contact with flames or boiling liquid can result in major burns that cause disfigurement, immobility, and sometimes death. Women who cook and heat their homes using unsafe woodstoves are susceptible to burn injuries. This

Table 1. Typical injuries caused by unsafe stoves.

Burns	• Flames exiting the fuel loading area ignite clothes and easily burn nearby children and adults • Excessive stove handle temperatures can lead to first and second degree burns • Excessively high surface temperatures cause minor to moderate burns with even minimal contact • Expulsion of embers from burning fuel cause burns to the body, particularly to the eye, and property damage
Scalds	• Protrusions along the upper edges of the heating surface create obstructions that cause heated liquid to be spilt • Stoves that do not maintain a stable upright orientation result in boiling contents spilt onto persons (especially children)
Cuts	• Sharp edges or points often result in cuts and may cause the stove to tip over if clothes become entangled
Property loss	• Containment of biomass and structural integrity are important so the fire stays within the stove • Large amounts of heat transmission to surroundings cause combustible materials in the area of the stove to be ignited

is especially true in societies in which women wear skirts that easily catch fire. These “skirt fires” can result in third-degree burns to the skin and muscle of the legs (Figure 12). In addition, long hair can easily catch fire and cause severe injury.

A scald is a common injury that occurs frequently to both children and adults. Women tend to receive scalds to the hands when moving cook pots by hitting improperly placed woodstove components that jut out from the heating surface of the stove. These obstructions also lead to spilling boiling liquid onto nearby children. More scald injuries occur when children tip cook pot contents onto themselves (Figure 13).

Figure 12. Third Degree Burns from Skirt Fire.

Cuts and abrasions occur through contact with sharp edges or points. These injuries generally are less severe than those associated with burns or scalds and receive less care. Unlit stoves are not completely safe since the stove does not need to be heated for these injuries to occur. Loss of property may result when flames or burning fuel come into contact with surrounding materials. Stoves that do not sufficiently enclose fire or have poor insulation can ignite structures if placed too close (Table 1).

One of the major challenges of implementing a stove safety program is gaining the support of stove manufacturers. If strict safety standards are created and used similar to those in the US and UK, all current stoves would be declared to be unsafe. This does not enable a manufacturer to improve their safety but rather is seen as threat. Because of this, it is recommended that in the near term stove safety be improved by taking four steps.

Figure 13. Scalded Child from Boiling Water.

These include:

1. Provide training and technical support on stove safety to manufacturers.
2. Implement a stove safety testing program based on rating stove safety in the same way that automobile safety is rated. For example, a stove could be rated as follows:

   Poor - major injuries could easily occur
   Fair - minor injuries likely, but reduced major injury risk
   Good - minor injuries occur, major injuries often avoided
   Best - significantly reduced risk any injury will result

   Stars or numbers could be used to convey the safety rating of the stove to consumers.
3. Connect stove safety to loans and grants available to consumers. Safer, more efficient stoves would qualify for better loans and grants.
4. Use the Energy Bus to educate consumers on stove safety. This can start the process of creating safer stoves.

A simple stove safety procedure that can be utilized by local manufacturers is given in Appendix B. This should be regarded as a starting point for thinking about safety rather than an ending point. It is a relatively simple procedure that can be used by local craftsman and manufacturers with a minimum of training. Implementing these guidelines and testing procedures would significantly improve stove safety. In the long term a more detailed approach to stove safety should be developed in cooperation with the Georgian government.

6. How stoves are accepted by the consumer

Often woodstove programs focus on efficiency and not on consumer preference. In fact, one of the key aspects of developing a sustainable woodstove program is how consumers perceive woodstoves. If stoves are perceived as time consuming, dirty, and something that the consumer hopes to replace with other more desirable technologies, then the consumer will be reluctant to invest in new woodstoves. In addition, manufacturers recognizing consumer preference will not invest in improved woodstoves. This creates a self fulfilling prophesy - because available stoves are of poor quality, consumers perceive them to be undesirable; because consumers do not want woodstoves, stove manufacturers do not manufacture improved woodstoves.

To overcome this downward spiral, high-efficiency, improved woodstoves need to become a product that every consumer would like to have if only they could afford it. However, it is important consumers should feel that they can purchase the product sometime in the future to encourage consumers to stay with wood heating rather than moving to other energy sources. In the few discussions in which rural Georgians were asked what kind of heating stove they would like to have if they had more money, none mentioned woodstoves, rather they discussed electric heaters and gas furnaces. This is a significant impediment for developing and maintaining a sustainable woodstove program. Consumers should strongly feel that improved woodstoves are a better choice than other types of household heating.

For wood stoves to strongly appeal to consumers, they will need several characteristics. While we have not performed a detailed consumer and market survey, stove characteristics that generally appeals to consumers are clean, easy to use (less time consuming), comfortable (temperature control), fuel efficient, attractive, and provide an image of upscale living. Meeting these kinds of needs will require developing multiple lines of stoves ranging from the current Georgian woodstoves to the woodstoves available in Europe and the US.

Recommendations

This is a long-term issue. A consumer survey should be performed to more clearly understand the role of consumer preference in the purchase of woodstoves. This could then be used to develop consumer education programs and new stove designs with appropriate capabilities and price points.

7. Plan for the Energy Bus

BP, USAID, and OSCE are working together to develop an Energy Bus that will travel through Georgia and provide education and guidance for rural Georgians on household energy efficiency. As a part of this, wood heating stoves need to be addressed. It is recommended that the Energy Bus have an improved stove with energy and safety improvements highlighted. Several of these improvements could be made by the users to existing stoves for which directions and perhaps improvement kits should be available. A passive and an electrically powered flue gas extractor should be available for demonstration, and directions on how to use a heat extractor should be provided. Handouts and tapes on stove safety and stove efficiency should be available to educate consumers.

Efficient stoves

The biggest challenge will be to build an improved stove for demonstration and establish the expected financial savings. It is recommended that

- The 4 different stoves available be tested to determine the approximate efficiency of each stove,
- Air control and a tight fitting door should be added to each stove, and then the stoves should be tested again,
- The stove should be modified to add additional surface area and then tested again, and
- Finally a stove pipe forced air heater should be added and the overall system tested for efficiency.

This will enable the expected fuel cost savings for each improvement to be determined, and this would enable consumers to judge the cost and the benefits of various stove improvements.

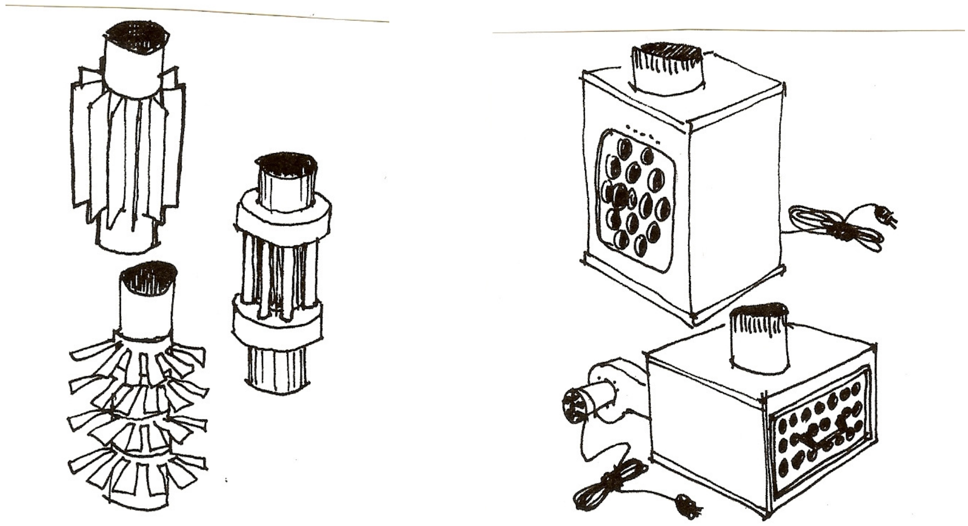
As the consumer demand increases for improved stove designs, local stove manufacturers will need training and support to create improved stoves. And there will need to be a program to certify their stoves as energy efficient and hence eligible for micro loans and grants. This training should be done by a local organization which would be trained by a stove design and testing expert. This would provide a low cost solution that will build capacity in Georgia to design, test, and build wood heating stoves.

Household energy efficiency

The Energy Bus should provide training and handouts on the importance of and how to caulk leaks around windows and doors, how to insulate homes, and how to seal doors against leakage. Simple measure like a tube of caulk and a “door step snake” could have a significant impact on household energy consumption.

Flue gas heat exchanger

One or two types of flue gas heat exchangers should be developed or purchased and demonstrated on the Energy Bus. These are easy to manufacture, can be installed by the consumer, and could have an immediate impact on energy efficiency.



(a) (b)

Figure 14. Flue gas heat exchangers (a) natural draft and (b) with electrically powered fans. [J. Shelton, *The Woodburners Encyclopedia*, Waitsfield, VT, Vermont Crossroads Press, 1976, p. 75.]

8. Recommendations

The overall performance of wood heating stoves in rural Georgia is poor. The stoves are designed and manufactured in an ad hoc fashion without a basic understanding of heat transfer, combustion, or safety. No testing equipment or procedures are available to guide the design and operation of the stoves. Because of this, stove manufacturers build wood heating stoves based on simple designs proven for their durability but with little concern for safety, efficiency, or emissions.

At the same time wood energy is an important part of the rural Georgian energy system. Natural gas is not available in all locations or is too expensive, and electrical heating is expensive. However, wood is a limited resource that is being rapidly depleted at a harvest to replacement ratio of 4 to 1. Because it is becoming scarce, wood is costly and needs to be shipped to communities from greater and greater distances. The problem of poor heating stove performance is compounded by homes that are poorly insulated and sealed.

Based on these observations, there are several recommendations. They are presented in a three-step approach—short term, intermediate term, and long-term changes. In the short term, there are some relatively small changes that can be made immediately to stove design that would significantly improve stove performance. In the short term (immediately) it is recommended that:

- Stove efficiency should be improved by including 1) an airtight combustion chamber, inlet air control, flue air control, and additional heat transfer area (smoke chambers). These changes should improve efficiency by 10 to 20% depending on application and how the stove is used. The cost of these changes is estimated to be less than 5% of the cost of the stove.
- Stove safety should be improved by 1) providing fire proof floor covering under the stove, 2) providing a tray to catch falling embers from the combustion chamber when the door is open, 3) promoting good craftsmanship (no sharp edges, not tippy), and 4) securing the stove pipe so that it is not loose and is out of the way so that it will not burn people. The cost of these changes is small and should not increase the cost of the stove by more than 5%. The floor covering can be installed by the user, and the cost will vary depending on consumer preference.
- The Energy Bus Project be implemented so as to provide an excellent forum to educate people on these issues. The Energy Bus should have an improved stove modified as recommended available that enables consumer to see the changes and know what to look for in an improved heating stove. The reduced heating costs, improved comfort, and safer operation should be highlighted.
- To provide consumers an opportunity to buy an improved stove, a program should be implemented in which the efficiency of small stove manufacturers' stoves is measured simply, the manufacturers are taught how to build improved stoves, and the efficiency of the improved stoves is verified.
- A program should be developed to address household energy efficiency. Rural Georgian homes are poorly insulated and drafty. It is likely that helping the consumer improve household efficiency would save as much or more wood as improving woodstove efficiency.
- Introduce flue gas heaters that attach to stove pipes. They are relatively simple to make and could immediately improve the performance of Georgian woodstoves.

This should be introduced to stove manufacturers as an additional product that could be offered to consumers.

These steps can be implemented almost immediately at low cost and are a starting place that will help build consumer understanding that heating costs can be reduced, their homes can be more comfortably heated, and that stove safety is a key concern in the home. By working with local stove manufacturers, these changes should be implemented along with a simple stoves testing program that could measure efficiency and help manufacturers improve their stoves. One of these improved stoves should be demonstrated on the Energy Bus. The Energy Bus should also educate consumers on stove safety. In addition, the Energy Bus could introduce a stovepipe heat extractor that would improve the overall efficiency of the heating system.

Over the next two years, a more in depth program that works closely with stove manufacturers and tests and validates stove designs should be developed. This program would help guide energy efficiency programs, aid customers in choosing high efficiency products, and help manufacturers develop improved stoves. This program should focus on three goals. These are 1) design and development of a small, high mass stove that can be fired at high power periodically and be used for heating water and cooking, 2) the development of a detailed testing procedure for efficiency and the certification of one or more labs to do this testing, and 3) an efficiency certification program.

In the intermediate term (0-2 years) it is recommended that

- Additional stove efficiency improvements should be implemented. These would include increasing the thermal mass of the stove to provide for better efficiency and increased consumer comfort. In addition, stoves should be designed to include a secondary combustion chamber.
- A more detailed stove testing program should be developed. Two laboratories have been identified that have the capability to perform this testing in their facility. On site testing would be a better solution. The cost for portable equipment for testing of simple efficiency is estimated to be approximately $4000 USD. In either case stove testing procedures would need to be developed and a local laboratory taught how to perform the testing.
- A stove certification should be developed in which vendors can sell improved stoves that can be verified to meet an efficiency standard, perhaps 50% efficiency, and to be safe.
- These certified stoves would then be eligible for micro credits and subsidies. This would encourage consumers to buy the improved stoves and manufacturers to build them.

It is likely that heating stoves will continue to have a place in rural Georgian homes for a long time. To support this, the long term stove design and manufacturing should grow to be like any other household appliance business with safety, performance, and emissions guidelines. Small-scale stove manufacturers will need to develop reproducible manufacturing techniques and modern stoves. A complete line of high-efficiency wood heating stoves that meet consumer wishes as well as their practical needs will need to be developed. Examples of the regulations, testing, and manufacturing processes can be seen in the EU or US. In the long term (3-10 years) Georgian stoves need to evolve to become high efficiency (70%+ efficiency) consumer preferred devices, similar to those in Europe and the United States. To achieve this will require Georgian testing and certification of stove designs, more advanced stove designs, and consideration of separating the heating and cooking functions of the stove. It is recommended

- A market based approach involving several stoves manufacturers and based on an understanding of consumer preferences and wishes should be developed.
- One or more testing laboratories that can certify stoves using a common stove testing protocol should be developed. This protocol should address heat output, efficiency, and emissions. It should be noted that there are several testing procedures available from various countries and that these vary widely. A Georgian testing procedure should be adopted from one of these standards. GIG has already established a relationship with an Italian stove manufacturer and will need to meet European standards for export. This could provide a starting place for adopting a stove testing procedure based on the European testing standards.
- A Georgian wood heating stove certification program should be developed. This could initially be based on the relatively simple tests discussed in this document.
- High efficiency heating stoves should be designed and manufactured. This should provide a range of stove options meeting consumer financial limitations, needs, and preferences. These designs could be developed in cooperation with manufacturers in the US, Canada, Norway, Sweden, Italy, and. other countries.
- Pellet fuel and stoves be developed as a way to take advantage of crop waste material and other biomaterials and improve heating stove efficiency.

Heating with wood can be a practical, environmentally sound practice provided that the stoves are efficient, clean, safe, and easy to use; the wood is harvested in a environmentally sound and sustainable way; and that the homes that are being heated are well insulated and energy efficient. This report has addressed only one of these three issues—wood heating stoves. Programs that address the issues of energy efficient homes could potentially have a greater impact and pay back than developing high efficiency wood heating stoves. Because of this, it is strongly recommended that a household energy assessment and improvement program be initiated as soon as possible. In addition, Georgia is in the process of changing how forests are managed. Regulations and educational programs that protect Georgian wood energy resources should be developed as soon as possible.

Appendix A

Proposed Efficiency Tests for Locally Manufactured Stoves

Intended Use of This Test

This test is intended as a means to obtain a reasonable in-field estimate of stove efficiency. This will enable the user to improve stove design and develop better more efficient woodstoves for use in home heating. Section 4 discusses the overall goals of woodstove testing and derives the mathematical basis for this testing.

Equipment needed

Gas analysis equipment capable of measuring CO, CO_2, and O_2 in the flue gas of a wood heating stove.

A precision balance

A temperature controlled drying oven to dry wood samples to determine wood moisture content

Sufficient wood (of uniform type and moisture content) to bring the woodstove to steady operation and maintain steady state operation for one hour.

Test Procedure

Prior to starting the test, wood moisture content should be determined in accordance with the applicable portions of ASTM D3172. This is a relatively simple test in which a sample of the wood is weighed and then dried at low temperature in a drying oven and weighed on a periodic basis until the weight remains constant, indicating that the wood is completely dry. From this the moisture content of the wood can be determined. Record the moisture content of the wood in the analysis spread sheet.

Set up the sampling equipment to draw a sample of the exhaust gases from the chimney.

Fire the stove using wood from a single species of tree and of uniform moisture content. Bring the stove to steady state operation and then continue operation of the stove for one-half hour.

After one-half hour of steady state operation record the CO, CO_2 and O_2 levels in the flue gas exhaust every five minutes for one-half hour. Record the CO, CO_2, and O_2 levels in the analysis spread sheet.

Summary

As discussed earlier, this procedure is relatively simple to implement and use. At the heart of the test is an analysis program based on the equation set presented in Section 4 that will need to be developed.

Appendix B

Proposed Safety Tests for Locally Manufactured Stoves

Intended Use of This Test

This test is not intended as a final or definitive woodstove safety test. Rather, it is intended as a starting point for improving woodstove safety in the absence of other guidelines. In the long term national standards for stove safety similar to those in the US and Europe should be developed.

Discussion

The starting point for developing a stove safety procedure discussed in this appendix are the existing standards used in the US for indoor and outdoor gas cooking appliances. These standards closely parallel the needed safety measures for woodstove use in rural Georgia. Georgian stoves are for heating and cooking and function like household appliances in accessible areas. Simply using the standards is not possible because the tests are too complex and require expensive equipment, limiting their use by local stove manufacturers. Because of this, these evaluation procedures were modified to allow testing to be performed by non experts in the field using relatively simple procedures and equipment. Specifically, equipment used to conduct the tests has been kept as simple as possible to allow testing to occur in the field when needed. As discussed in Section 4, levels of safety were included to show progress and encourage improvement rather than developing a safe/unsafe set of guidelines. Based on this, this procedure is composed of ten separate tests for safety. The combined result of these tests are used to rate the overall safety of the stove into four categories. These are:

Poor - major injuries could easily occur
Fair - minor injuries likely but reduced major injury risk
Good - minor injuries occur, major injuries often avoided
Best - significantly reduced risk any injury will result

In presenting the results to consumers, these levels could be represented with stars, numbers, or simply as Poor/Fair/Good/Best.

A rating of Best has been chosen to roughly model the level of safety required by the ANSI standards. However, the tests are different and Best does not mean that a stove meets ANSI safety ratings. Stoves receiving ratings below that of Best are less safe. By providing a range of safety ratings, it is hoped that stove safety can be improved more quickly as manufacturers consider possible tradeoffs between efficiency, emissions, cost, and safety, rather than rejecting stove safety out of hand.

Some criteria do not have an incremented safety rating and express a hazard as being present or not present. For example, the potential for contact with sharp edges and points will be given a rating of Best if none are present and a rating of Fair if they are. Other tests may yield a rating of Best if a certain risk cannot be associated with the woodstove. An example is that stoves secured to the floor or wall receives a rating of Best against tipping due to their immobility. However, multiple levels of safety ratings are given whenever possible to create greater diversity in the safety evaluation.

Proposed Testing Stove Safety Procedure

Equipment Needed

The following items are required for the safety evaluation process:

- One cook pot of the size most often used with the woodstove
- The typical biomass fuel used for the stove
- A tape measure or ruler, that can measure the height of the woodstove
- Cloth, rag, or some form of loose clothing
- Chalk used to make drawings on the stove and floor
- A thermometer to measure the air temperature
- A hand-held surface thermometer to measure stove surface temperature

Test 1: Sharp Edges / Points

Exterior surfaces of a stove should not catch or tear any article of clothing or cut hands during normal use. Sharp edges and points on a woodstove cut flesh or catch clothes and tip it over. Testing for this risk is conducted with a piece of cloth, rag, or loose clothing. The cloth is rubbed over the entire exterior surface of the woodstove. Areas are noted where the cloth becomes caught or torn.

The woodstove receives a rating of Best if the cloth does not get entangled and a rating of Fair if it becomes caught or torn. These are the only ratings for this criterion.

Test 2: Woodstove Tipping

Woodstoves should come back to rest upright after being slightly tipped from their original position. It is important that a woodstove be stable enough to maintain an upright orientation when in operation. Burning or boiling contents could otherwise spill onto persons or surrounding materials. This test is performed if the woodstove is not secured to the ground or wall. Stoves that are physically attached to the floor or wall receive a rating of Best in this category because tipping cannot occur.

All woodstove covers and/or utensils are left in their normal positions during the test. Fuel is placed in the loading chamber but not ignited. Several runs are conducted for this test, with the number of runs equal to the number of legs or corners on the base of the woodstove. This provides a number of trials that corresponds to the number of directions in which tipping most easily occur. Woodstoves with circular bases need four runs conducted with equal separations between each of the tipping directions (approximately one-quarter turn). Multiple tipping directions are used since the center of gravity of the stove may not be the geometric center.

A pictorial explanation of the test with a four-legged stove is shown in Figure B-1. The woodstove is tilted in directions facing outward and perpendicular to adjacent legs. The highest point on the side being tipped towards (which may be the cooking surface) is chosen and its height above the ground measured as the starting height. The woodstove is then tipped to that side until the stove begins to tip over on its own. The new height of the previously chosen point is then measured and recorded as the tipped height. Accurate and precise measurements should be taken with care because the change in height may be small. With these two measurements a ratio of the tipped height to that of the starting height is evaluated using a calculator and the following equation:

$$R = \frac{h}{H} \tag{B-1}$$

where R is ratio of heights, H is the starting height, and h is the tipped height at which the stove begins to tip on its own (fall over).

Table B-1 is used with this ratio to obtain the safety rating. The worst result of the trials is taken to rate the stove for its ability to counteract tipping. A cook pot used in this test would have better modeled a higher center of gravity but was removed to make testing easier. This was accounted for by slightly lessening the acceptable tipping ratios.

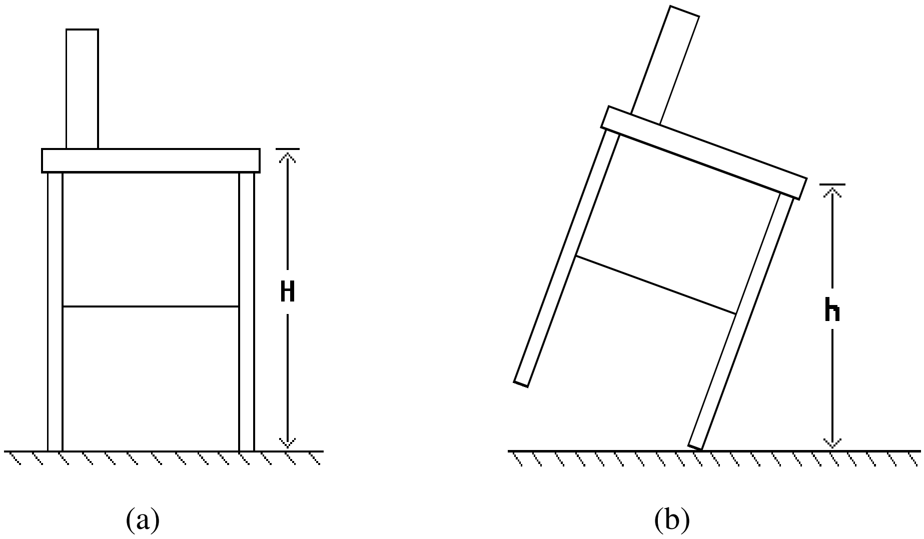


Figure B-4. Schematic of Height Measurements for Tip Test, (a) measuring H prior to tilting, (b) measuring h at the point of instability

Test 3: Containment

Flaming embers should rarely fall from the woodstove when it is overturned. Structural integrity and biomass containment is important to stop spillage if a woodstove tips over. Unless woodstoves are heavy or mounted, they will have at least some potential to tip. This test provides a way to gauge containment of biomass if the woodstove is overturned. Only movable woodstoves are tested; immobile stoves receive a rating of Best because they cannot tip. The woodstove is loaded with fuel from the last test, but not ignited. Small pieces of biomass with sizes approximately 1 to 3 cm^3 (about the size of a marble) are placed in the fuel chamber to simulate embers. A ruler or a tape measure can be used find dimensions if desired.

Table B-1. Metric for Tip Test.

Rating	Ratio
Poor	$R > 0.978$
Fair	$0.961 < R < 0.978$
Good	$0.940 < R < 0.961$
Best	$R < 0.940$

This test is conducted four times in each of the tipping directions found in Test 2. As previously stated, tipping directions are perpendicular to adjacent legs, or in the case of a circular base, approximately one-quarter turn apart. All operating equipment is left in place while the woodstove is tipped and allowed to fall. Visual inspection of the fallen woodstove for each run shows if biomass is expelled. The tip/inspection process is conducted until all runs have been completed.

A summation of the number of times wood fell from the woodstove is the result. If this total is two or less the woodstove receives a Best rating, three to five instances give a Good rating. Fair describes six to eight and a rating of Poor is given for woodstoves that allow embers to fall out nine or more times.

Test 4: Expulsion of Embers

Embers should have little chance of being expelled from the woodstove. The expulsion of embers from burning fuel can result in burns to the body or create property damage. Large embers have the greatest chance of starting a fire, while small embers are hazardous to the eyes. For the test the woodstove is loaded with biomass but not ignited. The usual pot or pan is placed in position to simulate cooking. Measurements are taken across each gap in the woodstove through which fuel can be seen. Table B-2 provides a relation between these measurements and the safety ratings. Smaller gaps receive better ratings because they are least likely to allow embers to pass through. The pot can be removed after this test.

Table B-2. Metric for Ember Expulsion.

Rating	Hole size (cm)
Poor	$d > 5$
Fair	$3 < d < 5$
Good	$1 < d < 3$
Best	$d < 1$

Test 5: Obstructions near Cooking Area

The area surrounding the cooking area should be flat. Handles or protrusions along the upper edges of the cooking surface create obstructions for pots being moved. This often results in heated contents being poured onto hands or nearby children. A ruler is used to measure the difference in height of the cooking surface to the height of any protrusions closely surrounding it. Typically these protrusions are handles along the sides of the stove or the combustion chamber encasement. The largest difference in height is used to rate the woodstove. A rating of Best is less than 1 cm, Good 1 to 2.5 cm, Fair 2.5 to 4 cm, and Poor has a difference in height greater than 4 cm.

Test 6: Surface Temperature.

Burns should not occur if the woodstove surface is touched for a short duration. Excessively high surface temperatures cause minor to moderate burns with even minimal contact. This contact is within the small amount of time it takes for the body to react after touching something warm. Cooking surfaces are not included in this test because they need to be hot in order to cook food. Because children are more sensitive to heat than adults, lower surface temperatures for heights within the reach of a child (0.9 m or less) are suggested. Adults are assumed to be able to come into contact with any height below 1.5 m. Heights above this are considered out of reach and are not tested.

Temperature measurements are taken at various points on the external surface of the heating stove. Horizontal heating surfaces such as burners or griddles are excluded. The first step consists of drawing a grid of chalk with approximately 8 x 8 cm squares along the external surface of the woodstove. Woodstove configuration determines what method is easiest for location referencing. Differentiating the lines with numbers or letters tends to be the most simple. Extra thick chalk lines marked at heights of 0.9 m and 1.5 m on the woodstove (if the woodstove is that tall) provide indicators of what areas are below and above the child line, yet below the maximum testing height.

Differences in temperature between the human body and the woodstove cause heat transfer. Larger differences in temperature produce burns more quickly and severely through higher heat transfer rates. Temperature of human skin varies from person to person and from body part to body part, making the ambient air temperature a steady yet approximate substitute. Material composition also affects heat transfer through differences in thermal properties. Composition can cause heat transfer to occur at different rates even though temperature differences may be similar. Materials are therefore grouped as metallic or nonmetallic to provide more accurate results.

The woodstove is loaded with fuel and ignited. More fuel is added when necessary until the woodstove reaches its normal working state. Surface temperature measurements are taken using a hand-held thermocouple while recording the following information: the data point, temperature above or below the 0.9 m child-line, and metallic or nonmetallic material. Maximum values are determined above and below the child-line and on both metallic and nonmetallic materials where applicable. The most deficient rating based on material, temperature, and location is used to determine the likelihood for a person to avoid burns when touching a woodstove. Differences between the ambient air and woodstove temperatures correspond to the safety ratings given in Table B-3. The temperature of the ambient air can be measured using a thermometer. The projected ranges for safe woodstove temperatures are then calculated. For instance, if the measured room temperature is 20 °C, then a "Good" rating for the temperature of metallic components below the child-line would be 58 < T < 64 °C.

Table B-3. Metric for heating stove Surface Temperature Test.

	Below child-line		Above child-line	
Rating	Metallic	Nonmetallic	Metallic	Nonmetallic
Poor	T>50	T>58	T>66	T>74
Fair	44<T<50	52<T<58	60<T<66	68<T<74
Good	38<T<44	46<T<52	54<T<60	62<T<68
Best	T<38	T<46	T<54	T<62

Note: T is the temperature difference between the heating stove surface and the temperature of the ambient air (°C)

Test 7: Heat Transmission to Surroundings

Woodstoves should not cause dangerously elevated temperatures on surrounding surfaces. Radiant energy transfer to surrounding areas can ignite combustible materials near the woodstove. This test is performed only if the woodstove will be placed within 10 cm of combustible material or has combustion chambers less than 5 cm in height from the ground. Procedures for this test are similar to that of Test 6, allowing for both tests to be done concurrently if chalk drawings are done before igniting the stove. Differences between temperatures of the wall or floor with that of the ambient air are used to create ranges of temperatures for each safety rating. These values are displayed in Table B-4.

The woodstove is placed in its normal operating location and orientation (if the test is not performed in the field with the usual stove location, a suitable location should be found as a supplement). Chalk is used to sketch a silhouette of the woodstove on the ground when

Table B-4. Metric for Environment Surface Temperature Test.

Rating	Floor	Wall
Poor	T>65	T>80
Fair	55<T<65	70<T<80
Good	45<T<55	60<T<70
Best	T<45	T<60

Note: T is the difference between the temperature of the wall/floor and the ambient air temperatures (°C)

looking from above. A silhouette is also sketched on the wall while looking towards the wall. The stove is pulled away and approximately 8 x 8 cm squares are chalked inside the silhouettes on the floor and wall. Additional squares are created two high (16 cm total) above the silhouette on the wall to capture risks from rising heat. Intersections of lines provide a form of reference. The woodstove is returned to its normal operating location and orientation and the fuel ignited. Fuel should be added until the woodstove reaches a stable, regular working state. Temperature is measured using a hand-held thermocouple at each line intersection while recording the data point and temperature.

Some measurements may be hard to take without moving the stove. In this case, the woodstove can be pulled away for a short period of time to take measurements. No more than one minute should transpire when taking data. The woodstove is then placed in its original position for a period of no less than three minutes to give time for surfaces to warm back up. This process of moving, taking data and replacing the woodstove occurs until all data points along the floor and wall have been checked. The maximum temperature on the floor and wall is used to find the most deficient rating used to describe the woodstove. For woodstoves that are designed to be attached to the floor or wall, the procedures of this test should be omitted. Instead the highest surface temperatures found in Test 6 are used by subtracting 15ºC to give approximated wall or floor temperatures. This accounts for loss of heat through the air, floor, or wall.

Test 8: Woodstove Handle Temperature

Woodstove handle temperatures should not reach a level where use can cause harm either directly or indirectly. Excessive woodstove handle temperatures cause improper use and lead to first- and second-degree burns and scalds. This test is performed on stoves that have components that may be handled during use. Examples are doors for the combustion chamber or handles to move the stove. Stoves that do not have components that need to be touched during use receive a rating of Best in this category. The stove is tested for this guideline when in its regular heated state, making it easy to complete along with Tests 6 and 7. Differences between the handle temperatures and ambient air temperatures are given in Table 5. The projected values for both metallic and nonmetallic handles can be computed in the same manner as done in Tests 6 and 7. Temperature readings are taken using a hand-held thermocouple. The highest temperature for each material is referenced against values in Table B-5. Safety for this guideline is given by the highest temperature difference.

Table B-5. Metric for Handle Temperature.

Rating	Metallic	Nonmetallic
Poor	T>32	T>44
Fair	26<T<32	38<T<44
Good	20<T<26	32<T<38
Best	T<20	T<32

Note: T is the temperature difference between the woodstove handle temperature and ambient air temperatures (°C)

Test 9: Flames Exiting the Fuel Chamber

Flames should not protrude from the fuel loading area. Flames that exit the fuel loading area can easily ignite clothes and burn nearby children and adults. Testing the woodstove with this guideline occurs while the woodstove is fully ablaze. Evaluation of the safety rating is done by observing the loading area for flames. The woodstove is given a rating of Poor if any flames exit and a rating of Best if flames do not. This test concludes the evaluation procedure, and the fire in the woodstove can be extinguished.

Overall Woodstove Safety Rating

An overall woodstove safety rating can be determined after calculating safety ratings for each criterion. The quality of each rating type is transformed into point scores based on the following: Poor-1, Fair-2, Good-3, Best-4. The results are summed for the overall safety rating. A stove can receive a maximum of 36 overall points. Woodstoves with 31 points or greater receive a rating of Best while those with 22 to 30 points are considered as Good. A Fair rating is given to stoves with 13 to 21 points and Poor for 12 or less points. This overall rating allows for various woodstove designs to be compared against their safety along with efficiency, cost, and fuel consumption.