1-1-2005

Risk analysis and safety evaluation of household stoves in developing nations

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Risk analysis and safety evaluation of household stoves in developing nations

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Mechanical Engineering

Program of Study Committee:
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Iowa State University

Ames, Iowa

2005

Graduate College
Iowa State University

This is to certify that the master's thesis of

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

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1. INTRODUCTION

Combustion of biomass is the primary form of household energy for nearly three billion people worldwide. Secondary methods of household energy production in developing countries include solar power and the combustion of propane and alcohol derivatives. Approximately 50% of all households worldwide and 90% of rural households utilize solid fuels for cooking or heating (Desai et al. 2004; Kamen 1995; Yevich and Logan 2002), with the remaining households in developing nations utilizing secondary methods of energy production. These forms of energy use create significant health, social, and economic consequences for low-income and impoverished families most apparent when cooking. These impacts include disease, pollution, injury, excess time spent gathering fuel, deforestation, and high fuel costs relative to income. Numerous state and non-governmental organizations have attempted to address these problems by developing several cookstove designs over the past five to ten years to replace traditional three-stone open fires. These organizations include the US Environmental Protection Agency, HELPs International, Trees Water and People, and the Aprovecho Research Center, to name a few. Their designs have focused on increasing fuel efficiency, decreasing fuel use, and reducing particulate emissions (Bryden et al. 2003; McCorkle et al. 2003; Smith et al. 2004).

These pursuits have been driven largely by the availability of relatively straight-forward fuel efficiency tests for biomass cookstoves developed in the past 10-20 years and the ability of researchers to adapt current air pollution testing methods towards stove analysis. In contrast design principles for the creation of safer cookstoves are recent phenomena. Because of this cookstove safety is seldom explicitly considered as part of the design process. Seeing that public safety is paramount in the design process (ASME 2003) a need exits for the establishment of safety guidelines and evaluation procedures. Currently there is only one published work over stove safety (Johnson et al 2005). This was the first attempt at creating standardized methods for safety evaluation and is restricted to biomass stoves. Therefore its scope is limited and does not include guidelines for stoves using alternative forms of fuel. More attention should be drawn to the hazards of all stoves used by impoverished peoples in developing nations. Furthermore added development of present safety evaluation procedures is warranted for greater ease of use. This thesis provides designers and manufacturers with a tested set of guidelines to increase the safety of their stoves, regardless of the fuel type and applicable by those with minimal capabilities and tools.

The creation of sustainable engineering practices and appropriate technologies are essential in the effort of global development. These efforts primarily affect poor families in developing nations. Household cooking is one area that has been emerging as a focal point of intervention for international developers. However these good intentions are often constrained within an inadequate mental construct due to an assumed "simplicity" of cultures and problems in developing nations. Efforts for stove improvement often focus on only one area and lack a holistic solution to problems. This leads to safety seldom being considered as part of the design process. The process of creating cookstoves to improve the lives of the world's poor can be well complimented by the introduction of safety measures. Safety should be considered a necessity in third-world appropriate technologies and not an expendable luxury.

This thesis examines hazards associated with cookstove use and proposes a set of safety guidelines for the evaluation of injury risk. Safety considerations include those that can be controlled by changes in stove design. Chapter Two discusses general stove design, introduces injuries incurred through cookstove use, and examines the varying needs and capabilities of stove users. Methods of stove use and associated hazards are covered in Chapter Three. Chapter Four provides an explanation of safety practices employed by indigenous peoples and examines existing safety standards in the United States for household stoves. A critique of these standards is given and includes possibilities for simplification to allow use by non-English speakers with minimal tools. An improved set of safety guidelines and testing procedures is introduced in Chapter Five. Field testing and implementation of the procedures are discussed in Chapter Six with explanation of findings that allowed for improvement and greater usability of the guidelines. Chapter Seven concludes the thesis with a summary and proposes additional research into stove safety. A set of cookstove safety evaluation worksheets is given in the Appendix D to provide a condensed format of the procedures that allows easy use in the field.

2. BACKGROUND INVESTIGATION

Fieldwork conducted in developing nations and numerous group discussions provided information needed for the establishment of a holistic set of safety standards. Analyses of cooking practices in developing nations gave insight on how culture may affect safety guidelines. Further understanding of how geography and culture influenced standard applicability was derived from assessments of living environments. The analysis of these cultural factors was closely coupled to stove design and fuel use. It was found that cookstove design varied greatly according to local cooking practices. This produced a need for acquisition of a large number of stoves from throughout the world to better obtain how design influenced safety. Data acquisition also included discussion of the various injuries incurred during cookstove use. The severity and frequency of injuries will be shown to be an important component of the safety ratings introduced in Chapter 5.

2.1 PRELIMINARY DATA SET

Acquisition of data occurred during fieldwork and discussions with residents and visitors of developing nations. Personal fieldwork included two visits to Honduras during 2005. These visits entailed the observation of cooking practices and discussions over stove design with a local producers. Information from other regions of the world was acquired through discussions with stove enthusiasts at the 2004 and 2005 Engineers in Technical and Humanitarian Opportunities of Service (ETHOS) Conferences. The conferences included presentations on current research in stove design and how living conditions affect stove use.

Additional information on stove design was obtained during attendance at two sessions of a stove-building camp organized by the Aprovecho Research Center in Oregon. People from around the world gathered at these events to discuss stove design and construct new cookstoves for later implementation.

Personal experiences and communications during the conferences and camps provided information over design and use in developing nations outside of those already visited. Conversations with Stuart Conway (Trees, Water & People) and Dean Still (Aprovecho Research Center) gave additional insight on cultural practices in Central and South America. Information on the living environment and cooking needs in Africa was obtained through dialogue with Ken Goyer, Harry Stokes (Dometic), and Mathew Langol (resident of Uganda). Cooking practices and life in the developing nations of the Mid-East and Asia were acquired through discussion with Lutfiyah Ahmed (Winrock International and resident of Bangladesh), Dean Still, and Angran Xiao (resident of China). Information on stove design was also obtained from those discussions, though additional insight was provided by Larry Winiarski and Mike Hatfield (Aprovecho Research Center). Further communication at the ETHOS conferences led to conversation over cookstove injuries with Don O'Neal and Richard Grinnel (HELPs International). The information gathered through these dialogues and personal experiences are presented in the remainder of this chapter.

2.2 LIFE IN DEVELOPING NATIONS

The vast majority of the world's population that rely on locally-built, open-combustion household stoves reside in developing nations. Their locations and cultures are diverse with principal areas of cookstove use being in Central America, South America, Africa, South Asia, and the Asian-Pacific. Since the inclusion of cultural factors has proved important in the implementation of appropriate technologies (Sinha 2002, Bannister 2002), the consideration of these human-factors is warranted for this work. Therefore the cultural differences between these regions were examined to ensure that the safety guidelines would be applicable yet effective. Cultural factors analyzed include family culture, cooking needs, and local stove manufacturing practices, materials, and capabilities.

Nearly all of the three billion home-built cookstove users live in poverty. These families who do not have the luxury of owning improved cookstoves can reside in either urban or rural settings. It should be stressed that urban dwellers do not necessarily have safer stoves than their rural counterparts because stoves are often hand-made within the home when finances are too low to buy improved stoves. However differences between rural and urban lifestyles are apparent in the type of stove used, what is cooked, and how fuel is acquired.

2.2.1 Overview of Cooking Conditions and Family Culture

Small one-room or two-room houses (see Figure 1) are typical areas for stove use in Latin America and Asia while many stove users in Africa live in refugee camps (see Figure 2). These homes provide little room for activities and can cause problems when cooking with children present. Children are often present during cooking when they have no outside activities (school, sports) and must stay with their mother. Since impoverished families often lack these activities and since developing nations tend to have patriarchal societies, children stay with their mother while she cooks. Therefore children may frequently be around unsafe stove designs. These patriarchal societies also tend to have women gathering fuel more frequently then their male counterparts (Mahat 2003), which can lead to injury by sexual assault. Another large safety issue arises from this gender inequality through the type of clothing worn by women. Dresses and skirts are the traditional female dress in many regions in Latin America and Africa. These forms of loose clothing easily catch on fire and yield severe burns.

Figure 1. Two-room home in rural Honduas.[1]

[1] Photo taken July 30, 2005.

Figure 2. Housing conditions in Ethiopian refugee camp.[2]

2.2.2 Cooking Needs

Cooking needs vary in relation to population density and culture (Edwards et al. 2004). Families in Latin America use corn tortillas and beans as primary food sources. Corn tortillas are made through preparation of the flour by simmering dried corn for hours. Then the flour is pressed thin and shaped before being placed on a hot flat surface (griddle) for a short amount of time. Beans are cooked in simmering water for up to three hours. All processes for preparing tortillas and beans require high levels of heat. Persons in Africa primarily cook corn-meal mush – a dough-like substance that is thickened when heated and rolled into balls to eat. Meat is sometimes cooked but it is often too expensive for the impoverished stove-users to buy.

[2] Photo courtesy of Harry Stokes.

Stoves are used domestically in urban and rural settings though a market does exist for informal commercial cooking in areas with high population densities. These family-business stoves are often bigger than their household counterparts and used for longer periods of time at higher powers to provide food for customers during many periods of the day. Additional benefits of stove use to domestic food consumption include light, heat, and a communal gathering point. These helpful characteristics are most often found with open-fire stoves or three-stone fires (Manibog 1984). Varying interests in stove characteristics result in a wide range of stove designs with different types and degrees of safety concerns. This presents a great need for the safety guidelines to have general applicability while still being steadfast to basic safety principles.

2.2.3 Expertise and Technology

One interest in developing the safety guidelines was that they were capable of being used by people with limited technical knowledge and equipment. This would allow the methods to be applied by stove designers in impoverished nations. One constraint on the complexity of the evaluation process is the level of education. This is of primary concern in rural areas though illiteracy and minimal technical experience is present in urban areas to a lesser degree. This deficiency may result in the inability to perform simple written tasks without pictorial representations. Another constraint on the evaluation procedures is equipment availability. Often the average impoverished citizen has access to only simple cutting tools and blunt objects. However occupations such as farming, construction, crafts, and masonry may have additional tools to assist in the evaluation process. Urban citizens have better access to tools due to a greater likelihood of access to advanced forms of technology (tape measures and calculators).

2.3 COOKSTOVE TYPES AND DESIGN

As a part of this study over 40 different cookstove designs from around the world were hand-examined (see Appendix A. Cookstove Data Set). Stoves were found to have sets of defining characteristics that allowed grouping into three categories based upon the type of fuel used: biomass, solar, and gas and liquid. This differentiation proved pertinent in the creation of a robust set of safety guidelines. Although ethanol and pyrolized gases are bio-fuels they are not considered with biomass but with methanol and propane due to their physical properties and methods of use.

Electric stoves were sometimes found in homes though use was typically restricted to people with a relatively good income. Additionally, the majority of electric stoves are built by multinational corporations and therefore often comply with accepted safety practices. Electric stoves also have some additional and inherent safety characteristics over other stoves – electric stoves did not use an open flame. Because of this electric stoves were not considered in the safety standards developed.

2.3.1 Solid Biomass

Most domestic forms of fuel consumption in developing nations arise from burning solid biomass (Perlack et al. 1997; Zhang and Smith 2005), with significant amounts being used in cookstoves (Bailis et al. 2004; Winrock International 2002). The dependency on biomass as the principal household fuel led to much research into its various forms and associated stove designs. It was often found that wood was the primary biomass fuel (as shown in Appendix A). Secondary or alternative solid biomass fuels include animal waste, agricultural residues, garbage, and charcoal. The use of these secondary fuels varies greatly depending on geographical location. This is the consequent of varying agricultural practices, technological knowledge, and husbandry.

Improved wood cookstoves are primarily characterized by a combustion chamber, a fuel loading area, and a place to rest cookware, as with the Eco-Lenca from Honduras (Figure 3). Further modifications to stoves may include the addition of a flat cooking surface, insulation, and a chimney. The Guatemalan Onil (pronounced "O'Neal" after its designer) is an example of a stove with these additions (Figure 4).

Figure 3. Honduran Eco-Lenca.[3]

[3] Photo retrieved October 2, 2005 [http://www.repp.org/discussiongroups/resources/stoves].

Both the Eco-Lenca and the Onil have insulation around the combustion chamber to provide hotter and cleaner combustion using less wood. This is important to decrease time spent gathering wood, yield faster cooking, and produce less pollution. The benefit of adding a chimney is that it increases airflow through the stove and vents products of incomplete combustion that would be harmful to breathe (Baxter & Hanna 2002). The flat cooking surface, or griddle, is useful in areas of the developing world that frequently make tortillas. Both stoves also increase safety over that of an open or "three-stone" fire by concealing flames. Still however, three-stone fires are used when versatility of cooking location is preferred over the benefits of the "improved" stoves.

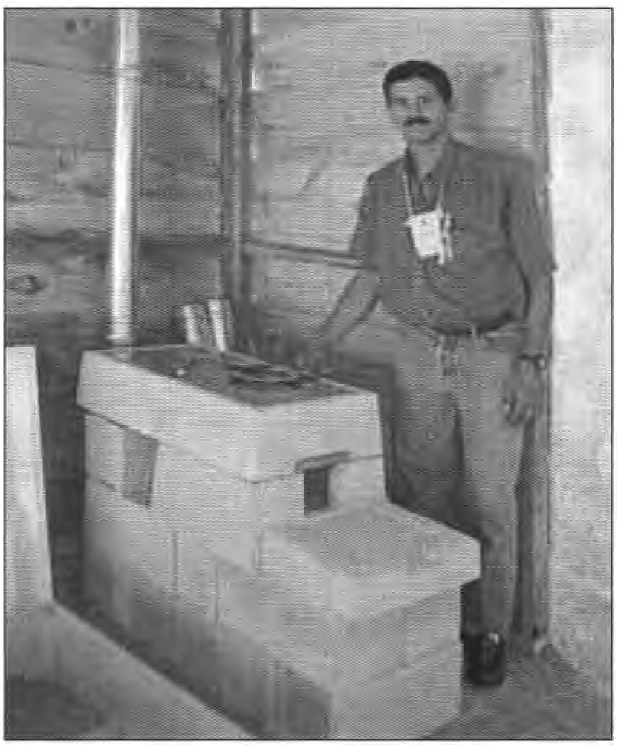


Figure 4. Guatemalan Onil stove.[4]

[4] Photo retrieved October 2, 2005 [http://www.onilstove.com].

Solid biomass wood substitutes are often renewable and provide further use for materials that would otherwise be discarded. Incorporated with the use of these alternative fuels are numerous changes in the basic wood stove design that need to be addressed. One fuel used to supplement wood as a solid biomass is agricultural waste. Many forms of agricultural waste (rice-hull, corn stalks, roots) can be burned directly or formed into briquettes for combustion. Direct burning is typically used when the ag-waste produces little pollution (though fuel density is also taken into account). Figure 5 depicts one of the many designs for a rice-hull stove. This model is from the Philippines.

Figure 5. Philipean rice-hull. [5]

[5] Photo taken at Aprovecho Stove Camp on August 22, 2005.

Charcoal briquette forms of agricultural residues and forest "waste" are used if burning untreated materials tends to produce high levels of smoke. These briquettes provide a denser fuel that burns for long periods of time with little pollution when compared to their constitutive material (Nienhuys 2003, Karve et al. 2001, Stanley 2003). Figure 6 depicts a "bee-hive" charcoal stove used in the Khumbu region of Nepal. Other wood alternatives include animal waste and garbage. They are used least frequently due to low energy capacities (capability to produce heat) and the need for high temperatures for clean combustion. Since this often requires a large combustion chamber for greater heat production the design does not often lend itself for use in household cooking.

Figure 6. Beehive charcoal stove from Nepal.[6]

[6] Photo retrieved October 2, 2005 [http://www.repp.org/discussiongroups/resources/stoves].

2.3.2 Gas and Liquid

Propane, natural gas, and bio-gas are common types of gaseous fuels used in developing nations for household stove use. Propane can be stored in reusable bottles while natural gas is often piped into the home from an exterior location. Bio-gas is similarly stored at the home like propane though often in larger containers. Bio-gas is created through capturing gases expelled by fermenting or decomposing biomass. Traditional methods of bio-gas production use cow dung in the decomposition process. Unfortunately this practice is inefficient and produces large amounts of unwanted by-product; therefore researchers are currently developing alternative means to create bio-gas using more user-friendly methods. For example, the Appropriate Rural Technology Institute of India has developed technology that uses starchy agrowaste, non-edible seeds, oil-cake of inedible oilseeds, and leftover food to produce bio-gas with minimal byproducts (Rural Energy from Agrowaste 2002).

Combustion of bio-gas and other gaseous fuels gives a reddish-blue flame and creates very little pollution (Acharya 2005), as shown in Figure 7 with a stove from China. Another useful aspect of gas stoves is that they often have a high turn-down ratio, meaning that the gas can be easily turned down to create a smaller flame. This is useful because it conserves fuel when changing from high-heat to low-heat cooking conditions. Another type of gas used in household stoves is producer gas. It is not pre-manufactured for use like the other gases, instead producer gas is created from the incomplete combustion of biomass. Producer gas is a yellowish smoke-like aggregation of the gaseous forms of solid biomass not fully burned in the fire. These gases can be ignited at high temperatures to create more heat and reduce air pollution through increasing the amount of complete combustion.

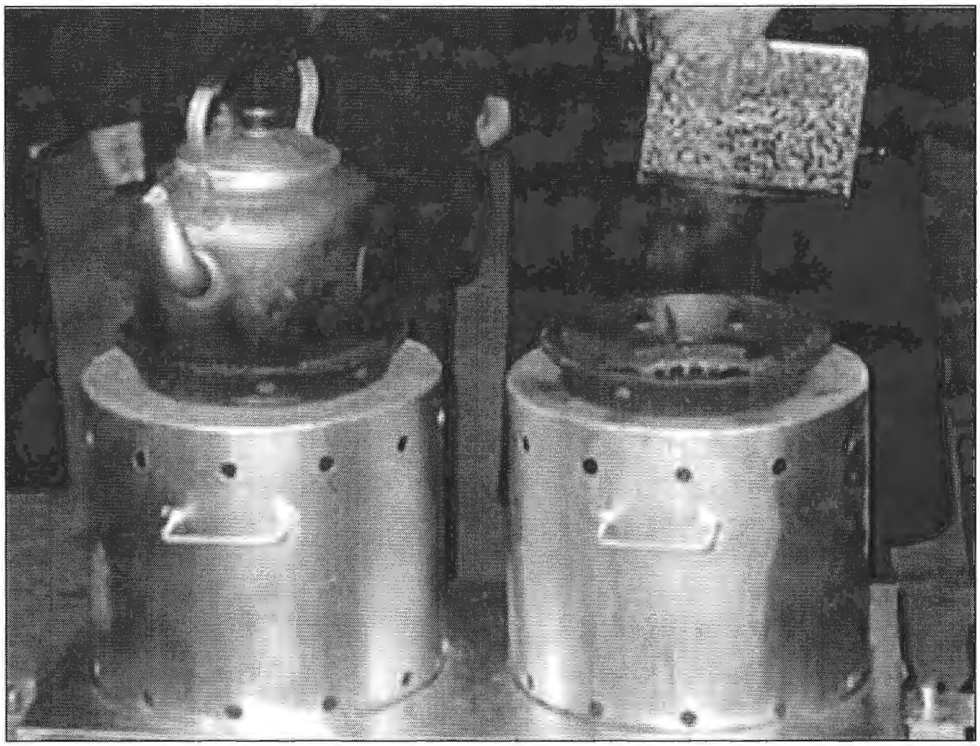


Figure 7. Bio-gas stove from China.[7]

Liquid combustibles often used in household stoves are kerosene, liquid petroleum gas (LPG) and alcohol derivatives. Liquid fuels are not pollution-free though they are several times less polluting than unprocessed solid fuels. Dissemination and storage of liquid fuels occurs in small individual containers rather than being pumped into the home or stored in large containers like gas. These storage characteristics make liquid combustibles highly portable. However, even though the storage characteristics of the various liquid fuels may be similar the methods of producing them are not.

Kerosene is distilled between temperatures associated with gasoline and diesel distillation. LPG on the other hand is not distilled but rather produced through compression and cooling of combustible gases. Varying blends occur but the composition is primarily

[7] Photo curtousy of Kirk Smith.

butane and propane. Further differences in production methods arise with alcohol derivatives. These fuels are renewable and have been undergoing an increasing amount of research (Bizzo et al. 2004, Stokes & Ebbeson 2005). For one, ethanol can be produced from the fermentation of agricultural residues. Another alcohol derivative is methanol and can currently be produced in large quantities using natural gas though movements are occurring to use portions of agricultural wastes for gas synthesis. An example of an alcohol-based stove used in Africa is shown in Figure 8.

Figure 8. Methanol stove from Africa.[8]

[8] Photo taken from Bryden et al 2005.

2.3.3 Solar

Solar energy is renewable and can be utilized for household cooking purposes. Proponents of this form of energy state its usefulness comes from the absence of collecting combustion materials and its lack of pollution (SunSmile 2004). This stove focuses multiple rays of the sun's energy in one location to produce great amounts of heat. With proper design this heat can be harnessed for cooking. The focusing materials that direct the sun's rays come in a variety of shapes and sizes. Some are large and rectangular and focus light into a box (see Figure 9). These stoves work through the use of radiative heat from the sun in addition to conductive heat from the warmed air within the container.

Figure 9. Box solar cookstove from Mid-East.[9]

[9] Photo retrieved October 15, 2005 [http://solarcooking.org].

A different form of solar cooking uses curved panels that direct the sun's energy to one location, the focal point. These focal-point solar cookstoves work solely by radiative heat and often employ small, concave mirrors or other reflective material for heating. Figure 10 shows an example of a solar cookstove using small mirrors and the focal point heating method. The cooking unit is centered and suspended outward from the panel to catch the reflections of the sun's rays. To achieve optimum efficiency the panel is rotated and kept in line with the sun.

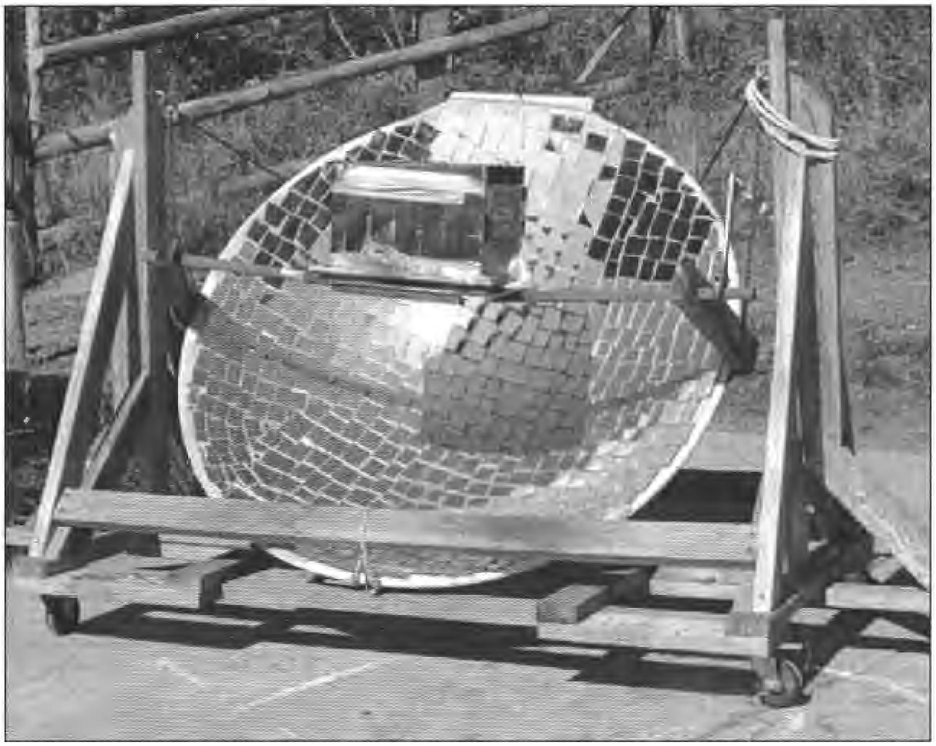


Figure 10. Focal solar cookstove.[10]

[10] Photo from Bryden et al. 2005.

2.4 COOKING INJURIES

An examination of the injuries associated with cookstove use provided empirical evidence for the creation of practical safety guidelines. Much of the information described in this section was obtained through discussions with stove producers working to increase safety of their own stoves in Guatemala (personal communication, Don O'Neal & Richard Grinnel, January 30, 2005). Discussion yielded definitions of four undesirable consequences of stove use, namely burns, scalds, cuts, and loss of property (though the last is not a direct injury). These unwanted occurrences can be stopped by persons in the design and manufacturing phases of stove creation (the primary audience of this work). Therefore injuries related to gathering or transporting fuel are discussed but not factored into the overall analysis due to the difficulty for designers to influence decisions made by users in this area.

2.4.1 Burns and Scalds

A burn is characterized by the destruction of skin cells through the absorption of more heat then can be dissipated in a given timeframe. Minor burns are superficial and entail redness to the surface skin layers. Intense or "deeper" burns go beyond the skin and can cause damage to the muscle and bone (see Figure 11). These major burns cause much disfigurement and result in a constriction of skin that restricts movement. Scald injuries have similar consequences to burns though damage does not often reach the bone. Even though scalds and burns produce similar results the method of injury occurs through different means. Whereas burns form through contact with hot surfaces or flames, scalds result from contact with heated liquid. Persons suffering from scald injuries often have much disfigurement and restricted movement (see Figure 12).

Figure 11. Third-degree burn from skirt fire.[11]

Figure 12. Scald from overturned pot.[12]

[11] Photo retrieved July 7, 2005 [http://www.fni.com/~dononeal/Safety.htm].
[12] Photo retrieved July 7, 2005 [http://www.fni.com/~dononeal/Safety.htm].

Common terminology for the destruction of cells through heat absorption is first degree, second degree, and third degree, with third being the most harmful. Medical professionals often refer to burns in terms of the thickness to which damage occurred (OPE UHCC 1999). Table 1 provides a description of burn/scald varieties.

Table 1. Description of burns/scalds. [13]

Degree	Surface Appearance	Color	Pain Level	Healing Time
First (Superficial)	Dry, no blisters	Pink	Painful	2-5 days with peeling, no scarring, may discolor
Second (Partial Thickness)	Moist blisters	Pink to cherry red	Painful	Superficial: 5-21 days, no skin grafting; deep: no infection, 21-35 days; infected considered full thickness, possible scarring
Third (Full thickness)	Dry and leathery, charred blood vessels visible	White, pearly mahogany, charred	No pain, nerves dead	Much scarring; large areas may need months with grafting; small areas weeks

2.4.2 Lacerations and Abrasions

Lacerations are open wounds in the skin (Cuts 2004) while abrasions are areas where skin cells have been rubbed away or "friction-burned". These injuries vary in magnitude but are generally less severe than those associated with burns and scalds. Lacerations can be superficial and heal in a matter of days or they may be deep into the tissue, resulting in weeks of healing. Deep tissue wounds may also slice through connective tissues and disable movement of body parts. Stitches are often required to mend these deep wounds. Abrasions on the other hand are confined to superficial layers of the skin though heal in approximately

[13] Table adapted from OPE UUHC 1999.

the same time span as cuts due to a lack of moisture for rebuilding cells. Both injuries cause minor to moderate levels of pain but increase the chance of infection. Without proper medical attention these injuries may worsen and lead to infections that result in fever, amputation, and possibly death.

2.4.3 House Fires and Property Loss

Though not an injury, property loss is considered an immense burden. House fires can result in injury both during and after the fire has been extinguished. First, burning homes may cause injury if occupants do not evacuate quickly. This is an important risk for children who are not yet able to walk. Risk can be extended to the whole village when uncontrolled fires spread to other homes. This is often seen in areas such as refugee camps where housing units are within a foot of each other. Typically built out of biomass, these refugee huts catch fire rapidly and winds can spread damage to many livelihoods in rapid succession. Without homes families may need to temporarily live outside and endure extreme weather, poisonous animals, or predators. Furthermore, uncontrolled fires may result in the destruction of forests and lead to loss of fuelwood, a source of food, and traded goods, further creating potentially harmful situations.

2.5 SUMMARY OF PRELIMINARY INVESTIGATION

Several elements in this chapter will be later shown to provide invaluable information in the creation of a standardized, easy to use, and effective safety evaluation. First, the factors associated with indigenous cooking practices and technological capabilities gave insight into what qualities would make acceptable safety guidelines and evaluation processes. Second, the large variety of stoves used in the developing world demonstrates the need for the guidelines to have general applicability, regardless of fuel type or local cooking needs. Lastly, information acquired on cooking related injuries shows the unfortunate consequences of improper stove design this thesis works to prevent.

3. IDENTIFICATION OF COOKSTOVE HAZARDS

Forty-seven stove models from throughout the world (see Appendix A) were examined to identify hazards that may lead to the injuries described in Section 2.4. This examination was essential in establishing a relationship between design and injury. Therefore this chapter provides detailed information on the injury-causing components of the cookstoves introduced in Section 2.3. Common cooking practices are also discussed to determine if varying methods of use affect the potential for injury. This relationship between cookstove hazards and injury will be employed in Chapter 5 to develop guidelines for designing safer cookstoves.

3.1 HAZARD ANALYSIS DATA SET

Hazard types and cooking practices were derived through personal experience and dialogue; which is similar to the data acquisition methods outlined in Section 2.1. Personal travels to Honduras provided observation of Latin American cooking methods and hazards associated with their stove designs. More information from Latin America was obtained through dialogue with Don O'Neal and Richard Grinnel of HELPs International (personal communication, January 30, 2005). Information on cooking styles and hazards from Africa was discussed with South African resident Kobus Venter (personal communication, November 19, 2005) and Mozambique resident Peter Coughlin (personal communication, November 5, 2005). However stove use and design hazards from the Mid-East and Asia were obtained through conversations with Bangladesh resident Lutfiyah Ahmed (personal communication, August 23, 2005) and Angran Xiao (personal communication, July 18, 2005), resident of China. These conversations proved necessary in the development of safety guidelines that could encompass the great variety of stove designs.

3.2 EXPLANATION OF STOVE USE

To develop an understanding of the potential safety hazards of stoves, methods of use were analyzed alongside the critiques of stove design. This examination provided insight on hazards that may not otherwise be apparent. These analyses allowed greater understanding of what circumstances led to injury.

3.2.1 Solid Biomass Stove Use

Methods of using solid biomass stoves differ depending on type of fuel. Wood stoves are often started by setting fire to small twigs or leaves in the combustion chamber. Bigger sticks are then placed into the fire to increase its intensity. Sticks are burnt lengthwise by putting one end into the fire and pushing the burning pieces of wood further into the combustion chamber as they turn to ash. Trimmed branches and small trees may often be used for fuelwood because they burn for a greater period of time, allowing longer durations without tending the fire. Variations in these methods arise with the secondary biomass fuels, namely agricultural residues, animal waste, and garbage. These fuels are typically briquetted and dried to increase their capacity to produce heat. Dried blocks of wood substitutes can be small and dropped into the combustion chamber, or large, and set burning individually underneath the pot.

Solid biomass stove use also varies according to what type of food is being prepared. Soup or foods that need to be boiled are placed within a pot set directly into the flames or on top of a hot griddle. A griddle can also be used at slightly lower temperatures to cook solid items that do not need large amounts of heat. These cooking temperatures can be adjusted through changing the amount of fuel input or adjusting airflow.

3.2.2 Gas and Liquid Stove Use

Liquid and gas stoves are most often used to boil contents in a pot (beans, corn). These stoves are lit using a match, flint and steel, or an electric starter, though the latter is rare. Heat output can be closely monitored through the ability to easily vary fuel flow. Valves and restrictor plates controlled by levers provide a simple and precise method to change the amount of fuel input. These regulating devices are also used to completely shut off the flow of fuel.

Liquid fuel is loaded into the stove from individual canisters whereas most forms of gaseous fuel are pumped into the house through pipes from an exterior location. These cooking fuels are often obtained outside of the home. Liquid and some forms of gas are sold in containers though natural may be piped in (the later is expensive and was rarely seen). Bio-gas and producer gas on the other hand may be produced in the home through methods described in Section 2.3.2.

3.2.3 Solar Stove Use

Solar cookers are most effective during times of the day when the sun is near its peak. This and minimal cloud covering give ideal conditions for solar cookstove use. Solar stoves are therefore used mostly in "sunny" regions of the world near the equator. Additionally the amount of fuel-wood available is another deciding factor to use these stoves since not all regions may have ideal conditions for solar technology. Cooking occurs by placing food into a closed container. One example of this cooking style is the "box" solar cooker seen in Figure 9. The sun's rays are trapped within the box, heating both the food and the air around the food to keep the contents warm. Conversely curved or "focal-point" solar cookers employ only radiative heat to cook food (as described in Section 2.3.3). Both types of stoves are positioned in relation to the sun for optimal collection of radiative heat.

3.3 COOKSTOVE HAZARDS

This section discusses how the injuries from Section 2.4 relate to the type of stove and how it is used. This connection provides a means to pinpoint cooking related hazards. Areas of concern include hot surfaces and open flames, cookstove stability and pot placement, cookstove integrity, sharp edges, and fuel hazards.

3.3.1 Hot Surfaces and Open Flames

Burns can range in severity according to Table 1 from Section 2.4.1. Minor burns occur from slight contact with a hot exterior surface. More severe burns may happen instantaneously if cookstove users touch un-insulated combustion chambers or chimneys. Other components of the stove that may become dangerously hot are handles used during cooking to open doors or adjust fuel input. These elevated temperatures can cause burns or other injuries from misuse if proper precautions are not taken. This is of primary concern with solid biomass stoves and liquid/gas stoves though some solar stoves have this problem as well. Stoves with griddles also pose a problem because the cooking surface looks safe but in fact easily burns when touched. Other burns may occur by touching the reflective surfaces on a solar stove. Burns incurred from coming into contact with the reflectors is related to the type material (metal, Mylar, mirror) and its capacity to conduct heat. Burns may also occur from solar stoves if hands are placed too close to the focal point.

Risk of burns through contact with open flames is most apparent with solid biomass stoves. Flames are well contained within some models (such as those with griddles) though most allow flames to drift outward and come into contact with the pot. This can yield open flames around pot handles or greater amounts of open flames when the pot is not being used. Liquid and gas stoves also present a hazard from contact with an open flame when no pot is present on the burner. These open flames yield the greatest risk to women using the stoves. This is due to the traditional female dress in Latin American and African cultures (as described in Section 2.2.1). Skirts can easily catch on fire and cause major burns to the legs and rest of the body. Traditional long hair may also ignite and therefore presents additional safety concerns.

3.3.2 Cookstove Construction and Center of Gravity

Non-ergonomic construction and a high center of gravity create a potential for scald and burn injuries. These design characteristics can easily lead to boiling liquid or burning fuel being spilt onto nearby persons, especially children. One cause of these injuries is obstructions near the edges of the cooking surface. This includes handles or other components that extend slightly above and near the cooking surface (see Figures C4,C5 in Appendix C for an example). They can collide with pots and pans being moved from the stove and result in hot food being spilt. This hazard is present with solid biomass and liquid-gas stoves due to use of open cooking containers.

Stoves may have a large potential to tip depending on the weight and placement of the center of gravity. Low weight and a high center of gravity are characteristics of a stove that can easily be tipped over. Stove overturnment leads to burns from hot surfaces, scalds from boiling water, and bruises from the blunt force of the falling stove. Stoves with a lower center of gravity or a wide base often decrease the risk of injury from this hazard.

Poor encasement of burning materials is yet another hazard associated with cookstove construction. This is a typical problem with solid biomass stoves when much of the combustion chamber is exposed. This creates two problems, one being that fuel can be expelled from the combustion chamber and burn surrounding people or materials, and the other for children who are learning to walk that they may fall directly into the fire. An additional hazard for children comes from cooking surfaces that are positioned low to the ground and are therefore easy to reach and produce burns.

3.3.3 Cookstove Integrity and Uncontrolled Fire

Poor cookstove integrity and uncontrolled fire lead to house fires and other forms of property loss. Cookstoves may be fragile or loosely assembled and fall apart when tipped over. For solid biomass and liquid stoves this leads to burning fuel being spilt onto surrounding areas. The release of flaming contents is not often present with gas stoves because fuel release is restricted by a regulator or valve. Also solar stoves do not have this hazard do to the absence of burning material.

Uncontrolled flames and intense indirect heat have the capacity to catch surrounding combustible materials on fire when the stove is standing in an upright position. This occurs with solid biomass or liquid-gas stoves when they are placed in close proximity to walls. Additionally solar stoves may cause unintended fires if mirrors are improperly directing the sun's rays. Even if physical injury does not occur the loss of a home is highly undesirable. Building a new home takes much time and money and can greatly lessen the economic stability of the family and result in further harm.

3.3.4 Sharp Edges and Points

Household stoves are hazardous even when they are not being used to cook. Sharp edges and points create a potential for cuts and abrasions regardless of use. Children at play around the stove are perhaps most susceptible to this hazard. They can be unaware that the stove may cause injury even though it is not lit. Women are also at high risk from these hazards when spending large amounts of time using the stove. The traditional female skirts may become snared and result in an overturned stove with similar injuries described in the previous section.

Home-made or hand-manufactured metal stoves typically are the most hazardous in this category. Solid biomass stoves made from clay or mud do not have this problem due to the inherent smoothness of the construction material. Liquid and gas stoves on the other hand may result in a few cuts and abrasions when they are manufactured by persons with little technical background or machinery. This hazard group may also be associated with solar stoves if the reflective material is made from metal or mirrors.

3.3.5 Fuel Concerns

Various injuries may arise in the collection, transportation, and storage of fuel. These injuries are prevalent with solid biomass and liquid-gas stoves though not with solar stoves because the fuel (sun's rays) need not be transported or stored. The collection of wood often entails risk from attack by predators or poisonous insects. Additional concerns over safety to females results when collecting wood in regions where they are susceptible to sexual assault. Furthermore musculo-skeletal injuries arise from carrying large bundles over long distances (see Figure 13).

Figure 13. Wood bundle transportation.[14]

The collection of flammable liquids (kerosene, LPG, alcohol) for home cooking occurs through a commercial provider and usually entails no risk. Unfortunately these liquids are sometimes consumed instead of being stored. This results in injuries to people (most often to teenagers) who drink the fluid to obtain a temporary drunkenness or sniff the fumes to provide a sensation of being "high". To discourage this improper use, alcohol derivatives can be denatured with a colorant to make them odiferous and unpalatable (Stokes 2004).

[14] Photo retrieved October 21, 2005 [http://www.fni.com/%7edononeal/page1.htm].

Solar fuel, or the sun, does not produce risks related to storage, transportation, and collection; it is merely used and does not entail those procedures. However, solar reflections from the mirrors are often more intense then looking at the sun itself. This creates a potential for injuries to the eyes when reflected light is not fully absorbed. On a separate note, gaseous fuel may be dangerous when appropriate piping and flow jets (burners) are not installed.

3.3.6 Summary of Hazards

A summary of the hazards previously described is provided in this section for better understanding of how specific injuries can be caused. Analyses showed that hazards could be grouped according to four types: burns, scalds, property loss, and cuts. Risks associated to the flammability of traditional dress, hair and methods of fuel collection, transportation, and storage are important though not included in the safety evaluation. They were discussed to provide a more complete view of potential hazards though this study focuses on those that can be affected by the designer. Box 1 lists ten concerns for stove safety organized by the type of injury they potentially create.

3.3.7 Hazard Reduction: Not a Simple Issue

It should be noted that improved household stoves often provide a safer cooking environment over that of a three-stone open fire yet they are not hazard free. For example, a cookstove may enclose much of the fire but still allow flames to surround the cookpot and burn the user's hands. In addition some biomass cookstoves have combustion chambers that become very hot and look seemingly safe but in fact have surfaces that cause burns.

Cookstoves may also increase the potential for some injuries. For instance, stoves made from metal induce a risk of receiving cuts from sharp edges not present in a three-stone fire. Further improvements such as increasing the height of the cooking area for added usability may entail greater risk as well. This modification is typically added to improve cooking comfort but at the same time increases the potential for scalds and burns to children by tipping the stove or pulling boiling water down onto themselves. These examples provide evidence that creating a safer cooking environment is not a side-effect of "improved" stove use and therefore reinforces the need for a tested and standardized set of safety guidelines.

Box 1. Hazard types

Burns:

- Large amounts of flames surrounding the cookpot
- Flames exiting the fuel loading area
- Uninsulated walls with excessively high surface temperatures
- Excessive cookstove handle temperatures
- Unshielded chimneys

Scalds:

- Obstructions along upper edges of the cooking surface
- Inability to maintain a stable upright orientation

Property loss:

- Containment of biomass and structural integrity
- Large amounts of heat transmission to surroundings

Cuts:

- Sharp edges or points

4. PROCESSES CONSIDERED

Consideration of established safety protocols was essential in the creation of an effective set of safety guidelines for household stoves in developing nations. Of primary interest was the lack of safety measures among indigenous populations of stove users. Secondly, stove standards in the United States were examined to provide insight into safety evaluation procedures that adhere to the most rigid forms of scrutiny. It will be shown that these conventional standards need modification and additional tests to fully encompass safety concerns of the hand-made stoves, yet do so in a simple, effective evaluation process.

4.1 ABSENCE OF INDIGENOUS SAFETY PRACTICES

It was found that stove safety considerations among indigenous populations were frequently not present before the introduction of improved stoves (stoves introduced in Section 2.3). Hazards of three-stone, open fires simply could not be avoided without advanced materials, equipment, and technical expertise. The creation of improved stoves to reduce risk of injury was often not possible due to these deficiencies. Design of improved stoves and increased safety practices were therefore often the result of interactions with "outsiders" or "developers" who brought technical expertise and knowledge of safety practices with them. The absence of indigenous technical skill and advanced safety considerations was the greatest difficulty in overcoming the creation of hazardous stoves and unsafe cooking practice. To increase knowledge and understanding of safety, an education process is discussed in Chapter 6 to create awareness of the findings in this study.

The lack of technical related safety knowledge sometimes led to stove design and cooking styles that actually increased the potential for injury (though the intention was often for increased comfort). For example, legs placed on the bottom of pots in Maputo, Mozambique raise the pots slightly off the ground to allow the fire to be more easily tended. Unfortunately this increases the possibility for children to fall directly into hot coals since the fire is no longer surrounded by stones, as with the three-stone (personal communication, Crispin Permberton-Pigott, November 5, 2005). These harmful modifications were seen to be reduced after the introduction of improved stoves and education. This further supports the need for an understandable and easy-to-use set of safety guidelines by demonstrating that indigenous understanding has lead to safer practices.

4.2 CONVENTIONAL WESTERN STANDARDS

Most safety standards present in the United States for domestic products are created by the American National Standards Institute (ANSI) or Underwriters Laboratories Inc. (UL). They are often considered the strictest safety measures in the world. These resources provided background information on an established set of procedures to evaluate the safety of cooking ranges and heating appliances. The strength of the standards is apparent from their wide-spread use and acceptance in design and manufacturing communities in the developed world. They contain an exacting and all-or-none rating system to insure that a high level of safety is maintained. However, their application is not possible towards hand-made stoves produced in developing nations due to the expanse of cookstove design diversity and a lack of testing equipment and indigenous technical expertise.

4.2.1 Indoor Range Safety

An examination of the ANSI standard "Household Cooking Gas Appliances" (ANSI 2000) gave insight on safety considerations for large in-home stoves. This was used instead of the standard for electric ranges because gas ranges better resembled stoves used in developing nations due to the presence of flames. Several safety considerations within the gas range standard were important in the development of design guidelines for traditional, hand-made stoves. Cuts and abrasions are referenced as a concern in the document seeing that exposed edges "shall be smooth" (p.3). The standard also states that surface temperatures should not exceed certain levels as defined within the document (p.82). These temperatures are based off a specified temperature difference from ambient air, the material used to construct the range, and the height at which the temperature is taken. The last criterion provides differential temperature limits under a certain height since children have an increased susceptibility to receive burns. Restrictions are also placed on handle temperatures (p.84) to restrict misuse throughout all cooking tasks. Additionally the standard gives temperature limits on any surrounding wall, floor, or structure (p.85) to insure there is no risk of starting a house fire.

4.2.2 Outdoor Cookstove Safety

The ANSI standard entitled "Outdoor Cooking Gas Appliances" (ANSI 1993) provides safety measures for smaller stoves that closely resemble the ad-hoc stoves used in developing nations. Again a standard based on gas stoves was used due to their similarity to the abundant use of open-flame cookstoves. Several elements within this standard were found to be closely related to those in "Household Cooking Gas Appliances," such as the non-allowance of construction that would permit cuts and abrasions (pp.2,4), limits on surface and handle temperatures to lessen the occurrence of burn injuries (p.35), and similar heat restrictions to the wall and floor that may lead to house fires (p.36). The most important addition this standard provides is metric to rate safety on the possibility of the stove to tip over (p.4). This is useful for rating biomass and liquid stoves when considering that burning fuel can spill out if a unit is disturbed. Further usefulness is derived from a tipping evaluation seeing that it characterizes a stove on how well it reduces scalds from over-turned pots.

4.2.3 Fireplace Stove Safety

Examination of the UL standard "Fireplace Stoves" provided yet more safety concerns applicable to cookstoves (UL 1995). First, similar temperature metrics were given for cookstove surfaces, handles, and surrounding structures as found in the ANSI standards (ANSI 1993, ANSI 2000). However the UL standard gave additional information that supported thoughts for taking temperature readings on the walls at heights above the cooking surface (pp.22,26,32). This is important when seeing that as heat rises it often creates greater temperatures on higher parts of the vertical walls surrounding the stove. The UL standard also suggested a timeframe of 1.5 hours for sustained maximum temperature before taking readings (p.30). This is a useful thought, yet proved to be too difficult to perform with biomass stoves and solar stoves having an inherently inconsistent heat production and distribution. Additional tests included concerns against tipping hazards (p.39). This test was not used due to the metric that stoves need to remain upright against a horizontal force of 667 N, which was simply not reasonable. Instead the tipping test from "Outdoor Cooking Gas Appliances" was found to be sufficient. More safety concerns mentioned that all welds and assembled parts should be of a good workmanship quality (43). Lastly, the standard provided safe dimensions for openings to moving mechanical components (48). This will be shown to relate to "shielding" that may restricting finger touch to hot chimneys.

4.3 MODIFICATIONS NEEDED TO EXISTING SAFETY STANDARDS

Simply using the ANSI and UL standards was not feasible due to the need for expensive equipment and performance of complex testing procedures. However their intentions were taken into consideration when developing a set of guidelines more applicable in developing nations. Similar temperature restrictions were used for stove surfaces, handles, and surrounding walls. However the procedures used to evaluate these temperatures required a sophisticated thermal-sensitive test probe that would not be available in developing nations. An infra-red thermocouple was the closest substitute and had much greater availability though still moderately expensive ($200 US). Conversely, some tests included very little or no data-taking methods with the safety guideline. Hired testing personnel in developed countries would have little trouble creating a testing method, but this may not be the case with non-experts in developing nations. This was improved upon by including step-by-step methods that could be chronologically followed for quick completion and accurate results.

The guidelines introduced in this thesis are intended to be applied in rural parts of the developing world as well as design laboratories. Within design laboratories persons often have greater knowledge and expertise than those who use the stoves in rural areas. However, these designers, often foreign, may not account for cultural considerations of stove use. This was taken in account through metrics including diverse cultural cooking styles and home life. To account for those non-experts in the field interested in evaluating stove safety, the guidelines in Chapter 5 reflect abstractions of basic principals to a more general and straight-forward testing process.

Design diversity was another aspect of cookstoves taken into consideration beyond that of the ANSI and UL standards. The ANSI standards provided safety ratings only for gas appliances and the UL standard only for solid biomass. Since stoves used in developing countries may be biomass, solar, or liquid/gas stoves (see Section 2.2), further modifications to existing standards were needed in the creation of holistic set of. These modifications further increase the applicability of safety measures to all parts of the developing world and expand the scope of this work to allow for an ever larger arena for safe cookstove design.

One more problem with the application of ANSI and UL stove standards in developing nations is their "all-or-none" safety rating. Cookstoves are manufactured by persons with varying capabilities and interests leading to differences in safety interests. This work is not intended to prescribe a restriction on who is able or who is unable to create stoves (as would be done by the all-or-none rating in Western standards). Rather, this work aims to motivate designers and manufacturers to enhance safety through using an incremental safety rating system that shows progress and encourages improvement. The tiered rating system introduced in Chapter 5 additionally allows for greater diversity in the evaluation process. This diversity provides information on areas that could use a little attention or areas where a much greater amount of consideration would be useful.

5. SAFETY GUIDELINES

This chapter presents a novel set of guidelines and safety evaluation procedures for household cookstoves used throughout the developing world. Simple equipment is introduced for utilization in the evaluation. This allows for people with minimal equipment in the developing world to perform most, if not all, safety tests. Also given are ten individual guidelines for use by designers to create safer stoves. Each guideline includes straight-forward, step-by-step procedures for easy use and accurate results. Additionally, an overall safety rating is proposed through a combination of individual test results.

5.1 SAFETY EVALUATION EQUIPMENT

Equipment used to conduct the test has been kept simple to allow testing to occur in the field when needed. One or two items may need to be borrowed or bought though the costs have been kept as small as possible. However, if some equipment cannot be acquired, such as a calculator or a thermocouple, much of the test can still be completed and improvements made in those areas. The items shown in Box 2 are those utilized during the safety evaluation process.

Box 2. Test Materials and Equipment.

- Cookstove
- Cookpot of size most often used with the cookstove
- The typical fuel used with the stove
- Tape measure or ruler, (SI units)
- Calculator for division (though long-hand can be used)
- Cloth, rag, or some form of loose clothing
- Chalk to make drawings on the stove, floor, and wall
- Thermometer to measure the air temperature (SI units)
- Hand-held infra-red thermocouple to measure cookstove and environment surface temperature (SI units)

The tape measure, or any length-measuring device, is used to determine the height of the stove during tests that examine its potential to tip. Also, the calculator is used in the tipping test for division purposes (though long-hand can easily be used). Cloth provides a simple material which can be utilized to discover where cutting and other penetrating objects protrude from the stove. Chalk on the other hand is used to make markings on the stove and its surroundings to distinguish areas that need temperature measurement. Other equipment employed in temperature analyses are a thermometer to measure air temperature, and an infra-red thermocouple to take surface temperatures.

5.2 RATING PROCEDURE

The inadequacy of the "all-or-none" safety rating system employed by conventional Western standards was shown in Section 4.3. Primarily they could not be used because the metrics were too strict and they had little diversity in level of stove safety (the absolute "safe" or "unsafe" did not provide this). Therefore an incremental rating system is introduced to show design progress and encourage improvement. Four levels of safety have been created in this graded system to address differing injury severity and likelihood for injury (see Table 2).

Table 2. Description of safety levels.

		Risk of Injury	
Degree	Description	Minor	Major
1	Poor	very high	moderate to high
2	Fair	high	moderate
3	Good	moderate	low
4	Best	low to unlikely	unlikely

The safety descriptions given in Table 2 account for minor injuries and major injuries. For example, risks associated with sharp edges and points would be rated based off minor descriptions due to the often non-severity of cuts and abrasions. Conversely a stove that can easily tip would utilize the major risk category considering the severe injuries that can occur from an overturned pot of boiling water. The safety grades in Table 2 may however apply to both levels of severity when a single hazard can result in multiple forms of injury. When this occurs, safety is assessed off the likelihood to cause minor injuries (an example being with open flames that may cause minor burns to the hands or major burns from skirt-fires),. This greater restriction from using the minor injury category is employed with the intent to prevent all forms of injuries, no matter the severity.

Typically the metrics given in the American National Standards Institute (ANSI) and Underwriters Laboratories Inc. (UL) are taken to represent cookstove safety levels in the Good category. They were not chosen to represent the Best level of safety due the minor inconsistencies likely to arise in methods and data taking by persons with little technical experience and equipment. Safety rating levels based off the Western reference points were determined qualitatively to provided increased sensitivity and allow for progress to be documented more accurately. This also provides stove designers and manufacturers a way to consider possible tradeoffs between efficiency, emissions, cost, and safety.

Some criteria do not have an incremented safety rating and express a hazard as being present or not present. One example of this arises during testing when flames exit the fuel loading chamber, canister or pipework. There is just no middle ground for leaking gas or flames engulfing the stove. Therefore the stove receives a Best rating if none of these areas have protuding flames and a Poor rating if they do. On the other hand, some tests may simply not employ the incremented rating system if the stove inherently does not have a particular hazard. One example arises when stoves are secured to the floor or wall. They receive a rating of Best against tipping due to their inherent immobility. However, multiple levels of safety ratings are given whenever possible to create greater diversity in the safety evaluation.

5.3 SAFETY GUIDELINES AND TESTS

Results from the risk analysis covered in Section 3.3 identified ten hazards associated with cookstove use. Each hazard was used as a reference from which to create corresponding safety guidelines and metrics. Some of the guidelines were adapted from existing ANSI and UL standards whereas others have been newly created to safeguard against hazards not addressed in conventional methods. Five guidelines from Western standards have been used and five added specifically for hand-made cookstoves. These ten safety assessments address hazards related to burns, scalds, property loss, and cuts.

Procedures in the evaluation are detailed for easy use and organized in a manner to allow efficient use of time. Examination begins with the stove unlit to conduct measurements when heat is not needed. Later in the process the stove is ignited and further measurements taken. Reasoning behind each metric and rating sytem is given as they are introduced. Additionally, a summary of the procedures, metrics, and all necessary equipment is provided in the Appendix D to allow easier application in the field.

Specific safety examinations associated with fuel risks, though important, have not been included in this analysis for several reasons. One reason is that several fuel related concerns have been covered within other tests (does fuel spill out, leak, or produce uncontrollable flames). Furthermore fuel concerns were left out of the evaluation process because this work focuses on improving safety through design and not through the regulation of fuel collection or storage practices. Therefore the methods do not include these outside and highly relative factors that cannot easily be affected in absolute manners by designers and manufacturers throughout the world. However, fuel concerns were provided in Section 3.3.5 to give better awareness of the many hazards associated with cookstove in hopes that designers and users may be able to use this knowledge in local efforts.

A few safety guidelines from the ANSI and UL standards (ANSI 1993, ANSI 2000, UL 1995) introduced in Section 4.2 may be useful to cookstoves but have been left out of the overall analysis due to poor applicability to cookstove design and manufacturing styles. For example, conventional Western standards present concern with the quality of construction and general "workmanship" of the stove or fireplace. This could be directly extended to cookstoves but the testing method includes dropping the stove or tipping it over to examine if parts stay intact. This is not helpful to traditional stoves made from clay or mud/sawdust because that may be the only available material. Furthermore, cookstoves are individually made, unlike the assembly line method used in Western factories, meaning that each stove produced may need to be tested due to inconsistencies in the hand-manufacturing process. Another test that was not tranferable to cookstoves was the tipping test from UL 1995. This test required the stove to remain upright during a horizontal force of 667 N. This large force would have toppled almost all un-mounted cookstoves (generally much smaller than the fireplaces under evaluation in UL 1995). Therefore the tipping test from ANSI 1993 was used since the outdoor cooking gas appliances under study more closely represented the general size of cookstoves.

One safety concern introduced in Section 3.3 stated that children may receive burns from placing their hands on hot griddles. This is an important concern but not included in the safety metrics due to the highly relative methods for a child to touch the heated griddle. It simply does not belong in the absolute, world-wide safety evaluation process. Establishing testing methods would require discovering a relation between a child's height, reach, hand size and the stove height and placement of griddle, not to mention what would then be considered an acceptable safety metric. This concern is not even addressed in the conventional Western standards under reference. Therefore it has been at least spoken of here to highlight another potential cause of injury for increased designer awareness.

5.3.1 Test One: Sharp Edges and Points

Sharp edges and points present on a cookstove can cut flesh or entangle clothes and overturn the stove. A cookstove without these hazards is a safer cookstove. Consequently exterior surfaces of a cookstove should not catch or tear any article of clothing or cut hands during normal use (ANSI 1993, ANSI 2000). The stove does not need to be lit for this evaluation. Equipment for testing this risk is a piece of cloth, rag, or loose clothing. The cloth can be rubbed gently over the entire exterior surface of the cookstove to find areas that catch or tear the cloth. These areas represent parts of the stove that have the potential to cut flesh or overturn the stove when clothes become entangled. It should be noted that stone or clay stoves may produce resistance to the material being run over the surface, but this should not be deemed unsatisfactory unless the stove moves or the rag becomes completely snagged.

The safety rating for this hazard can be determined by adding together the number of times the cloth becomes caught or entangled. This sum is then applied to the metric in Table 3. The reference point for this metric was determined from Western safety standards stating that no sharp edges and points be present (ANSI 1993, ANSI 2000), a Best rating. Ratings below Best have been formulated through beliefs that one, two or even three sharp edges/points may be somewhat hazardous but that four or more is simply poor construction.

Table 3. Metric for sharp edges and points.

Rating	Number of clothing snags
Poor	four or more
Fair	three
Good	one or two
Best	none

5.3.2 Test Two: Cookstove Tipping

It is important that a cookstove be stable enough to maintain an upright orientation when in operation. Otherwise, burning or boiling contents could spill onto surrounding persons or materials. Therefore cookstoves should come back to rest upright after being slightly tipped from their regular resting position (ANSI 1993). Testing for this hazard is performed only if the cookstove is not considerably heavy nor secured to the ground or wall. These immobile stoves receive a rating of Best in this category because tipping cannot occur.

All cookstove covers and/or utensils are left in their normal positions during the test. Fuel is placed in the loading area but not ignited (if applicable). To develop a thorough assessment of the stove's potential to tip, several runs are conducted during this test. This is done because it is not always clear where the center of gravity is located. The number of runs conducted is equal to the amount of legs or corners on the base of the cookstove. This provides a number of trials corresponding to the amount of directions in which tipping most easily occurs. For example, three tipping directions would be assessed for a three-legged stove, each spaced apart by roughly one-third turn (or 120°). On the other hand, cookstoves with circular bases need four runs conducted with equal separations between each of the tipping directions (approximately one-quarter turn or 90°).

A pictorial explanation of the test for a four-legged stove is shown in Figure 14. The cookstove is tilted in directions facing outward and perpendicular to adjacent legs.

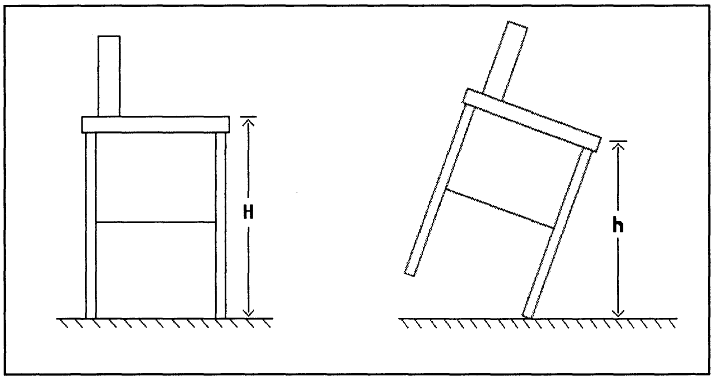


Figure 14. Schematic of height measurements for tip test.

Note: height H is measured prior to tilt, height h is measured after tilt

A height measurement is taken from the tallest point (may be the cooking surface) on the side being tipped towards. This measurement is regarded as the starting height (H). Next the cookstove is tilted to the chosen side until the stove is able to tip over on its own (when the center of gravity is directly above the point of contact with ground). The new height of the previously chosen point is measured and recorded as the tipping height (h). These measurements should be taken with care because the change in height may be small. With these two measurements a ratio of the tipping height to that of the starting height is evaluated using a calculator (or long-hand division) and the following equation:

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

where: R = ratio of heights H = starting height h = tipping height

Table 4 is used with this ratio to obtain the safety rating. The acceptable limit associated with existing standards (ANSI 1993) was at first chosen to represent the middle of the Good range. It was not chosen to represent the Best result because stove weight was not a consideration in the ANSI standard (like in UL 1995[15]). This was believed to be a minor inadequacy due to the great diversity of stove designs present in the developing world. Weight could have been allowed as another parameter in this test but was not included after seeing that stoves are rarely disturbed by an intense, impulse force. Therefore, the degree of tipping present before overturnment was seen as an appropriate test with the addition of greater restrictions.

Table 4. Metric for tip test.

Rating	Ratio
Poor	$R \geq 0.978$
Fair	$0.961 \leq R < 0.978$
Good	$0.940 \leq R < 0.961$
Best	$R < 0.940$

Note: R represents the ratio of the tipping height to the original height

The worst result of all trials is taken to rate the stove for its ability to counteract tipping. The use of a cookpot in this test would have better modeled a higher center of gravity but was removed to make testing easier. This was accounted for by further lessening the acceptable tipping ratios which moved the current ANSI standard limit to the lower end of the Fair range. Ranges outside of Fair correspond to 4-degree increments of tilt while the reference point ratio was calculated off 15 degrees from the ANSI standard (ANSI 1993).

[15] See Section 4.2.3 for reasoning on not using UL 1995.

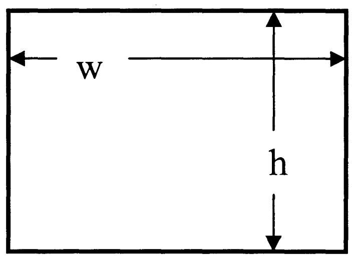
5.3.3 Test Three: Containment of Fuel

Burning fuel may be expelled from a combustion chamber or spilled when a stove becomes overturned. This can cause burns to the eyes and may also set fire to surrounding materials or construction. Therefore flaming fuel should rarely fall from the cookstove when it is overturned (ANSI 1993, ANSI 2000) and embers/burning fuel should have little chance of being expelled from the combustion chamber. The likelihood of injury is greatest with this hazard when using solid biomass stoves. Biomass tends to be loose or breaks up and can easily spill from the stove, also, the non-homogeneous nature of biomass gives rise to occasional "pops" of burning fuel that send embers flying.

Solar stoves do not need to be tested on this metric and receive a rating of Best due to the absence of burning fuel. Similarly, gas stoves receive a rating of Best due to the use of a regulating device that restricts uncontrolled fuel flow. This leaves solid biomass stoves and liquid stoves for evaluation. Liquid stoves using canisters may be thought to propose no danger with this hazard, however, some liquid stoves do not have a regulating device and are open when in use, which may result in some liquid spilling from the container when tipped over.

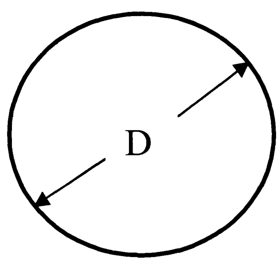
This test provides a method for determining the likelihood for stoves to release burning fuel whether standing upright or after being overturned. Enclosure of the combustion chamber or fuel canister is important to restrict the uncontrolled movement of fuel during use. This test is conducted with fuel still loaded from the last test, but need not be ignited. A pot or pan is placed on the stove in its regular position to simulate cooking conditions. Then, visual inspection is used to find areas that the fuel can be seen through (often around the sides of the pot or through the fuel loading chamber). These areas are considered as "gaps" and are measured to determine their approximate areas. Gap areas can be approximated using formulas for two simple geometric shapes (EQ 2,3) through choosing the closest resemblence. Gap location is recorded along with gap area for future reference when attempting to improve stove safety.

Square:



$$\text{Area} = w*h \tag{2}$$

Circle:



$$\text{Area} = \pi * D^2 / 4 \tag{3}$$

where $\pi \approx 3.1416$

All exposed areas are added and the sum (A) is matched to the metric given in Table 5. Stoves with smaller gaps receive better ratings because they are least likely to allow burning fuel to pass outside of the combustion area. The referene point for this metric was established through examinations of construction constraints of the stoves in Appendix A and was consequently given a Best rating. Ratings other than Best where chosen in regards to similar constraints in the design of biomass stoves (the principal stove covered by this test).

Table 5. Metric for fuel containment.

Rating	Area exposed (cm^2)
Poor	$A \geq 250$
Fair	$150 \leq A < 250$
Good	$50 \leq A < 150$
Best	$A < 50$

Note: A represents the area through which fuel is exposed

5.3.4 Test Four: Obstructions Near Cooking Surface

Areas surrounding the cooking surface should be flat so that pots being moved from the stove do not collide with protruding components and overturn boiling contents onto hands or nearby children. Typically, these obstructions include handles perpindicular to the griddle that are used for removing the cooking surface during cookstove maintenance (see Figures C4,C5 in Appendix C for an example).

This test is conducted on stoves that have small but solid obstructions near the cooking surface. However, some stoves may have pots that sit partially into the stove rather than on a cooking surface. An example of this is shown in Figure 15. This stove has a near-cylindrical extension to its combustion chamber that allows more time for hot gases to be in contact with the pot. Stoves with this form of construction are commonly said to have "skirts". These stoves automatically receive a Good rating because the impeding construction is easy to see yet it is still possible for a user to not lift the pot fully out of the skirt before tyring to move it, resulting in spilage of hot contents.

Figure 15. Stove with moderate-sized skirt.[16]

All other stoves that do not have skirts, aside from solar stoves, are judged for their potential risk for this hazard. Solar stoves do not need to be tested for this hazard and received a Best rating since food is often placed in a container or closed structure and cannot be "spilled out".

A ruler or tape measure is used to find the difference in height of the cooking surface to the height of any protrusions closely surrounding it. Often these protrusions are handles along the sides of the griddle or combustion chamber encasement that may extend above the

[16] Photo retrieved November 2, 2005 [http://www.repp.org/discussiongroups/resources/stoves/Crispin.]

cooking surface. The largest found difference in height (D) is used with the metric in Table 6 to rate the safety from this hazard.

Table 6. Obstructions near cooking surface.

Rating	Difference (cm)
Poor	$D \geq 4$
Fair	$2.5 \leq D < 4$
Good	$1 \leq D < 2.5$
Best	$D < 1$

Note: D represents the difference in height between obstructions and the cooking surface

In creating this metric, personal obeservations and discussions (Don O'Neal and Richard Grinnel, personal communication, Janurary 30, 2005) over injury risks were used to establish the safety ranges.

5.3.5 Test Five: Surface Temperature

This test is employed with the intention that burns should not occur if the cookstove surface is touched for a short duration (ANSI 1993, ANSI 2000, UL 1995). This short duration is the time it takes for the body to react after touching something warm. These warm surfaces can have excessively high temperatures that result in minor to moderate burns with contact.

The importance of this test is apparent since children have a tendency to touch cookstoves (Street et al, 2002) and women are likely to come into contact with stove surfaces after using it many times. Since children are more sensitive to heat than adults OPE UUHC, 1999), lower surfaces temperatures are suggested for heights within the accidental touch of a child (0.9 m or less). Conversely, adults are assumed to be susceptable to accidental contact at heights below that of 1.5m (ANSI 2000). Therefore heights above this are considered out of reach from accidental contact and are not tested.

Differences in temperature between the human body and the cookstove cause heat transfer. Burns occur when more heat is put into the skin than can be disipated in a given time frame. These rates of heat tranfer causing burns correspond to differences in temperature between the stove and body, stove material properties, and the contact area. Factors such as large temperature differences, high material heat conductivity, and large contact areas produce burns more quickly and severely through higher heat transfer rates.

Temperature differences between the stove and body are used instead of merely stove temperature measurements because the temperature of the air can greatly change results. Results vary based on air temperature since they produce different surface temperatures through convective heat transfer[17]. This would lead to highly circumstantial results and not allow different temperature tests to be compared to one another. Therefore the ambient air temperature is used as a reference point to allow this needed comparison. Another possible variable that would alter results is radiative heat from the sun. Therefore, the stove should be shaded during the evaluation (except with solar cookers).

Temperature measurements are taken at various points on the external surface of the cookstove. Horizontal cooking surfaces, such as burners or griddles, are excluded from the analysis because they need to be hot to cook food. Also, the chimney temperature is measured until Test 8. The first step in this test consists of using chalk to draw a horizontal-vertical grid composed of approximately 8 x 8 cm squares along the external surface of the cookstove. However, cookstove configuration determines what method is easiest for creating

[17] This means that with two stoves having the same heat of combustion, the stove surrounded by colder air would get a safer rating because the cold air would cool the surface and give it a lower temperature.

a grid for easy location reference. 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 cookstove (if the cookstove is that tall) provide indicators of what areas are below and above the child line yet below the maximum testing height.

In this test the cookstove is loaded with fuel and ignited. More fuel is added when necessary until the cookstove reaches its normal operating state (at least 30 minutes run-time). For solar stoves the unit should be in the sun for a similar duration of half an hour. First, the temperature of the ambient air is measured. Next, surface temperature measurements are taken using an infra-red thermocouple while recording the following information: data point reference, temperature, above or below the 0.9 m child-line, metallic or nonmetallic material.

Maximum surface temperatures 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 cookstove. Differences between the ambient air and cookstove temperatures correspond to the safety ratings given in Table 7. For example, if the measured air temperature is 31.5 °C, then a Good rating for metallic components below the child-line would be $69.5 \leq T < 75.5$.

Table 7. Metric for cookstove surface temperature test.

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

Note: Values represent difference between cookstove surface and ambient air temperatures (°C)

Existing standards (ANSI 1993, ANSI 2000, UL 1995) used a different method of calculating temperature limits. They involved an assumed ambient air temperature and created temperature restrictions based from this value. The tabulated temperature limits were then adjusted according to how many degrees the ambient air temperature differed from its assumed value. This did not seem efficient for use in developing countries where environment temperatures are highly irregular, therefore the numerous calculations required to change all tabular values were removed and replaced with the differences between the ambient and surface temperatures, which allowed for a smaller number of calculations.

The ANSI/UL reference point used in this test was placed in the middle of the Good range. These values were based off an assumed atmospheric temperature of 25°C. Other safety level ranges were created through qualitative experiment and discussion with indigenous Hondurans on what seemed to be “too hot” (personal communications, July 22-August 3, 2005).

5.3.6 Test Six: Heat Transmission to Surroundings

Large amounts of heat transmission to surroundings may ignite combustibles or construction in the area of the cookstove. Therefore cookstoves should not cause elevated temperatures on surrounding surfaces in the environment (ANSI 1993, ANSI 2000, UL 1995).

An exception with this test arises with solar stoves. They can direct large amounts of heat onto surrounding materials without showing much result until catastrophe. Therefore array collectors with open mirror configurations similar to those shown in Figure 10 of Section 2.3.3 automatically receive a rating of Poor. Solar cookers that are more enclosed (Figure 9) and have a better limit on where sun rays are directed receive a rating of Fair. This test has been simplified in this manner due to the great complexities associated with measuring radiative heat. Ratings were chosen with knowledge that solar stoves can produce fires without warning (personal communication, Norida Hudelson, January 30, 2005).

The following test procedures are used if the cookstove is placed within 10 cm of a combustible or has a combustion chamber less than 5 cm in height from the ground. If the stove is located outside these bounds it receives a rating of Best. For cookstoves that are designed to be attached to the floor or wall, the procedures of this test should be omitted. Instead the highest surface temperatures on the stove near where it attaches to the ground or wall are used for evaluation in this test.

Preparatory 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. First, the cookstove 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 alternative location can be used). Chalk is then used to sketch a silhouette of the cookstove on the ground when looking from above. A silhouette is also sketched on the wall while looking at the cookstove from the side, towards the wall. The stove is pulled away and approximately 8 x 8 cm squares are chalked in a horizontal-vertical grid inside the silhouettes on the floor and wall. Since heat rises, additional squares are made above the top of the sihouette on the wall to assess any flammability concerns of the wall above the stove. Two additional squares in height and as wide as the stove can be used (adapted from UL 1995). The intersections of grid lines provide a form of reference for taking temperature data and finding trouble spots. After making the grid, the cookstove is returned to its normal operating location and orientation with the fuel ignited (if not already ablaze). Fuel should be added until the cookstove reaches a stable, regular working state, at least 30 minutes. Temperature is measured using an infra-red thermocouple at each line intersection while recording the data point and temperature.

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 8 and utilized in the same manner as those from Test Five. The maximum temperature on the floor and wall is used to find the most deficient rating to describe the cookstove.

Table 8. Metric for environment surface temperature test.

Rating	Floor	Wall
Poor	$T \geq 65$	$T \geq 80$
Fair	$55 \leq T < 65$	$70 \leq T < 80$
Good	$45 \leq T < 55$	$60 \leq T < 70$
Best	$T < 45$	$T < 60$

Note: Values represent difference between environment surface and ambient air temperatures (°C)

Temperature limits associated with current ANSI and UL standards were again chosen to represent those in the middle of the Good range; other ranges created by qualitative testing on what seemed to be "too hot" for wall and floor temperatures. An exception arises with this metric if the stove is placed next to walls made of straw or hay. Instead, the exceptable wall temperatures should correspond to those given for the floor. This increased restriction accounts for the greater flammability with straw/hay over that of the plywood testing walls used during ANSI and UL analyses.

To complete this test, some measurements on the floor or wall may be hard to take without moving the stove. In this case, the cookstove can be pulled away for a short period of time to take measurements (use of hot-pads or other heat-resistant material for the hands may be necessary). No more than one minute should transpire when taking data with the stove moved away from its original position. After the data taking period, the cookstove is placed back 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 cookstove occurs until all data points along the floor and wall have been checked.

5.3.7 Test Seven: Temperature of Operational Construction

Parts of the cookstove that need to be touched during regular operation should not reach a level where use can cause harm either directly or indirectly (ANSI 1993, ANSI 2000, UL 1995). Components where excessive temperatures may occur, yet need to be handled during regular use, include doors for combustion chambers, handles to regulate the flow of gas/liquid, or hatches to open some styles of solar cookers. Stoves that do not have forms of these components needing 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, or after at least 30 minutes of use. This allows Test Seven to be easily completed with Tests Five and Six. The temperature differences leading to burns/misuse are given between the operating construction and ambient air temperatures in Table 9. The projected values for both metallic and nonmetallic handles can be computed in the same manner as done in Tests Five and Six.

Temperature readings are taken using an infra-red thermocouple. The highest temperature for each material is referenced against values created from Table 9. Safety for this guideline is given by the most deficient rating found.

Table 9. Metric for temperature of operating construction.

Rating	Metallic	Nonmetallic
Poor	$T \geq 32$	$T \geq 44$
Fair	$26 \leq T < 32$	$38 \leq T < 44$
Good	$20 \leq T < 26$	$32 \leq T < 38$
Best	$T < 20$	$T < 32$

Note: Values represent difference between handles and ambient air temperatures (°C)

Again, ANSI/UL standard limits were placed within the middle of the Good range with other ranges created through personal experience and communication with indigenous Hondurans on what seemed to be "too hot" for easy use (personal communications, July 22-August 3, 2005).

5.3.8 Test Eight: Chimney Shielding

Chimneys can become extremely hot during use and easily cause burns. The high temperatures present on a chimney are from hot flue gases leaving the stove, often creating higher temperatures on the chimney than anywhere else on the stove. To prevent these injuries, insulation can be placed around the chimney, or a cage may utilized to "shield" people from accidental contact (see Figures C5,C6 in Appendix C for an example). Solar stoves do not have this hazard due to the absence of hot flue gases and a chimney (they consequently receive a Best rating).

Testing for this hazard occurs in two steps. First, the ambient air and chimney surface temperature are taken and applied against Table 7 (Test 5: Surface Temperature) to determine a safety rating. If that rating is unacceptable for the designer or user, a shield can be employed to increase safety from dangerous chimney contact. If a shield is being used, the exposed area allowed to the chimney provides a method of determining risk of contact. Since chimineys are nearly always made from a uniform pattern for reduced cost, only one “gap” in the shielding need be measured (using EQ 2,3 from Section 5.3.3). This single area is applied against Table 10 to provide an alternate method, as opposed to temperature differences, in calculating risk of injury from touching a chimney.

Table 10. Metric for chimney shielding.

Rating	Hole size (cm^2)
Poor	$A \geq 300$
Fair	$100 \leq A < 300$
Good	$10 \leq A < 100$
Best	$A < 10$

Note: A represents the area of one segment in the pattern of the shielding

The Best rating was established as a reference point in this metric through experiments that 10 cm^2 area is unlikely to allow the accidental slip of a finger to touch the stove. Whereas 100 cm^2 corresponds to the area likely to disuade accidental chimney contact from a grown boy’s hand. The last level, 300 cm^2, corresponds to an area that should prevent accidental touch of an elbow or side of an adult’s arm.

5.3.9 Test Nine: Flames Surrounding the Cookpot

Flames touching the cookpot should be concealed and not able to come into contact with hands or clothing. Large amounts of flames around the cookpot can easily ignite clothes or produce severe burns to the hands and other parts of the body. Cookstoves that fully enclose all flames (such as stoves that use a griddle) receive a rating of Best because there is no danger from a stray flame. Solar stoves also automatically receive a rating of Best in this category because no flames are present (any unintended heat transfer associated with stray solar rays was covered in Test 6).

During this test the stove is loaded and fully ablaze as in the past four tests. The typical cookpot for the stove is placed in its normal operating position to simulate how the stove is most often used. Amounts of uncovered flames surrounding the cookpot are observed and applied to the metric given in Table 11.

Table 11. Metric for flames surrounding cookpot.

Rating	Amount of Uncovered Flames Touching Cookpot
Poor	entire cookpot and/or handles
Fair	most of cookpot, not handles
Good	less than 4 cm up the sides, not handles
Best	none

The Best rating was established first as the ideal safety rating for this hazard since there is no risk associated with this hazard if no flames are exposed. Second, the Poor rating was created from the worst possible scenario. Then the Good and Fair ratings were taken as intermediate points between these two extremes.

5.3.10 Test Ten: Flames/Fuel Exiting Fuel Chamber, Canister, or Pipes

Flames or fuel should not protrude from any fuel loading area, storage container, or flow-pipes during use. Uncontrolled flames that exit these areas very easily ignite clothes and burn nearby children and adults. Furthermore, flames or fuel exiting fuel canisters or pipes, as with liquid/gas stoves, show fuel leaks and pose great risk. On the other hand, flames exiting the fuel loading chamber characterize biomass stoves[18]. Solar stoves conversly are characterized by a Best rating due to their inherent absence of flames and fuel leaks.

Testing the cookstove against this guideline occurs while the cookstove is fully ablaze. Evaluation of the safety rating is done by observing the specified areas for flames or fuel leaks. Biomass stoves are checked to see that no flames exit the fuel loading area. Liquid fuel cansisters can be observed to see if any "wet" areas are present along canister walls or the floor. As for gas fuel pipes, a liquid-soap and water mixture (50/50) can be made and rubbed along joints and areas of potential leakage to see if any "bubbling" occurs (meaning that gas is being expelled). The cookstove is given a rating of Best if no flames are present, no liquid leaks, and no "bubbling" soap-water occurs from a gas leak. Otherwise, a Poor rating is used. No incremented rating system is employed because there is simply no middle ground for this hazard. After completely this test, and fire present can be extinguished and equipment put away. .

5.4 OVERALL SAFETY RATING

An overall cookstove safety rating can be determined after calculating safety ratings for each individual criterion from the previous section. This overall rating is useful for two reasons. First, it enables all types of cookstoves to be openly compared against each other for their potential to lessen injury and therefore encourages designers to improve safety based of competition, if not shear desire to make safer equipment. Additionally, the overall rating can be used as selection criteria alongside efficiency and emissions when purchasing stoves or

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[18] Though many persons using biomass stoves stick large pieces of fuel into the loading area, this is not considered in this test. Only the presence of flames in this area are taken as a definite risk.

funding projects producing stoves (such as conducted by numerous governmental and non-governmental organizations).

In calculating overall cookstove safety the quality from each of the ten ratings is transformed into point scores based on the following: Poor-1, Fair-2, Good-3, Best-4. These individual results could then be summed (S) to obtain an abstraction able evaluate the overall safety rating of the stove. Table 12 provides a possible method to find the overall rating based on the sum of these point scores. A stove could receive a maximum of 40 overall points by obtaining a Best rating for all tests and a minimum of 10 points for receiving Poor marks on all tests.

Table 12. Possible metric for overall safety rating.

Rating	Point score
Poor	$10 \leq S \leq 25$
Fair	$25 \leq S \leq 31$
Good	$32 \leq S \leq 36$
Best	$37 \leq S \leq 40$

Note: S represents the sum of points from all individual safety tests

However, this did not seem very representative of the individual hazards when they received the same rating regardless of the severity of injury. For instance, a Poor rating in Test 1 would show that cuts cut easily occur (a minor injury), but in Test 9, a Poor rating entails that skirt-fires and hands have great potential to receive third-degree burns (a far worse injury than a cut). Therefore the individual ratings were given weights based upon relative injury severities (see Table 13). Use of this weighted system also broke ties between stoves receiving similar final scores (but based on different individual test results, see Appendix B). This was beneficial because it allowed more diversity in overall safety rating comparisons.

Table 13. Individual multipliers used to obtain final safety rating.

Test	1	2	3	4	5	6	7	8	9	10
Multipliers	1.5	3	2.5	2	2	2.5	2	2.5	3	4

The average value of the weights is 2.5, giving 100 points as the maximum score and 25 points as the lowest possible score. Table 14 shows the weighted scores in the final analysis (a comparison between the un-weighted and weighted methods can be found in Appendix B).

Table 14. Final metric for overall safety rating.

Rating	Point score
Poor	$93 \le S \le 100$
Fair	$84 \le S \le 92$
Good	$76 \le S \le 83$
Best	$25 \le S \le 75$

Note: S represents the sum of points from weighted individual safety tests

These rating levels were determined from the evaluation trials in Appendix B. The preliminary attempt at establishing overall safety levels gave Poor (25-49), Fair (50-69), Good (70-89), Best (90-100). At first this seemed reasonable, but after consulting the results from Appendix B, it was found that these levels would put all but one stove in the Good and Best levels, with the outlier being in the Poor state. This was not logical sense some consumers did not want to use certain stoves due to safety concerns, even if they were within the proposed "Good" range (personal communications, January 29-30, July 24-26, 2005). Therefore, the ranges given in Table 14 reflect a desire to create a better distribution of overall ratings in response to consumer and researcher interests for more diversity.

6. IMPLIMENTATION

The last chapter introduced procedures and guidelines to provide valuable stove safety knowledge to designers, manufacturers, as well as the occasional consumer. Chapter 6 discusses how the methods have been tested, how the current version can be applied, and methods of safety education to increase awareness.

6.1 TESTING SAFETY EVALUATION PROCEDURES

Testing of safety evaluation procedures occurred in several design laboratories in addition to fieldwork in Honduras. Modifications to safety measures were the primary result of an interest to include more safety concerns and better accommodate design diversity. Constant self-reviews were conducted and several exterior resources were utilized to provide insight on possible improvements.

6.1.1 Trials in Design Laboratories

Preliminary testing of safety evaluation procedures occurred in the Stove Analysis Laboratory at Iowa State University. First attempts at creating guidelines concerned only solid biomass stoves using fuelwood. Evaluation procedures were continually modified and tested to incorporate concerns over burn and scald hazards. After several modifications to these testing procedures had taken place, a metric from the American National Standards Institute (ANSI 1993, ANSI 2000) and Underwriters Laboratories (UL 1995) provided a reference for acceptable safety limits. The ANSI standards also provided information that surfaces shall be smooth to avoid risk for laceration injuries. Additional measures, such as heat transmission to surrounding materials, were included to provide a way to rate the risk of property loss. These new methods added to the set and established a set of ten principals to rate wood stove safety.

Peer-reviewed assessments of the wood stove safety tests were conducted by Nordica Hudelson and Dean Still, long-time stove enthusiasts of Aprovecho Research Center. Their results from 18 separate stove tests showed the methods did not well adapt to stoves with fuels other than solid biomass, namely solar and liquid/gas stoves. The safety guidelines and evaluation procedures were then further modified to address this interest and incorporate cookstove fuel design types in the scope of this analysis. Some tests did not need to change, such as risk of cuts or elevated surface temperatures, but others needed major modifications to allow for complications brought by fuel diversity, as in tests three and ten which deal with fuel containment or leaks.

6.1.2 Field Work in the Developing World

At this time, the ten guidelines and evaluation procedures solidified to a well-tried and documented work that was ready for testing in the developing world. These trials were conducted during site-visits (July 22 - August 3, 2005) to rural homes (see Figure 1, Section 2.2) and manufacturing shops in Honduras while accompanied by stove producers from the Asociación Hondureña Para El Desarrollo (abbreviated AHDESA or translated as "The Honduran Association for Development").

Results from the field tests showed that some procedures were unnecessarily complex or simply did not apply well. One modification to improve this deficiency entailed using temperature differences between the ambient air and the object being tested rather than solely temperatures of the object (reasoning given in Section 5.3.5). Other helpful additions included the facilitation of diagrams to demonstrate how to take measurements during the tip test (Test 2) and how to evaluate area for the containment of fuel (Test 3) and chimney shielding (Test 8). The chimney shielding test was in fact created after examining stoves in Honduras that employed the protective barrier. One more modification to the set of ten guidelines taken to Honduras was the removal of a stability test for the stove. This test involved tipping the stove over or dropping it from a small height to see if it held together. This was not appropriate for traditional biomass stoves made from mud/sawdust, clay, or bricks and mortar, since they were often the only material available. Therefore the test was taken out of the analysis, and the ten guidelines introduced in Chapter 5 were the result of this removal and the addition of the chimney shielding test.

6.2 USING THE SAFETY EVALUATION

The final version of the safety guidelines and procedures were used to evaluate the safety of 23 stoves (see Appendix B). This data provides information on specific safety concerns for each stove, demonstrating to designers which aspects of a stove could use improvement. Furthermore, the overall safety ratings can be used as selection criteria when purchasing a stove or when organizations are looking to fund projects that make stoves (such as the US Environmental Protection Agency or the Shell Foundation).

An example of the safety evaluation is provided in Appendix C. This testing was conducted while in Honduras and working with stove producers from AHDESA. The Eco-Fogon is one of the stoves they began marketing in August 2005. The evaluation shows that the stove performs well with reducing cuts and abrasions, property loss, and scalds. However, stove surfaces often become hot near the cooking surface and the handles on the griddle may collide with pots being moved from the stove. Though all things considered, the stove performed well in the safety evaluation. Improvements in some areas may be helpful, but the added cost may not be worth the effort since poor families may not be able to purchase the more expensive stove (when the original is already expensive for highly impoverished families that pay in installments). If the cost of the stove became greater, less people would be able to use the already good technology to reduce indoor air pollution, fuel use, and increase safety over that of a 3-stone fire.

The method of examining the trade-offs between fuel efficiency, pollution reduction, cooking speed, cost, size, and safety is an important design consideration in determining how to provide the most value to the customer. Since this is a complex issue and safety is not the only benefit of using an improved stoves, choices on stove designs should not be chosen off of safety alone.

6.3 EDUCATION

Effective implementation of the guidelines to regions in the developing world requires communication channels and well-planned education methods. This section introduces the connections utilized for testing in Honduras and suggests similar models for increased safety awareness and use of the evaluation procedures in other areas of the world.

If working internationally, Section 6.3.1 provides a good method for establishing contact with local persons in the developing world for utilization of the safety methods. However, if the guidelines are being applied locally, there is no need to bridge the international / cultural gap and stove safety proponents can move to Section 6.3.2 which discusses methods to motivate use.

6.3.1 Making Contact

For those who need to bridge the international gap (geographic, language, culture), communication perhaps best starts with a local or international Non-Governmental Organization (NGO). This is due to their greater likelihood for humanitarian goals and lessened bureaucracy when compared to governments. Trees, Water & People is the international NGO based out of the United States that established contact with local groups in Honduras for trials of the safety tests.

Making connections through established NGOs is often simpler and more effective than attempting to make new connections because of the time saved and trust already in place. More examples of contacts that may assist in establishing greater use of the safety guidelines include local humanitarian groups, religious organizations, or local governments, to name a few. They also can provide great resources for establishing relations within their communities.

6.3.2 Procedure Explanation and Motivation for Use

An essential part of the education process is to provide a useful and understandable explanation of the procedures while demonstrating their importance and motivating use. First, guidelines and metrics may need to be translated into another language to be implemented (the summarized version located in the Appendix D is best suitable for this). However if literacy is a problem, pictorial representations of the hazards can be created to provide useful information of potential dangers to users if testing can not take place (though the vast majority of designers and manufacturers have some technical skill enabling them to perform several tests).

It has been found that a participatory approach towards implementing foreign practices is highly effective in indigenous communities (Ranganathan et al. 2003). For the safety procedures, this would include a joint safety evaluation between designers and local or foreign persons already versed in the guidelines. As for stove users, safety awareness can be increased through community-based activities organized by local leaders. These activities would entail conversation on safety and include feedback in planning and implementing the safety measures. Of primary importance in these activities is that women and children are involved; they are most likely to notice the improvements and utilize the added hazard awareness. They will receive the direct benefits and may in turn become instigators for the implementation process by demonstrating its usefulness and persuading friends to join (Ranganathan et al. 2003).

7. FINDINGS AND FUTURE WORK

7.1 SUMMARY

Guidelines and metrics introduced in Chapter 5 are supported by analyses explained in Chapters 2 through 4. Research outlined in Chapter 2 provided essential knowledge of life in developing nations for the creation of culturally appropriate guidelines. The chapter continued with explanations of the numerous cookstoves design types encompassed in the safety evaluation. Chapter 2 concluded with descriptions of injuries incurred through cookstove use and led into Chapter 3 which covered the hazards causing these injuries.

Chapter 3 began with an explanation of cooking practices to better determine how injuries and hazards are related. Chapter 3 also included a thorough discussion of how the cookstove hazards produced unwanted consequences, such as burns, scalds, cuts, and property loss. These concerns were addressed when producing the guidelines of Chapter 5. Fuel concerns were discussed to provide further information on potential hazards but were left from the evaluation because this thesis focuses on safety from the design side, and not through regulation of fuel collection or storage practices.

Processes considered in the inception of safety guidelines and metrics for hand-made cookstoves were explained in Chapter 4. It was discovered that no conventional safety practices had been independently developed in the third-world. Consequently, a need existed for safety awareness and guidelines. First thoughts on establishing safety guidelines lead to inspection of conventional Western standards. However, the metrics and procedures created by the American National Standards Institute (ANSI) and Underwriters Laboratories Inc.

(UL) were too complicated to be used in developing nations; also, they did not fully encompass all hazards associated with cookstoves. Therefore, five of the guidelines were chosen and simplified and five were newly created to establish a total of ten guidelines and procedures to assess cookstove safety.

Novel safety guidelines and corresponding evaluation procedures were introduced in Chapter 5. The chapter provided a comprehensive assessment of stove safety. Furthermore, each guideline, metric, and method introduced was accompanied by detailed reasoning to provide information supporting their use. This chapter also gave an incremented safety rating as a supplement to the ANSI and UL "all-or-none" rating methods. This helped to show progress and encourage improvement. This incremented rating system was used with each guideline to show designers specific areas of concern and provide grades that showed how much improvement was necessary to be considered a safer stove. At the conclusion of the chapter, an overall safety rating system was introduced to provide designers a method to assess possible trade-offs between safety, cost, fuel use, and other design features. Additionally the overall safety rating can be used by consumers to help determine which stove to buy, or for a funder, which stove producer to provide financial backing.

Chapter 6 provided background on how the methods from Chapter 5 had been developed and tested. It included explanations of the innovations resulting from trials in design laboratories and in communities of the developing world. Explanations were also given for methods of peer-reviewed assessment and results from trials of the evaluation. The latter half of the chapter included discussion over possible methods for others to help implement the cookstove safety evaluation.

7.2 DISCUSSION AND CONCLUSIONS

Safety guidelines and evaluation procedures developed in this study provide a well-defined and tested method for reducing risk of injury from household stoves in developing nations. The guidelines give designers and manufacturers a reference to use in finding individual risks associated with a stove and allow each to be addressed accordingly. The overall stove safety rating given allows stove distributors and consumers another choice variable alongside efficiency, pollution levels, and fuel usage. Further benefits are incurred by the end-user through owning a product that has undergone safety evaluations where previous stoves had not.

Many cookstove related injuries can be avoided if stoves are properly maintained and operated. The educational process outlined in this thesis provides methods to increase safety awareness for consumers and encourage use of the safety guidelines by designers and persons in the research community (who have the obligation to produce safe products).

The process can be used to show that using safer cookstoves need not induce added cost if thorough planning and reviews of local cooking practices are conducted prior to design conception (especially when foreigners are involved). The only obstacles left to using the analysis would then be literacy and time. Illiteracy can be addressed with the use of pictures and figures to explain the process (as outlined in the Education Section 6.3), and time is not an issue because a stove model can typically be fully tested in 90-100 minutes. Therefore little reason exists for not using the guidelines to help save users from potentially disfiguring or life-threatening injuries.

7.3 FUTURE WORK

A few topics related to cookstove safety and its implementation could be further developed with more research. One area research would be in creating specialized sets of tests for each stove based on fuel type. This would be helpful since solar stoves have several exceptions in the guidelines. Also, different sets of tests may be able to address specific fuel concerns that simply could not be evaluated on an abstract level. They had been left out of the analysis due to their highly relative nature. Further possible research could entail investigations of the cooking environment, and yield safety considerations based on house orientation/size, social interactions, floor elevation, and other factors not found by looking simply at the stove. Also, greater focus on safety education is essential to create forward progress with the guidelines. The development of more pictorial representations of the safety guidelines is crucial in reaching minimally literate peoples. This is perhaps the next most plausible step from current work.

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9. DEFINITIONS

Complete combustion: when little to no smoke is left in the air after ignition of fuel

Cookstove: general name for hand-made stoves used in developing countries

First degree burn: superficial burn characterized by redness

Focal point: area where sun's rays are focused and heat greatly intensified

Hazard: potentially injury-causing circumstance

Incomplete combustion: when large amounts of yellow-ish smoke are present in the air due to inadequate oxygen sources

Injury: an infliction of pain onto the body that often persists over time

Open-fire: a fire that is not enclosed by a combustion chamber

Pot skirt: construction surrounding the pot that creates a narrow gap for flow of flue gases and yields better heat transfer

Radiative heat: heat transferred through radiation

Range: term used in place of "stove" in some developed countries

Second degree burn: partial thickness burn characterized by blistering

Skin grafting: placing skin from another area on the body, or another person, over burned tissues

Third degree burn: full thickness burn characterized by charred skin and connective tissues

Three-stone fire: another name for an open-fire, created by using three stones to provide resting points for pots and pans

APPENDIX A. COOKSTOVE DATA SET

Fuel Group[1]	Stove Name[2]	Fuel Type	Location
Wood Biomass	3-stone fire	wood	all developing countries
	Bangladesh wood	wood	Bangladesh
	Buchari	wood	Pakistan
	Eco-Barril	wood	Honduras
	Eco-Fogon	wood	Honduras
	Eco-Horno	wood	Honduras
	Eco-Lenca	wood	Honduras
	Ghana wood	wood	Ghana
	Henya	wood	Kenya
	Justa	wood	Central/South America
	Lorena	wood	Mexico
	Mud/Sawdust	wood	traditional[3]
	Onil	wood	Guatemala
	Patsari	wood	Mexico
	Prolena EcoStove	wood	Nicaragua/Brazil
	The Lion	wood	Swaziland
	Ugandan 2-Pot	wood	Uganda
	VITA	wood	West Africa
	Wood flame	wood	Canada
	Wood-cooker	wood	China
	World Food Program	wood	Africa
Other Biomass	2-burner rice hull	rice hull	Philipeans
	Gyapa	charcoal	Africa
	Ipa-Qalan	rice hull	Philipeans
	Lakech	charcoal	Ethopia
	Lao Bucket	charcoal	Laos, Cambodia
	Laxmi	charcoal	India
	Makoti	ag-waste	South Africa
	Mali charcoal	charcoal	Mali
	Nepal Beehive	charcoal	Nepal

Fuel Group	Stove Name	Fuel Type	Location
Gas/Liquid	China bio-gas	bio-gas	China
	Clean Cook	methanol	Africa
	Kerosene	kerosene	Hong Kong
	Generic propane	propane	various[4]
	Hybrid butane/solar[5]	butane/solar	Morroco
	Natrual draft gassifier	producer gas	India
	Straw gas cooker	bio-gas	China
	T-LUC gassifier	producer gas	Latin America
	Wood gas	producer gas	Nicaragua
Solar	Cob	box solar	Mid-East
	Dadaab box	box solar	Mid-East
	Girassol	focal solar	Kenya
	Hans & Bich's focal	focal solar	Vietnam
	Heaven's Flame	box solar	Persia
	Hybrid butane/solar[5]	butane/solar	Morroco
	Kenyan focal	focal solar	Kenya
	Schwarzer	box solar	South Africa
	Sola Kooka	box solar	Austrailia

Notes:

1. The large portion of biomass stoves in the data set is reflective of biomass being the most common fuel used throughout the world (see Introduction, p.1).

2. Approximately half of these stoves were found through working with researchers at the Aprovecho Research Center in Oregon and can be found in Byden et al. 2005.

3. Traditional refers to preliminary indigenous attempts at creating improved stoves.

4. The propane stove was found to be used in various places, but in little frequency. This meant a specific continent or developing country was not be established.

5. The hybrid stove is listed under both the Gas/Liquid category and the Solar category but is only counted once in the data set.

APPENDIX B. STOVE SAFETY COMPARISONS

Test 1: Sharp Edges and Points

Test 2: Cookstove Tipping

Test 3: Containment of Fuel

Test 4: Obstructions Near Cooking Surface

Test 5: Surface Temperature

Test 6: Heat Transmission to Surroundings

Test 7: Temperature of Operational Construction

Test 8: Chimney Shielding

Test 9: Flames Surrounding Cookpot

Test 10: Flames/Fuel Exiting Fuel Chamber, Canister, or Pipes

Stove	1	2	3	4	5	6	7	8	9	10	Total[1]
Onil	3	4	4	4	4	4	4	3	4	4	38
Wood Flame	3	4	4	4	2	4	4	4	4	4	37
Banladesh wood	4	4	2	4	3	4	4	4	4	4	37
Eco-Lenca	4	3	3	4	3	4	4	4	3	4	36
Justa	4	4	4	3	4	4	4	1	4	4	36
Generic propane	3	3	4	4	3	4	4	4	3	4	36
Clean Cook	4	4	4	4	2	4	3	4	3	4	36
Kerosene	3	3	4	4	2	4	4	4	3	4	35
Mud/Sawdust traditional	4	3	3	4	2	1	4	4	4	4	33
Eco-Fogon	4	3	4	2	2	4	4	2	4	4	33
Patsari	3	4	4	2	2	4	4	1	4	4	32
World Food Program	2	2	4	4	1	3	4	4	4	4	32
Ghana wood	3	4	2	4	1	3	4	4	3	4	32
Parabolic solar cooker	3	4	4	4	2	1	2	4	4	4	32
Prolena EcoStove	3	3	4	3	2	4	4	1	4	4	32
Uganda 2-Pot	3	2	4	3	2	4	4	1	4	4	31
Mali Charcoal	3	3	3	3	1	2	4	4	4	4	31
Wood Gas	3	2	4	4	1	3	2	4	4	4	31
Gyapa charcoal	3	1	2	4	2	3	4	4	4	4	31
Eco-Horno	4	3	4	2	1	4	1	2	4	4	29
VITA	1	2	3	3	1	2	4	4	4	4	28
T-LUD gassifier	3	1	4	4	1	4	2	1	4	4	28
3-stone fire	4	1	1	2	2	1	1	4	2	1	19
Multipliers:[2]	1.5	3	2.5	2	2	2.5	2	2.5	3	4	

Overall Rating	Stove	Total[3]	Change in Rank[4]
Best	Onil	96	*
	Wood Flame	94.5	*
	Banladesh wood	93	-1
Good	Clean Cook	91	*
	Justa	90.5	+1
	Generic propane	90.5	+1
	Eco-Lenca	89.5	+3
	Kerosene	88.5	*
	Eco-Fogon	84	*
Fair	Mud/Sawdust traditional	83	+1
	Patsari	83	+1
	Parabolic solar cooker	83	-1
	World Food Program	82.5	+2
	Ghana wood	82	+3
	Prolena EcoStove	82	+3
	Mali Charcoal	80	*
	Wood Gas	80	*
	Uganda 2-Pot	79	+2
	Gyapa charcoal	78	+3
	Eco-Horno	76	*
Poor	VITA	74	*
	T-LUD gassifier	72	+1
	3-stone fire	44	*

Notes:

1. This total is out of 40 points (max of 4 for all ten tests).
2. Multipliers given based off discussion in Section 5.4.
3. This total is out of 100 points.
4. Change in rank shows how the weighted rating system (out of 100) affects stove placement in relation to the original rating system (out of 40). Astricks are used to represent stoves that had no change (e.g. +1 = New Rank – Old Rank).

APPENDIX C. EXAMPLE SAFETY EVALUATION

Stove	Eco-Fogon	**Location**	Tegucigalpa, Honduras
Tester	Nate Johnson	**Date**	July 27, 2005

Test 1: Sharp Edges and Points **Rating 1: Best**

Rubbing a cloth over all exterior components of the stove resulted in no snags.

Test 2: Cookstove Tipping **Rating 2: Good**

The direction of the largest tipping ratio (the most easily to tip) was found when tipping towards the front of the stove. This occurred since the combustion chamber was placed more near the front. The starting height was measured as 85 cm, and the tipping height 81 cm. This gave a ratio of 0.953.

Test 3: Containment of Fuel **Rating 3: Best**

The griddle covered up most of the combustion chamber though the fuel loading area did expose about 45 cm^2 of area.

Test 4: Obstructions Near Cooking Surface **Rating 4: Fair**

Handles extended 3.5 cm above the cooking surface.

Test 5: Surface Temperature **Rating 5: Fair**

The main portion of the stove was below the child-line so all measurements were applied against that part of the metric. Also, the stove was made of metal. The atmospheric temperature during testing was 32.1° C and the highest observed temperature was 80.3° C, giving a temperature difference of 48.2° C. This was found at a height of 83 cm from the ground, very close to the child-line. Had this temperature been above 90 cm from the ground, the stove would have received a Best rating under this hazard.

Test 6: Heat Transmission to Surroundings **Rating 6: Best**

There was no danger to the floor since the combustion chamber was greater than 5 cm from the ground. Also, placement of the stove at 10 cm from a wall showed no drastic increase in house wall surface temperatures.

Test 7: Temperature of Operational Construction **Rating 7: Best**

There was no handles, levers, or valves needing to be used during stove operation.

Test 8: Chimney Shielding **Rating 8: Fair**

When looking at chimney temperatures under the metric from Test 5, this would have given a Poor rating. However, a shield was employed to disuade contact with the chimney. The openings in the shielding were calculated to be 252 cm^2 (9cm x 28cm).

Test 9: Flames Surrounding Cookpot **Rating 9: Best**

No flames could surround the cookpot since a griddle was used as a cooking surface.

Test 10: Flames/Fuel Exiting Fuel Chamber, Canister, or Pipes **Rating 10: Best**

No flames were present exiting the fuel loading area.

Overall rating without weights: **Good** (33/40)

Overall rating with weights: **Good** (84/100)

Figure C 1. Iso-metric view including front of stove.

Figure C 2. Wood loading area.

Figure C 3. Side view.

Figure C 4. View of cooking surface and handles.

Figure C 5. Iso-metric view including back of stove.

Figure C 6. Chimney and shielding.

APPENDIX D. SUMMARIZED EVALUATION PROCEDURES

Stove ______________________	**Location** ______________________
Tester ______________________	**Date** __________

1. SHARP EDGES AND POINTS

Equipment: Cloth, rag, or loose clothing

Procedure:

a) Rub cloth along exterior surfaces

b) Note number of times cloth catches / tears

Rating	No. of catches
Poor	four or more
Fair	three
Good	one or two
Best	none

No. _____

Result	

Notes:

2. COOKSTOVE TIPPING

(imobable cookstoves get Best rating)

Equipment: Fuel, ruler / tape measure, calculator

Procedure:

a) Set stove on flat surface and load with fuel but do not ignite

b) Pick a side to tip towards and measure the height of its highest point, place value into Table A

c) Slowly tip the cookstove in that direction until the stove can tip on its own, hold cookstove there

d) Measure the new height of the point, place value into Table A

e) Using a calculator, divide the tipped height by the standing height to find the ratio R, place into Table A

f) Repeat process as many times as there are legs on the stove, or four times for a circular base

g) Use the largest ratio in Table A with the metric in Table B to find the most deficient rating for the result

A

Run	Starting Height	Tipped Height	Ratio (R)
1	_______	_______	_______
2	_______	_______	_______
3	_______	_______	_______
4	_______	_______	_______
5	_______	_______	_______
6	_______	_______	_______

B

Rating	Ratio
Poor	$R \geq 0.978$
Fair	$0.961 \leq R < 0.978$
Good	$0.940 \leq R < 0.961$
Best	$R < 0.940$

Result 2	

Notes:

3. CONTAINMENT OF FUEL *(solar stoves receive Best rating)*

Equipment: Fuel, ruler / tape measure, cookpot

Rating	Area exposed (cm^2)
Poor	$A \geq 250$
Fair	$150 \leq A < 250$
Good	$50 \leq A < 150$
Best	$A < 50$

Procedure:
a) The cookstove should be stocked with fuel but not ignited
b) Place cookpot onto burner
c) Sum approximate areas through which fuel can be seen
d) Use the summation of area, A, to find the rating

Area _______

Notes:

Result 3	

---

4. OBSTRUCTIONS NEAR COOKING SURFACE *(skirt-stove = Good; solar = Best)*

Equipment: Ruler / tape measure

Rating	Difference (cm)
Poor	$D \geq 4$
Fair	$2.5 \leq D < 4$
Good	$1 \leq D < 2.5$
Best	$D < 1$

Procedure:
a) Inspect cookstove for skirt, give good rating if skirt is present
b) Measure height difference between the cooking surface and obstructions surrounding the cooking surface
c) Use the largest height difference, D, to find the rating

Largest _______

Notes:

Result 4	

---

5. SURFACE TEMPERATURE; 6. HEAT TRANSMISSION TO SURROUNDINGS; 7. TEMPERATURE OF OPERATIONAL CONSTRUCTION *(solar Result 6 = Poor)*

Equipment: Fuel, igniter, chalk, ruler / tape measure, hand-held thermocouple

Procedure:
a) Chalk 8 x 8 cm grid onto cookstove and also within an outline of cookstove on the floor if within 5 cm of undercarriage, and within an outline of cookstove onto the wall if within 10 cm, while continuing the grid 16 cm higher up the wall than the top of the cookstove, if stove is mounted to floor or wall, take supplimentary wall and floor temperatures by using cookstove surface temperature near where it attaches to floor or wall
b) Chalk extra thick lines at 0.9 m and 1.5 m onto cookstove, if applicable ***c***) Ignite fuel and continue up to step 'g' then wait at that step until cookstove has reached max temp before proceeding, adding fuel when necessary
d) Design a convienient method for your stove that will tell what data taken corresponds to which data point tested
e) Measure air temp ***f***) Compute values for Tables B by adding air temp to temps located in Tables A
g) Take data using thermocouple at grid intersections ***h***) Start with wall and floor by moving cookstove away to take measurements for up to one minute, then return cookstove for at least five minutes, taking surface temp and operational conststruction temp data while waiting, repeat step 'h' until all data points have been checked
i) Find max temps for all scenarios ***j***) Find which rating is given by the max temp using Tables B
k) Use most deficient ratings for the results

Air temp _______

SURFACE TEMPERATURE

	Rating	*Below child-line (< 0.9 m)* Metallic	*Below child-line (< 0.9 m)* Nonmetallic	*Above child-line (> 0.9 m)* Metallic	*Above child-line (> 0.9 m)* Nonmetallic
5A	Poor	$T \geq 50$	$T \geq 58$	$T \geq 66$	$T \geq 74$
	Fair	$44 \leq T < 50$	$52 \leq T < 58$	$60 \leq T < 66$	$68 \leq T < 74$
	Good	$38 \leq T < 44$	$46 \leq T < 52$	$54 \leq T < 60$	$62 \leq T < 68$
	Best	$T < 38$	$T < 46$	$T < 54$	$T < 62$
5B	Poor	T ≥ ___	T ≥ ___	T ≥ ___	T ≥ ___
	Fair	___ ≤ T < ___	___ ≤ T < ___	___ ≤ T < ___	___ ≤ T < ___
	Good	___ ≤ T < ___	___ ≤ T < ___	___ ≤ T < ___	___ ≤ T < ___
	Best	T < ___	T < ___	T < ___	T < ___
	Max/Rating	___ / ____	___ / ____	___ / ____	___ / ____

HEAT TRANSFER TO THE ENVIRONMENT

	Rating	Floor	Wall
6A	Poor	$T \geq 65$	$T \geq 80$
	Fair	$55 \leq T < 65$	$70 \leq T < 80$
	Good	$45 \leq T < 55$	$60 \leq T < 70$
	Best	$T < 45$	$T < 60$
6B	Poor	T ≥ ___	T ≥ ___
	Fair	___ ≤ T < ___	___ ≤ T < ___
	Good	___ ≤ T < ___	___ ≤ T < ___
	Best	T < ___	T < ___
	Max/Rating	___ / ____	___ / ____

HANDLE TEMPERATURE

	Rating	Metallic	Nonmetallic
7A	Poor	$T \geq 32$	$T \geq 44$
	Fair	$26 \leq T < 32$	$38 \leq T < 44$
	Good	$20 \leq T < 26$	$32 \leq T < 38$
	Best	$T < 20$	$T < 32$
7B	Poor	T ≥ ___	T ≥ ___
	Fair	___ ≤ T < ___	___ ≤ T < ___
	Good	___ ≤ T < ___	___ ≤ T < ___
	Best	T < ___	T < ___
	Max/Rating	___ / ____	___ / ____

Result 5	

Result 6	

Result 7	

Notes:

8. CHIMNEY SHIELDING

(solar stoves receive Best rating)

Equipment: Fuel, igniter, chalk, ruler / tape measure, hand-held thermocouple

Procedure:

a) If the chimney has no protective shielding, sufrace temperature metrics from Test 5 are used for rating

b) If the chimney has protective convering, measurements are taken to calculate the average area of gaps, A

Rating	Hole size (cm^2)
Poor	$A \geq 300$
Fair	$100 \leq A < 300$
Good	$10 \leq A < 100$
Best	$A < 10$

Notes:

Area _____

Result 8	

9. FLAMES SURROUNDING COOKPOT

(solar stoves receive Best rating)

Equipment: Cookpot

Procedure:

a) Keep cookstove fully ablaze from previous tests
b) Place cookpot into position
c) Observe the amount of uncovered flames surrounding the cookpot and record a description
d) Compare description with table to find rating
e) Remove cookpot

Rating	Amount of Uncovered Flames Touching Cookpot
Poor	entire cookpot and/or handles
Fair	most of cookpot, not handles
Good	less than 4 cm up the sides, not handles
Best	none

Result 9	

Description ______________________

Notes:

10. FLAMES/FUEL EXITING FUEL CHAMBER, CANISTER, OR PIPES

Equipment: None

(solar stoves = Best)

Procedure:

a) Keep cookstove fully ablaze from previous tests ***b***) Visually inspect the amount, if any, of flames coming out of the fuel chamber, canister, or pipes and record if flames do or not protrude ***c)*** Consult table to find rating
d) Additionally for gas stoves, a liquid soap-water mixture is rubbed over joints in the pipes and attachments to the flow regulator (where leaks are likely to occur), the coating is obseved for bubbles that signal a gas leak.
e) For liquid fuel stoves, the fuel canister is inspected for liquid leaks on its surface, its connections, and on the ground

Rating	Release of Fuel/Flames
Poor	Flames/Fuel exscape
Best	Flames/Fuel do not exscape

Result 10	

Description ________________

Notes:

OVERALL COOKSTOVE SAFETY RATING

Test	Value		Weight		Totals
1	_____	x	1.5	=	_____
2	_____	x	3	=	_____
3	_____	x	2.5	=	_____
4	_____	x	2	=	_____
5	_____	x	2	=	_____
6	_____	x	2.5	=	_____
7	_____	x	2	=	_____
8	_____	x	2.5	=	_____
9	_____	x	3	=	_____
10	_____	x	4	=	_____
			SUM		

Individual Rating	Value
Best	4
Good	3
Fair	2
Poor	1

Overall Rating	Total point score
Best	$93 \leq S \leq 100$
Good	$84 \leq S \leq 92$
Fair	$76 \leq S \leq 83$
Poor	$25 \leq S \leq 75$

Overall Rating	

Notes: