# 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.

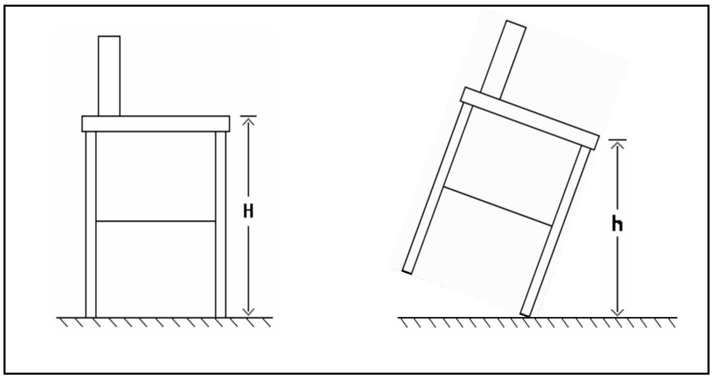



**Figure 14. Schematic of height measurements for tip test.**

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

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

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).

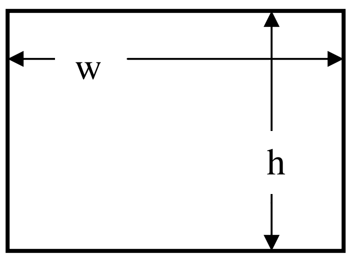
### 5.3.3 Test Three: Containment of Fuel

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.

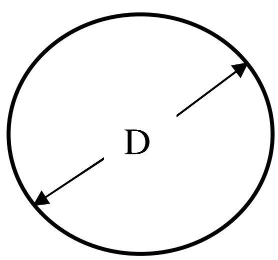
This test provides a method for determining the likelihood for stoves to release burning fuel whether standing upright or after being overturned. Enclosure of the combustion chamber or fuel canister is important to restrict the uncontrolled movement of fuel during use. This test is conducted with fuel 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:




$$\text{Area} = w*h \qquad (2)$$

Circle:




$$\text{Area} = \pi*D^2 / 4 \qquad (3)$$

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

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[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 < 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 MacCarty, 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

[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 | $93 \leq S \leq 100$ |
| Fair | $84 \leq S \leq 92$ |
| Good | $76 \leq S \leq 83$ |
| Best | $25 \leq S \leq 75$ |

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.