



## An evaluation of a biomass stove safety protocol used for testing household cookstoves, in low and middle-income countries



Michael Gallagher<sup>a</sup>, Maria Beard<sup>a,\*</sup>, Mike J. Clifford<sup>a</sup>, Michael Craig Watson<sup>b</sup>

<sup>a</sup> Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK

<sup>b</sup> School of Health Sciences, University of Nottingham, Queens Medical Centre., Nottingham NG7 2UH, UK

### ARTICLE INFO

#### Article history:

Received 5 October 2015

Revised 28 March 2016

Accepted 29 March 2016

Available online xxxx

#### Keywords:

Improved cookstoves

Safety

Burns

Sub-Saharan Africa

### ABSTRACT

To mitigate the impact of excess pollution, deforestation, and injuries attributable to cookstoves in low and middle income countries, humanitarian and private sector organisations have made a commitment to increase the adoption of improved cookstoves (ICS) to 100 million households by 2020. In order to evaluate the safety of these ICS for the end users, a ten-test “biomass stove safety protocol” (BSSP) has been developed by the Global Alliance for Clean Cookstoves (GACC). However, there is no published evidence that this protocol has been independently assessed or benchmarked. This study aimed to determine whether the BSSP is fit for purpose such that, it will produce repeatable safety ratings for a range of cookstoves when performed by different testers. Results indicated that the scores for each stove varied considerably between each of the six testers with only one of five ICS receiving the same overall safety rating. While individually some tests produced relatively coherent scores, others led to large discrepancies. We conclude that although BSSP is an important starting point in highlighting the need for stove safety assessment, there are some aspects of the protocol that require further development to ensure that it can be reliably replicated by different testers.

© 2016 The Authors. Published by Elsevier Inc. on behalf of International Energy Initiative. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

### 1. Introduction

Although there are no reliable global statistics on the number of fatalities associated with burns sustained during cooking, the World Health Organisation (WHO) reports that fire-related burns account for over 300,000 deaths per year (Mock et al., 2011). The burden of these injuries disproportionately affects the world's poorest populations with 95% of fire-related deaths occurring within low and middle-income countries (LMIC) (Mock et al., 2008). For economically fragile households, injuries resulting in death or disability place a long-term financial burden onto families (Mock et al., 2008; Golshan et al., 2013). The use of open fires and crudely assembled ground-level cookstoves is a dominant factor associated with burn injuries within LMIC, particularly within Sub-Saharan Africa and Asia (Justin-Temu et al., 2008; Ndiritu et al., 2006; Zwi et al., 1995; Outwater et al., 2013; Hyder et al., 2004; Albertyn et al., 2006; Peden et al., 2008).

At present, three billion people worldwide rely on the combustion of biomass on open fires and inefficient stoves as a primary source of household energy (Global Alliance for Clean Cookstoves, 2015a

(GACC)). Approximately 50% of households worldwide and 90% of rural households use solid fuels for cooking or heating (Kammen, 1995; Desai et al., 2004). These forms of energy production can generate significant health, social, and economic problems for low-income families in developing nations. The use of traditional stoves have been linked to excess pollution, increased time spent gathering fuel, deforestation, injury, respiratory diseases, and high fuel costs (Jones, 2015; Simon et al., 2014; WHO, 2014; Thomas et al., 2015; Kurmi et al., 2010). Since the 1970s, a number of state and non-governmental organisations have aimed to alleviate these problems through the dissemination of “improved” cookstoves (ICS) (Sesan, 2012; Kshirsagar and Kalamkar, 2014). Their designs often focus on increasing fuel efficiency, decreasing fuel use and reducing the emissions of harmful particles rather than the immediate safety for the user.

As humanitarian organisations continue to develop a variety of more refined cookstoves, the need for international standards to rate stove performance has been expressed (GACC, 2012). In February 2012, a group of international organisations and stakeholders joined together to produce an International Workshop Agreement (IWA) (GACC, 2012). The aim of the IWA was to create a framework that was easy for governments, donors, and investors to make decisions and measure progress of cookstove technologies (GACC, 2012). The IWA allocates cookstoves into a tier system based on four indicators: efficiency, indoor emissions, total emissions, and safety. Stoves are rated for each indicator separately and thus may fall into one or more of the tiers depending

\* Corresponding author.

E-mail addresses: [msfg94@gmail.com](mailto:msfg94@gmail.com) (M. Gallagher), [maria.beard@nottingham.ac.uk](mailto:maria.beard@nottingham.ac.uk) (M. Beard), [mike.clifford@nottingham.ac.uk](mailto:mike.clifford@nottingham.ac.uk) (M.J. Clifford), [michael.watson@nottingham.ac.uk](mailto:michael.watson@nottingham.ac.uk) (M.C. Watson).

on their individual test performance. Tier 4 represents “best” and tier 0 represents “poor” performance outcomes.

The protocol recognised by the IWA to measure stove safety was developed by Johnson in 2005 (Johnson, 2005). Until this point, research addressing the issue of cookstove safety was limited to the users' exposure to particulate matter and the link to respiratory diseases rather than injuries associated with the direct contact and use of the stoves (O'Brien, 2006, Curtis, 2006; Adkins et al., 2010).

It should be noted that at the time this study was conducted, Johnson's (2005) protocol for testing safety was the only published method of risk analysis. Subsequently, the protocol has been developed by the GACC and renamed “biomass stove safety protocol” (BSSP) (GACC, 2015a). The methods, and majority of the wording, that form the BSSP come directly from Johnson's (2005) thesis (GACC, 2015a). Any variation between Johnson's (2005) original protocol and the updated BSSP guidance will be highlighted within this paper.

The BSSP evaluates cookstove safety through ten independent tests (GACC, 2015a). The tests were designed to capture hazards that expose the user to burns and scalds, lacerations and abrasions, and house fires and property loss (Johnson, 2005; Johnson and Bryden, 2015). Each test produces a quantitative score of safety, which corresponds to a qualitative band (“best”, “good”, “fair”, and “poor”).

In the original test, to calculate the overall safety rating of a cookstove, each of the qualitative bands would be converted to a numerical score. This would then be summed to provide a value that matched an overall banding for best, good, fair, and poor (Johnson, 2005). However, since the protocol was created, the process for generating an overall score has been adjusted. Each test is now weighted based on the hazards that could result in greater harm (Johnson and Bryden, 2015). For instance, the test for “flames or burning fuels exiting the fuel chamber” has been given the highest weighting of each of the tests, as an injury caused by excess flames may result in severe burns and property loss. The addition of a weighting system to determine the overall safety of a stove ensures that greater significance is placed on the tests that assess for the more life threatening hazards (Johnson and Bryden, 2015).

While the protocol outlines a good starting point for a standardised risk assessment of cookstoves in the field, it appears that the protocol itself has not been critically evaluated. There is a concern that as the IWA is used as a means to levy funding for present and future stove programmes, the protocols administered to rate stoves into the framework need to demonstrate a sufficient level of reliability and validity. Therefore, the aim of this study was to determine whether the BSSP will produce repeatable scores for a cookstove if carried out by different testers.

## 2. Materials and methods

### 2.1. Methods

To test the replicability of the BSSP, the investigation brought together a number of “testers” from a range of technical backgrounds to assess the safety of five different ICS designs currently in circulation across East and Southern Africa.

### 2.2. Selection of testers

The BSSP was designed to be a simple method for designers and manufacturers to test stoves, in the field, without the need of complex or expensive testing equipment which cannot be accessed easily in developing countries. To ensure the protocol was suitable for both international and local manufacturers, the guidance was designed to be understood by people who have different levels of technical experience and knowledge. As such, six testers for this experiment were purposively selected to represent a variety of different skill levels, exposure to ICS technology, and awareness of the risk assessment. All testers were

based at a University in the UK and had a good level of written and verbal English.

### 2.3. Cookstove selection

To effectively assess the reliability of the protocol, it was important that the cookstoves tested represented the range of design materials (metallic and non-metallic) and fuels (wood, charcoal, and bio-ethanol). Table 1 provides an overview of the stoves selected for testing.

### 2.4. Testing procedure and materials

Each tester was given a copy of the safety evaluation protocol to record the scores for each stove. No additional written or verbal guidance was provided to the testers. Each tester carried out the assessment individually, at different times, so conferring was not possible. The first author was present at each of the tests for the purpose of observation only. They remained strictly independent of the testers and did not advise or assist during any of the ten assessments.

Testing was carried out in a combustion chamber laboratory at The University of Nottingham. Although the laboratory based setting is not true to the typical household setting in which an ICS are designed to be used, it was deemed appropriate for these assessments to provide a consistent environment for each of the testers. It was considered that although an outdoor setting may provide a more true-to-life setting. The impact of extenuating variables (weather, damp etc.) may also influence the test scores. Therefore, to ensure that minimal outside effects were present the test environment was controlled.

The equipment provided was also kept consistent. For instance, fuel provided to light the stoves were obtained from the same source. The clay and rocket cookstoves used wood from the same bag, and the Jikokoa and Zambia used charcoal from the same bag. This was to reduce variability due to differences in fuel, as it has been found that fuel moisture levels can have a significant effect on cookstove performance (L'orange et al., 2012). Although the environment was kept consistent, the order in which the stoves were assessed by each tester was random.

Once the tester had completed the assessment for each of the stoves, they were provided with a self-completion questionnaire. The questionnaire was designed to gather opinions on the simplicity, difficulty, and risks associated with undertaking protocol. Additional questions prompted the testers to consider the benefits or limitations of the guidance and, if possible, provide suggestions on how this might be improved. The questionnaire was sent electronically to each participant to complete and returned via e-mail.






#### 2.4.1. Data analysis

The results were analysed in two parts; initially, the quantitative test data were analysed for both the individual tests and overall scores in order to identify which tests demonstrated the greatest variability across testers. The qualitative data analysis from the self-completion questionnaires was compared alongside each of the individual and overall test guidance to explore the benefits and limitations of the BSSP.

#### 2.4.2. Ethical considerations

As the study involved human participants, the protocol was independently reviewed by the University of Nottingham, Faculty of Engineering Research Ethics Committee; ethical approval was obtained from the committee prior to undertaking the research. A risk assessment was also carried out to ensure the safety of the testers. Before agreeing to take part, participants were given a copy of the risk assessment and a participant consent form. Once consent was obtained, participants were allocated individual time slots to

**Table 1**  
Cookstove selection

Stove	Country	Description	Fuel	Retail Price (£)	Manufacturing standards	IWA tier: safety performance
	Malawi	Portable stove produced in Malawi using locally sourced clay. It is promoted widely throughout Malawi both commercially and by charitable donation.	Firewood crop waste (maize cobs)	~£1.20	Produced by small groups who have been provided with specific training on quality control and clay handling.  Biomass energy practitioners working within Malawi have developed a product standard and quality control tools to ensure that, as stove groups scale up, the quality and efficiency of the stoves should not be compromised (Cloma, 2013).	3
	Universal design	Originally developed at the Aprovecho Research Centre, employs a number of design principles required to achieve efficient combustion at a high temperature by <ul style="list-style-type: none"> <li>ensuring the fire has a good draft,</li> <li>insulation around the fire,</li> <li>method to lift burning firewood off the ground and the firewood can be fed into the fire at a steady rate as the tips burn (Bryden et al., 2005)</li> </ul>	Firewood	N/A	The stove tested within this study was a prototype designed and built at The University of Nottingham for the purposes of demonstrating common cookstove designs. As such, it may not be a representation of more sophisticated commercially produced rocket stoves.	N/A
	Kenya	Commercially available charcoal stove. It has much more complex design than the other biomass cookstoves tested within this study. Construction includes an ash tray, ceramic insulation, chrome grate, and rubber grip handles (BURN, 2015).	Charcoal	~£25	All parts made to strict specifications and manufactured, in a modern facility, in Kenya.  To maintain standards, incentive payments are used for assembly line staff. Payments are based on quantity, quality, safety, and tidiness (Ashden, 2015).	3
	Zambia	Produced and sold by local artisans at market. The stove is currently adopted by urban and peri-urban populations.	Charcoal	~£10	In comparison to the Chitetezo and Jikokoa, which have adopted official quality control standards, this stove demonstrates a much more crudely assembled stove. There is no formal standard for this stove. Therefore, quality and design may vary across manufacturers.	Unrated
	Ethiopia Kenya	Originally designed for US and European camping markets. It has since been distributed amongst refugee camps and informal settlements in Ethiopia and Kenya to ease the pressure on women and children to procure firewood (Raftery, 2009).	Bio-ethanol	~£17	Stoves are manufactured by CLEANCOOK Sweden AD.	4

undertake their assessments and provided with personal protective equipment.

### 3. Results and discussion

Tables have been included within this section to illustrate the scores allocated to each stove, by each tester. If the test produces consistent results, each stove will receive the same rating from each tester. This would be indicated by columns containing the same qualitative score of “best” (green), “good” (yellow), “fair” (orange), or “poor” (red). If there has been a variance between the testers' scores, then columns will contain different qualitative ratings (and colours). Where a stove is allocated more than two ratings per column, there is a need to understand what caused this variance. This will be explored in detail below.

#### 3.1. Individual test results

##### 3.1.1. Test 1: sharp edges and points

This test is designed to capture sharp edges or points that may cut the skin or catch clothing, which could cause the stove to tip (GACC, 2015a). The test requires assessors to rub a cloth over the stove and count the number of times that the cloth catches. To reduce a potential source of random error, the same cloth was used by all testers.

Test 1 produced the biggest variety of ratings than any other test. However, due to its relatively low weighting compared to other tests, it is not a cause of significant variance in the overall scores. Scores for test 1 can be seen in Table 2.

One reason for variance in the clay stove was due to its coarse surface leading to human error. Testers 1, 2, and 3 did not consider that cloth catching due to the surface texture significant enough to warrant a tally, whereas testers 4, 5, and 6 did. Although in Johnson's (2005) summarised testing protocol this aspect is not clear, within his more

**Table 2**

Test 1: sharp edges and points.

Test one: sharp edges and points										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Best	6.0	Poor	1.5	Best	6.0	Best	6.0	Best	6.0
2	Best	6.0	Good	4.5	Best	6.0	Best	6.0	Good	4.5
3	Best	6.0	Poor	1.5	Best	6.0	Good	4.5	Good	4.5
4	Good	4.5	Poor	1.5	Poor	1.5	Good	4.5	Poor	1.5
5	Good	4.5	Poor	1.5	Good	4.5	Good	4.5	Poor	1.5
6	Fair	3.0	Poor	1.5	Poor	1.5	Fair	3.0	Fair	3.0
Range	3–6		1.5–4.5		1.5–6		3–6		1.5–6	

detailed guidance and the current BSSP protocol, it is noted that “stone or clay stoves may provide 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” (GACC, 2015a, p. 2, Johnson, 2005, p. 46). Therefore, future test results may not necessarily experience the same level of variation.

However, there were two further issues identified with the test that led to a variance in the results. First, there were discrepancies in what external parts should be counted in the test. For example, the Jikokoa provided the largest range of results. This was due to the edges of the five metal supports that the cookpot sits on. Testers 4 and 6 deemed these to be exterior surface points that clothing or skin could catch on, whereas the other testers decided that these points were not part of the external surface as they are not accessible when a pot is on the cookstove. Second, the technique applied to rub the cloth over the stove varied between testers. Testers 4, 5, and 6 were observed holding the cloth firmly and flat to the surface of the stove which led to more catches. While testers 1, 2, and 3 who held the cloth more loosely had fewer catches. In both of these instances, it is difficult to assume that one particular method is right or wrong, as there is no clear description of the techniques that should be applied during this test within the BSSP protocol.

Responses from the self-completion questionnaire highlighted that all participants found the test easy to carry out, although some issues were identified. For instance, tester 2 explained that they found themselves specifically targeting sharp points for tallies, while tester 4 stated that the results may vary depending on the age of the stove and level of corrosion.

Four of the testers (1, 2, 5, and 6) suggested that the test may lead to variable results due to the subjective nature of the test. For example, different people may take different amounts of time or apply different techniques of rubbing the cloth over the stove which may cause some inconsistency in the results. Therefore, further direction is needed for the testers.

### 3.1.2. Test 2: cookstove tipping

The purpose of this test is to ascertain if the cookstove is stable enough to maintain a steady upright position while cooking (GACC, 2015a). Assessors are required to measure the stove in an upright and “tipped” position. The tipped position is recognised as the point “when the centre of gravity is directly above the point of contact with the ground” (GACC, 2015a, p. 2).

Test 2 was one of only two tests that produced consistent results for each test on every stove (Table 3). However, this may be related to a broad rating system. Recorded values of the ratio of tipped height to original height ranged from 0.53 to 0.7. However, for a cookstove to rate anything less than “best”, it needed a tipping ratio of 0.94. As such further consideration is needed to identify if the current marking scheme is sensitive enough to differentiate between stoves.

Testers 1, 3, 4, and 5 all suggested that in order to obtain an accurate measurement for this test, two people are required: one to hold the stove until the point of tipping and another to take the measurement.

With respect to what the test was measuring for (stability). Testers (1, 2, 4, and 6) suggested that additional assessments could be included to measure not only stove’s stability but also how stable the pots can sit on the stove.

“The most immediate risk with the cookstove tipping would be a cookpot of boiling water or hot food falling on somebody”. Tester 1

While cook pots may vary from house to house, the need to ensure that the pot remains stable on the cookstove is just as important as ensuring the stove itself remains upright. While flame burns are accountable for the greatest number of child deaths from burn injuries (Peden et al., 2008). Scald burns are a leading cause of morbidity and disability in children (Peden et al., 2008). As such, a means to assess pot stability needs further consideration.

### 3.1.3. Test 3: containment of fuel

The objective of this test is to identify the area in which fuel may be expelled from the fuel chamber or spilled if the stove is tipped (GACC,

**Table 3**

Test 2: cookstove tipping.

Test two: cookstove tipping										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
2	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
3	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
4	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
5	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
6	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
Range	–		–		–		–		–	

**Table 4**  
Test 3: containment of fuel.

Test three: containment of fuel										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Fair	5.0	Fair	5.0	Best	10.0	Best	10.0	Best	10.0
2	Good	7.5	Good	7.5	Best	10.0	Best	10.0	Best	10.0
3	Fair	5.0	Fair	5.0	Best	10.0	Best	10.0	Best	10.0
4	Fair	5.0	Fair	5.0	Best	10.0	Best	10.0	Best	10.0
5	Poor	2.5	Poor	2.5	Good	7.5	Best	10.0	Fair	5.0
6	Good	7.5	Fair	5.0	Best	10.0	Best	10.0	Fair	5.0
Range	2.5 – 7.5		2.5 – 7.5		7.5 – 10		–		5 – 10	

2015a). For this test, assessors are asked to measure the area of exposed fuel. Results are presented in Table 4.

Results for test 3 were generally consistent; the relatively large ranges are a result of the high weighting of the test. Inconsistencies in the results were possibly related to the varying levels of thoroughness employed by the testers. For example, the author observed testers 5 and 6 adjust themselves into irregular cooking positions to seek all openings where fuel was visible; whereas other testers opted for a standard crouch only.

The variance seen in the clay and rocket stoves scores was considered a result of the shape of the fuel apertures. Both stoves feature apertures with round edges, this lead to assessors making approximations in the measurement of the area in which fuel could be seen. For example, four testers (2, 3, 4, and 6) noted that they either found it difficult to calculate the area of the opening or had to use estimations to record a value for the test. Although both Johnson (2005) and BSSP provide guidance on measuring the fuel apertures (either by calculating an area of a square or circle), the protocols do not account for fuel apertures that have a different shape.

There was also confusion at what point to take measurements of exposed fuel areas. For example,

“Measurements are taken when the cookpot is on the stove, so the jikokoa and Zambia stoves scored well, however when you actually load fuel you have to remove the pans and it is here that a lot of fuel is on show which by the standards of the protocol should result in poor scores”. Tester 6

Although the guidance notes that the cookpot should be placed onto the stove for the assessment, this may not reflect all risks present during stove operation. For example, stoves that require the pot to be removed to add fuel will, at points during the cooking process, expose the cook (and surrounding family) to a larger hazardous (burning) area. Therefore, further evaluation is needed to establish whether the risk assessment should also incorporate user-exposure to hot fuel during igniting, loading and extinguishing the stove.

**Table 5**  
Test 4: obstructions near cooking surface.

Test four: obstructions near cooking surface										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Best	8.0	Best	8.0	Best	8.0	Best	8.0	Best	8.0
2	Good	6.0	Good	6.0	Best	8.0	Poor	2.0	Best	8.0
3	Best	8.0	Best	8.0	Best	8.0	Best	8.0	Best	8.0
4	Best	8.0	Best	8.0	Best	8.0	Best	8.0	Good	6.0
5	Good	6.0	Good	6.0	Best	8.0	Best	8.0	Best	8.0
6	Poor	2.0	Poor	2.0	Best	8.0	Poor	2.0	Good	6.0
Range	2 – 8		2 – 8		–		2 – 8		6 – 8	

### 3.1.4. Test 4: obstructions near the cooking surface

Protruding areas on the surface of a cookstove can act as an obstruction for the user when they need to remove a cook pot from the stove. Such obstructions are likely to mean that the user has to lift a hot pot higher to clear the obstruction. It is possible when doing this that the pot can tip and any hot contents spill on to people or property around the stove (GACC, 2015a). Results for test 4 are presented in Table 5.

The variation seen in the results of test 4 were possibly due to the different interpretations between an “obstruction” and the “cooking surface”. Some testers took the raised supports designed for the cookpots to sit on as obstructions, as they are possible points at which pots could knock when being removed or added to the stove. For example, one tester commented,

“I didn't completely understand the terms used, a better description of what the 'cooking surface' was and what is considered an 'obstruction' would have made me more confident in my testing”.—Tester 6

The ambiguity led Tester 6 to count both the lips and the stands on which the cookpot is rested as obstructions. This may explain why their results were noticeably different to that of the other testers. Tester 2 suggested that instructions could provide an additional diagram to aid those with less experience.

Additionally, testers considered whether the obstructions should be measured by height and latitude:

“There was little obstructions at the top of the clay cookstove, but the handles protruding out of the sides of the cookstove provided 'obstructions' when removing the pot from the stove to place on the floor”.—Tester 4

As such, testers identified two issues when conducting test 4. First, understanding which aspect of the stove should be measured as an obstruction. Second, what measurements should be taken (height or latitude)? Testers suggested that this could be clarified simply with an additional diagram and definition of what is to be measured.

**Table 6**

Test 5: cookstove surface temperature.

Test five: cookstove surface temperature										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Good	6.0	Poor	2.0	Poor	2.0	Best	8.0	Poor	2.0
2	Best	8.0	Poor	2.0	Best	8.0	Best	8.0	Poor	2.0
3	Best	8.0	Poor	2.0	Fair	4.0	Best	8.0	Poor	2.0
4	Poor	2.0	Poor	2.0	Best	8.0	Best	8.0	Poor	2.0
5	Poor	2.0	Poor	2.0	Best	8.0	Best	8.0	Best	8.0
6	Best	8.0	Poor	2.0	Best	8.0	Best	8.0	Best	8.0
Range	2–8		–		2–8		–		2–8	

### 3.1.5. Test 5: cookstove surface temperature

Tests 5, 6, and 7 are designed to be conducted together. They have been designed to measure the surface temperature of the stove and its immediate surroundings to identify the risk of contact burns or damage to surrounding objects (particularly those that may ignite when exposed to heat).

In preparation for the tests (5, 6, and 7), the protocol asks testers to draw a chalk grid of  $8 \times 8$  squares. However, there was some misunderstanding relating to the grid to be drawn on the cookstove. In the instructions, it is described as a “ $8 \times 8$  cm grid”. Testers 1, 2, and 5 took this to mean a single grid  $8 \text{ cm} \times 8 \text{ cm}$  containing squares within that. Testers 3, 4, and 6 took it to mean a grid of  $8 \text{ cm} \times 8 \text{ cm}$  squares over the whole of the cookstove. The latter were correct according to the detailed description in Johnson's (2005) thesis, but the BSSP does not make this clear.

The results for test 5 can be seen in Table 6.

From test 5, stoves should be lit and fuel added until the stove “has reached normal operating state” (Johnson, 2005, p. 56). Johnson's (2005) guidance recommends that the tests should be conducted from “at least 30 min run time”. However, the current BSSP guidance states testers “wait until the cookstoves has reached max temp (~20 min) before proceeding” (GACC, 2015c, p. 4). It is likely that “operating temp” and “max temp” will fluctuate between stove designs; therefore, setting a single time frame for the test may not provide the tester with a true reflection of the maximum heat of the stove.

Confusion around how to establish “operating state”, without cooking food, meant testers adopted a variety of different procedures for undertaking the assessment. This is evident in the variation of results found in the clay, Jikokoa, and Zambia cookstoves.

Some testers adopted quantifiable methods to determine when a normal operating temperature had been reached to keep consistency throughout their tests. For instance, Tester 1 waited for 30 min after lighting the stove, maintaining the supply of fuel during this time, before testing for the increase in surface temperature. Testers 3 and 4 filled a cookpot with water and when that pot reached boiling point,

regardless of how long it took, was when the stove was determined to have reached a normal operating temperature.

Due to the Rocket having thin metal walls, it quickly became extremely hot on the outside surface resulting in a poor rating. In contrast, the CleanCook, due its use of a bioethanol canister, showed very little temperature increase.

The ratings recorded for the clay stove best demonstrate some variability within this test. The rocket stove very quickly got above temperatures of  $100^\circ\text{C}$ , thus scoring poor on every test; however, given enough time, the clay stove could also reach these temperatures with its highest recorded temperature at  $132^\circ\text{C}$  and a lowest of  $28^\circ\text{C}$ . These results show that the test has the potential to miscalculate the operational temperature of a cookstove.

For example, all testers recognised that it would take longer for the surface of the ceramic cookstoves to get to extreme high temperatures but stated that it was possible in time.

“Ceramic cookstoves take hours to get to full operating temperature, I would measure temperature over a period of hours to record peak temperature and temperature after approximately 30 min of cooking. The test does not assess the real risk of burns from a ceramic body stove”.—Tester 2

Furthermore, Testers 1, 2, 3, and 4 noted that risks associated with the surfaces of stoves remaining hot after cooking are not considered in this test.

“Even though the clay cookstove took much longer to get to the dangerous temperatures of the rocket stove, it still got there. The test should account for the fact that over time the clay stove will get extremely hot, but also account for the fact the rocket stove got very hot very quickly”.—Tester 1

Understanding temperature variation over time is a significant factor when considering the “real life” use of stoves. Typically, stoves are lit until a meal is cooked, once food is prepared, the residual heat is often used for other things, i.e., to heat bath water. As

**Table 7**

Test 6: environmental surface temperature.

Test six: environmental surface temperature										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
2	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
3	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
4	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
5	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
6	Best	10.0	Best	10.0	Best	10.0	Best	10.0	Best	10.0
Range	–		–		–		–		–	

**Table 8**  
Test 7: operational construction temperature.

Test seven: operational construction temperature										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Best	8.00	Best	8.00	Best	8.00	Best	8.00	Good	6.00
2	Best	8.00	Poor	2.00	Best	8.00	Best	8.00	Best	8.00
3	Best	8.00	Best	8.00	Best	8.00	Best	8.00	Best	8.00
4	Poor	2.00	Best	8.00	Best	8.00	Best	8.00	Best	8.00
5	Poor	2.00	Best	8.00	Best	8.00	Best	8.00	Best	8.00
6	Best	8.00	Best	8.00	Best	8.00	Best	8.00	Best	8.00
Range	2–8		2–8		2–8		2–8		2–8	

such, a risk analysis needs to take into consideration the variation of stove temperatures over time rather than a particular point. It is likely that “operating temperature” and capacity to contain residual heat will vary between stoves; this will be discussed further in Section 3.3.

### 3.1.6. Test 6: environmental surface temperature

Test 6 requires the tester to take temperature measurements from nearby walls and floor to determine the extent the surrounding areas heat up when the stove is in use. Table 7 shows the results obtained by the testers.

Similarly to test 2, test 6 provided consistent ratings on each test for every cookstove. Due to the test location, there was no need to measure the temperature of the wall, thus leaving only temperature measurements to be taken from the floor beneath the cookstove. None of the stoves led to a significant increase in temperature of the floor. Potentially this was due to all the stoves, apart from the clay stove, having a raised fuel chamber. Additionally, the laboratory floor, a naturally cold and hard to heat concrete surface, would require high temperature changes to record a rating below best.

Testers were concerned that in order to conduct the assessment a lit stove needed to be moved.

“Moving a lit stove is dangerous and should not be done, the temperature measurements of the ground should be taken after cooking”.—Tester 2

While a risk assessment was undertaken prior to testing the protocol, some elements of the test do expose the tester to a certain amount of risk. This should be acknowledged by those who will undertake this assessment to ensure that safety and protective equipment are available to assessors.

### 3.1.7. Test 7: operational construction temperature

Test 7 was designed to measure the temperature of operational parts that need to be touched or handled during the cooking process. The results are as seen in Table 8.

**Table 9**  
Test 8: chimney shielding.

Test eight: chimney shielding										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
1	Average	6.25	Average	6.25	Average	6.25	Average	6.25	Average	6.25
2	Poor	2.50	Poor	2.50	Poor	2.50	Poor	2.50	Poor	2.50
3	Best	10.00	Best	10.00	Best	10.00	Best	10.00	Best	10.00
4	NA	0.00	NA	0.00	NA	0.00	NA	0.00	NA	0.00
5	Poor	2.50	Poor	2.50	Poor	2.50	Poor	2.50	Poor	2.50
6	Fair	5.00	Fair	5.00	Fair	5.00	Fair	5.00	Fair	5.00
Range	0–10		0–10		0–10		0–10		0–10	

However, additional commentary is needed where stoves do not have “typical” operational parts. For example, testers were unsure what should be measured if the stove did not have a handle(s).

At this point in the testing procedure, the stove had been in operation for a longer period of time. This may explain why the rating on test this test was always equal to, or less than, the rating received in test 5. Again, variation between when testers determined a “normal operating temperature” influenced the results of the test.

### 3.1.8. Test 8: chimney shielding

Test 8 measures, if a chimney is present, whether it has the shielding. If shielding is present, it is measured to determine to what extent this shielding protects children and cookstove users from contact burns (Johnson, 2005).

However, there is no guidance provided on what to do if there is no chimney present. As a result, the testers adopted five different techniques for scoring the stoves in this test. Results for test 8 can be seen below (Table 9).

As can be seen in Table 9 Tester 1 opted to rate each stove as average with a score of 6.25 as it seemed unfair to rate it with either best or poor. Tester 6 opted to rate the cookstoves as fair as there no way of telling the quality of shielding present if there was a chimney. Testers 2 and 5 opted to rate each cookstove as poor as, technically, there was no shielding present.

“The instructions state that if there is no shielding that the stove is to be rated ‘poor’, even though there was no chimney I just assumed that this was the right decision”.—Tester 5

Tester 3 rated each cookstove as best because, despite there being no shielding, there was no risk of burns from contact with a hot chimney.

“As there was no chimney there was no risk, so I decided it was appropriate to score the stoves as ‘best’”.—Tester 3

**Table 10**

Test 9: flames around the cookpot.

Test nine: flames around the cookpot										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighed	Rating	Weighed	Rating	Weighed	Rating	Weighed	Rating	Weighed
1	Good	9.0	Fair	6.0	Best	12.0	Best	12.0	Best	12.0
2	Best	12.0	Best	12.0	Best	12.0	Best	12.0	Best	12.0
3	Fair	6.0	Fair	6.0	Best	12.0	Best	12.0	Best	12.0
4	Good	9.0	Poor	3.0	Best	12.0	Best	12.0	Best	12.0
5	Good	9.0	Good	9.0	Best	12.0	Best	12.0	Best	12.0
6	Fair	6.0	Good	9.0	Best	12.0	Best	12.0	Best	12.0
Range		6 – 12		6 – 12		–		–		–

Tester 4 decided as there was no chimney, the test was “not applicable” to the cookstoves being tested. They removed the test from their final score and recalculated the final percentage out of 90 rather than 100.

However, this issue has now been clarified in the current BSSP guidance where a rating of “best” should be given to stoves without a chimney (GACC, 2015a).

As none of the stoves tested here had a chimney, it is impossible to comment on the procedures for testing chimney shielding; further benchmarking is needed with a greater variety of stoves.

### 3.1.9. Test 9: flames surrounding the cookpot

This test measures the flames that can be seen surrounding the cookpot when in use. Flames surrounding the cook pot could ignite the user's clothes, hair or cause flame burns to the hands. The results for test 9 (Table 10) varied depending on the amount of fuel added to the stove by the tester.

The instructions schedule the tester to inspect for flames after the temperature testing has been done, but this was not when flames were at their peak. Consequently, five testers determined the maximum height reached by the flames surrounding the cookpot from memory of when flames were at their peak (prior to temperature testing).

“When it came to test nine I found myself having use memory to remember how high the flames got earlier in the fire. The fire was burning with less flames by the point of testing”.—Tester 5

Another source of variation is in the rating scheme: for a rating of good, the flames must reach no higher than 4 cm; for a rating of fair, the flames will to cover “most of the cookpot”. However, there is a possible ambiguity between these two ratings, depending on the height of the pot used for the assessment. For example, the cookpot used was 25 cm in height, thus flames of approximately 6 cm in height neither applied to a rating of fair or good, leaving testers to make individual judgement calls which may have led to some variation.

“The rating table has a gap in it: for a rating of ‘good’ the flames must be less than 4 cm up the sides of the pot; for a rating of ‘fair’ the flames must be most of the cookpot but not the handles. What if the flames were greater than 4 cm but were still not covering most of the cookpot?”—Tester 1

There was a concern that the amount of fuel used varied, with each individual tester, which will also result in a fluctuation of flame heights, regardless of the stove or pot.

“Flames are dependent on amount of fuel and cookpot used”.—Tester 2

As such, results for test 9 appear to be influenced by the size of the cookpot and at what point the test is undertaken, if testers are assessing from memory and the amount of fuel used. Additional guidance may be required to reduce this subjectivity.

### 3.1.10. Test 10: Flames exiting fuel chamber, canister or pipes

Test 10 requires assessors to identify flames exiting the stove, from anywhere other than around the pot. The concern is if flames exit additional areas, they may ignite clothes or surrounding materials causing burns and property loss. The results for test 10 (seen in Table 11) were generally consistent.

Variation in this test was observed to be associated with the techniques used to load the wood into the clay and rocket stoves. Using slightly longer pieces resulted in flames creeping out of the large apertures featured on the cookstoves.

Responses to the self-completion questionnaire for test 10 were similar to test 9, with most noting that the flames were most prevalent earlier in the testing and that, especially with the clay and rocket stoves, the varying amount of fuel used by testers could lead a difference in results.

**Table 11**

Test 10: flames exiting fuel chamber, canister, or pipes.

Test ten: flames exiting fuel chamber, canister or pipes										
Tester	Clay		Rocket		Jikokoa		CleanCook		Zambia	
	Rating	Weighed	Rating	Weighed	Rating	Weighed	Rating	Weighed	Rating	Weighed
1	Poor	4.0	Best	16.0	Best	16.0	Best	16.0	Best	16.0
2	Best	16.0	Best	16.0	Best	16.0	Best	16.0	Best	16.0
3	Poor	4.0	Poor	4.0	Best	16.0	Best	16.0	Best	16.0
4	Best	16.0	Best	16.0	Best	16.0	Best	16.0	Best	16.0
5	Best	16.0	Best	16.0	Best	16.0	Best	16.0	Best	16.0
6	Best	16.0	Best	16.0	Best	16.0	Best	16.0	Best	16.0
Range		4 – 12		4 – 12		–		–		–



**Table 12**  
Overall results: quantitative scores.

Stove	Tester						Average	Range
	1	2	3	4	5	6		
Clay	74.3	88.0	77.0	76.1	66.5	77.5	76.6	21.50
Rocket	74.8	74.5	66.5	72.8	69.5	70.5	71.4	8.25
Jikokoa	90.3	92.5	96.0	95.0	88.5	90.5	92.1	7.50
CleanCook	96.3	86.5	98.5	98.3	91.0	86.0	92.7	12.50
Zambia	86.3	85.0	92.5	86.1	83.0	85.0	86.3	9.50
Average	84.4	85.3	86.1	85.7	79.7	81.9		

Overall rating	Total point score
Best	93 ≤ S ≤ 100
Good	84 ≤ S ≤ 92
Fair	76 ≤ S ≤ 83
Poor	25 ≤ S ≤ 75

### 3.2. Overall scores

#### 3.2.1. Overall results: quantitative

Table 12 presents the overall scores allocated by the testers: the columns represent the individual testers and the rows represent the stoves. If the stove has received a consistent overall rating across each of the testers, then the row will show a single colour. If a stove has received different ratings by the testers, then the row will show two or more colours.

Four of the five cookstoves tested had an overall score in multiple rating brackets. Only the rocket stove had unanimous “poor” rating. The largest range of results observed was the clay stove at 21.50, which fell into three different rating brackets. The cookstove with the smallest range of scores was the Jikokoa with a range of 7.5; however, this still returned scores across two rating categories.

In some cases, the overall scores could not clearly determine an absolute rating. For example, the Jikokoa and Zambia cookstoves were given a score of 92.5 (Testers 2 and 3 respectively). This score, in the overall rating scheme (Table 12), falls between the good and best rating bands. The same issue is also present in the overall average rating for the Jikokoa and CleanCook which score of 92.13 and 92.76, respectively. For the purpose of this assessment, it was decided that these scores should correspond to a rating of good, and that the established action would be to always round down to the lesser rating if scored in between rating brackets. To reduce subjectivity, there is a need to add guidance on how to categorise a stove when its overall score falls between two bands. In practice, this should ensure that despite the positionality of the tester, a stove with any given final score will be placed in the same band.

As indicated in Section 3.1, test 8 (chimney shielding) resulted in the largest variation of results. Therefore, it was deemed appropriate to investigate whether this had a significant effect on the overall score and rating. The results of test 8 were removed from the original overall rating; new scores were then calculated as a percentage out of 90 and rated according to the same rating scheme. Table 13 below shows the resultant overall scores.

Providing a consistent treatment for test 8 led to what appeared to be more consistent ratings amongst the stoves. The Jikokoa stove now had consistent “best” ratings. The Zambia cookstove had a consistent

rating of good across all testers. The range of results for the CleanCook decreased and with five of the six scores all in the same category. However, this impact was not found for either of the wood-burning stoves (clay and rocket). The scores for both stoves revealed an increased range of scores, especially for the rocket cookstove.

This demonstrates that, although removing a test where it is not applicable to the stove from the final score may provide a more consistent rating for some stoves, the effect is not universal. Therefore, where a test is not applicable, guidance is needed to indicate what score should be allocated to the stove in order to calculate the final rating.

#### 3.2.2. Overall results: qualitative

The protocol was considered useful by all testers. However, some tests were considered difficult to interpret. Participants identified additional hazards that the protocol, at present, does not include. These were pot stability, stove temperature over time, durability, and hazards associated with lighting and extinguishing the stove.

“It is important that all sources of risk are considered, this protocol does that for the most part but does not consider some potential dangers”.—Tester 6

When participants were asked about the difficulty of test as a whole, they explained that certain elements of the protocol could be challenging to carry out alone.

“It is not a protocol of testing that should be carried out by a single person, but instead should be carried out by at least two people or three where possible. Some of the tests are hard to carry out individually and some require constant monitoring throughout the testing, so more people conducting the tests would be beneficial”.—Tester 5

Lastly, testers highlighted that although the protocol tests the cookstove as an individual entity, there are a number of other environmental factors, which may influence the safety of the user during the cooking process.

**Table 13**  
Overall scores: test 8 (chimney Shielding) removed.

Stove	Tester						Average	Range
	1	2	3	4	5	6		
Clay	75.6	95.0	74.4	76.1	71.1	80.6	78.8	23.89
Rocket	76.1	80.0	62.8	72.8	74.4	72.8	73.2	17.22
Jikokoa	93.3	100.0	95.6	95.0	95.6	95.0	95.7	6.67
CleanCook	100.0	93.3	98.3	98.3	98.3	90.0	96.4	10.00
Zambia	88.9	91.7	91.7	86.1	89.4	88.9	89.4	5.56
Average	86.8	92.0	84.6	85.7	85.8	85.4		

Overall rating	Total point score
Best	93 ≤ S ≤ 100
Good	84 ≤ S ≤ 92
Fair	76 ≤ S ≤ 83
Poor	25 ≤ S ≤ 75

“How safe it is to cook a meal not the cookstove?”—Tester 4

Johnson (2005), in his recommendations, indicated that future research is needed that takes into account the cooking environment as well as the cookstove. “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” (Johnson, 2005, p. 76). However, this recommendation has not been taken forward by the GACC in producing the current guidelines. While each of these environmental issues could not be considered further within the scope of this study, an experiment was undertaken to understand what the variations of testing at “operational state” (Johnson, 2005) and/or “maximum temperature” (GACC, 2015a) mean for testing safety across clay and metallic stoves.

### 3.3. Draft residual heat test

It is possible that the variance seen in tests 5, 6, and 7 was due to the different times at which testers determined the cookstoves reached a “normal operating state”. Testers suggested to improve the protocol, measurements should be taken at regular intervals rather than at a singular point (when a normal operating temperature is considered to have been reached). Additionally, testers proposed that temperatures should be taken after a period of cooking is completed to see how much residual heat is present on the surface of the cookstoves. This is because burns can still occur from touching a cookstove even if the stove is no longer aflame (Johnson and Bryden, 2006).

To examine the fluctuation in temperatures of both metallic and clay stoves, a residual heat test was conducted. The test consisted of taking temperature readings from the same location on the stoves every 2 min. For the first 40 min of the test, the cookstove fire was maintained with fuel being added when necessary. A cookpot filled with water was applied to the cookstove to simulate how surface temperature would change whilst cooking. After 40 min, the cookpot was removed. Fig. 1 shows the results of the test.

The clay cookstove was found to reach 100 °C after 54 min and retain heat for a longer period of time, whereas the rocket cookstove heated up rapidly but also cooled more quickly.

The horizontal orange and blue lines represent the maximum surface temperature limits of test 5 (where blue is non-metallic boundaries and orange is the metallic boundaries). The bottom line is the maximum temperature for a best rating, the middle line is the maximum temperature for a good rating, and the top line is the maximum temperature for a fair rating. If the temperature exceeds the top line, the rating is poor.

The rocket stove quickly exceeded the maximum temperature for a fair rating into the poor area; however, once the fire is no longer being maintained, it only takes approximately 17 min to cool to the best area. Conversely, the clay cookstove took 30 min to heat up beyond the best temperature bracket but takes a lot longer to cool down. The clay cookstove actually continued to increase in heat after the 40 min mark due to its high thermal capacity keeping the combustion area of the cookstove hot.

The graph shows that despite the surface of the rocket stove being 180 °C during cooking, once cooking is complete, it cools rapidly. Whereas the clay cookstove, although considered safer whilst cooking, poses a greater risk of burns once cooking is completed than the rocket.

This test demonstrates that the current guidance for testing the stove from “at least 30 min” (Johnson, 2005) or “~20 min” (GACC, 2015a) as a means to determine the operating or maximum temperature may not be appropriate for clay stoves. For example, if the temperature of the clay stove is measured at 20–30 min, according to the guidance, it achieves a score of “best”. However, after another 10 min cooking time the same clay stove would score “poor”. Without “real world” testing to measure how long an average meal takes to cook, it is difficult to establish to what extent this extra cooking time, and extra heat, will have on the user or surrounding family. However, it is important to note that taking a temperature recording at only one subjective point in time can result in the difference between a “best” and a “poor” rating for a clay stove. Therefore, measuring surface temperature at different points during the procedure, then using the maximum recorded temperature to rate the stove, should be considered as a more repeatable method to measure surface heat.

From a safety perspective, a stove that retains heat may lead to contact burns, but for the consumer, maintaining a residual heat without the need for additional firewood is likely to be a distinct positive. For example, a stove that continues to retain heat after the fuel has stopped burning can be used for other tasks such as warming bathwater and space heating. As such, work is needed to develop stoves that can retain heat whilst protecting the user from contact burns during and following the cooking process.

## 4. Conclusions

The use of solid biomass and inadequate stoves for cooking and heating is set to increase (Mock et al., 2011; GACC, 2015b; Urmee and Gyamfi, 2014). To mitigate the impact of excess pollution, deforestation, injuries, and respiratory diseases, humanitarian and private sector organisations have committed themselves to reaching 100 million households with ICSs by 2020 (GACC, 2015c). While in high-income countries legislation has resulted in standardised safety criterion for energy using products (Lofthouse, 2006), there is still a need to develop

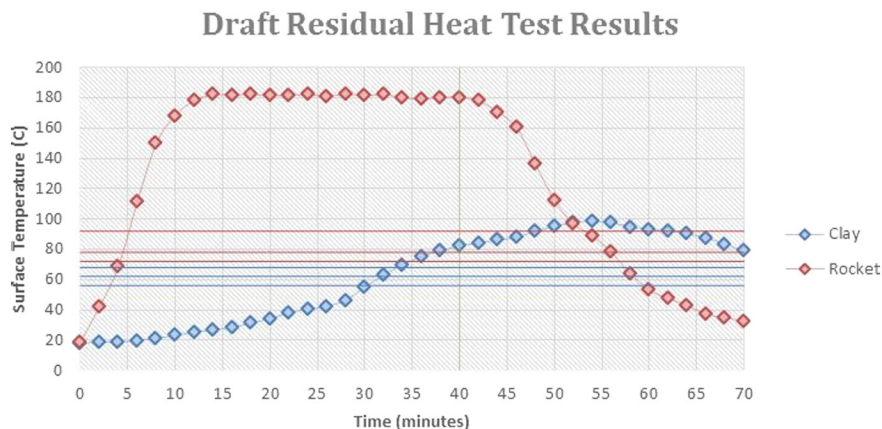


Fig. 1. Surface temperature of clay and rocket stove against time.

technological standards in low- and middle-income countries, to levy financial investment and governmental backing and most importantly protect the consumer.

The creation of the Biomass Stove Safety Protocol (GACC, 2015a) initiated by Johnson in 2005 and further refined by the GACC is an integral starting point in drawing attention to the need for a stove safety test, particularly for the use of ICSs programs and interventions across LMIC. However, following this evaluation, our results indicate there are some areas of the protocol that require development to ensure that stove safety can be reliably assessed. We draw the following specific conclusions:

- Without additional clarification, there is potential to categorise the same stoves into two or more safety ratings. In this assessment, six independent testers using the same protocol returned overall results which placed the same cookstove into three different categories. However, the qualitative findings suggest that small adjustments made to the methodology such as additional illustrations and guidance may reduce this variability.
- Results are subject to the way in which each tester operates the stove. For example, results for tests 9 and 10 are dependent on the amount of fuelwood that testers insert into the stoves. As each stove will require a different quantity of fuel, it is difficult to control for this within the test method. However, additional description for fuel loading may reduce some subjectivity.
- Variation in the overall rating of the cookstove is not due to any one test. Removing test 8, the chimney shielding test, and grading the cookstoves as a percentage of the remaining available marks did not improve repeatability. Consequently, variation seen in the test scores are a result of a number of smaller issues within each test, rather than one test in particular.
- Some significant hazards are not accounted for. For instance, test 2 measures the risk of the entire cookstove tipping; it does not measure the stability of a pot on the stove. Further development of the test could incorporate hazards such as un-even or loose pot rests.
- Some marking schemes do not always provide clear distinction between a “best” and “poor” stove. For example, the overall scores for each stove were significantly different; however, all stoves scored “best” for test 2 (cookstove tipping). This may indicate that the test is not sensitive enough to differentiate between a “poor” and “best” cookstove. Further evaluation is needed to identify if this is the case, and if so, to change the rating boundaries to ensure that distinctions can be made.
- An alternative method may be needed to determine what “normal operating temperature” is in a typical kitchen environment. Whether this is a specific time of fuel burning, the length of time to boil a quantity of water or how long it takes to cook a common meal. Additional detail would assist the testers and prevent misinterpretation. The work here suggests that measuring the temperature of a stove over time and scoring it based on the maximum temperature would provide a score that is representative of the highest risk of potential harm.
- The order of the tests could be adjusted to prevent testers from relying on memory to score the stove. For example, test 9 (flames surrounding the cookpot) and test 10 (flames exiting the fuel chamber) can be undertaken before or during the heat transfer tests to prevent testers forgetting the maximum heights of the flames around the pot and fuel chamber.
- The BSSP only assesses the safety of a cookstove as a solitary item rather than how safe it is to cook with or the environment in which it is used. In high-income countries, home accident prevention inventories (HAPIs) have been used to measure hazardous items accessible to children within the broader home environment (Tertinger et al., 1984). This is particularly important in relation to the storage of fuels. For example, the storage of liquid fuels for ethanol and kerosene stoves creates an additional hazard beyond that which is currently considered in the BSSP. As a liquid, the accidental ingestion of these

fuels is a leading cause of fatal poisoning in children, in low and middle income countries (Peden et al., 2008). The additional use of a HAPI would identify, not only the stove as a hazard but, a child’s exposure to additional dangers such as poisonous solids/liquids, electrical hazards, objects that can suffocate, choking hazards, sharp objects, trip hazards, and drowning hazards (Tertinger et al., 1984). However, the applicability of a HAPI created for use in high-income countries may not be directly applicable for housing in low and middle income countries; the notion that any home environment is likely to contain multiple hazards that expose children to danger needs further consideration. Public health approaches describe the importance of interpreting the cause of injuries as part of a multi-causal, rather than single causal, events (Christoffel and Gallagher, 1999). The Haddon Matrix is used by the WHO as a means of developing initiatives to prevent injuries (Peden et al., 2008). The Matrix adopts a holistic approach towards the analysis of injuries by incorporating factors such as the human, the agent (cookstove), and the physical and the socio-cultural environment during three temporal stages of an injury event (pre-event, event, and post-event) (Mock et al., 2011). In the case of BSSP protocol, the main focus is on the “agent” (or cookstove) only. While this is an important element within Haddon’s Matrix, it neglects other factors that, if not considered, are also likely to expose a child to an injury. Thus, the adoption of a safer cookstove is not equal to a safer kitchen, unless considered as part of a multi-factorial approach. Therefore, additional evaluation is needed, within a typical household environment, to ensure that the protocol is measuring hazards that are true to the experience of the end user. Field tests, testing within a typical kitchen environment, are already integrated within existing ICS performance and emissions protocols, such as the controlled cooking test that requires the cooking of a predetermined meal to analyse cookstove emissions (Bailis, 2004) and the kitchen performance test used to assess the impact ICS have on household fuel consumption (Bailis et al., 2007). As field testing is not a recent phenomenon in the testing of ICS, the addition of a safety protocol that can be used and incorporate the measurement of risks in a real-life setting has the potential to be incorporated into existing field based tests.

#### 4.1. Recommendations

Before altering the existing protocol, revisions should be drafted and independently assessed for replicability. There is an urgent need to properly benchmark the biomass stove safety protocol used by the GACC to ensure that stove safety ratings are accurate and repeatable. We also suggest that the following additional tests are considered:

- Residual heat test: How much heat does the cookstove retain? For instance, what is the risk of burns occurring after cooking is complete?
- Pot stability on the cooking surface: How easy is it for a pot to fall off of the cookstove? What is risk of the pot or its contents falling on to the person cooking?
- Ease of lighting test: How close to 90° does the operators have to hold a match above the fuel. What is the risk of burns occurring as a result of lighting, and refuelling, the cookstove?
- Ease of extinguishing test: How quick and safe is it to extinguish the cookstove? What features does the cookstove possess to efficiently extinguish the cookstove?
- Does the safety of a stove deteriorate over time?
- Other areas for exploration should include an evaluation of the information, if any, that is provided to the customer at the time they receive their stove. For instance, are customers given written or illustrated instructions on how to handle, use, and manage risks associated with their cookstove? If so what information is provided? Can it be clearly interpreted and retained?
- Exploration and addition of hazards associated with the stove. How

fuel is stored and managed, e.g., the risks of liquid ingestion and choking controlled for?

This was a small-scale study comprising of six UK based testers. Nevertheless, the results from this sample demonstrate that different testers can produce considerably varied stove safety scores. Looking ahead, future research should consider the development of a larger detailed user study that includes a wider sample of international testers and locations. In addition, further evaluation of the protocol should identify any additional training or guidance (written or pictorial) that is necessary for testers to produce consistent scores.

Practitioners working within the stove sector who are concerned with fuel efficiency and emissions testing should also have a responsibility to demonstrate that the safety of the stove user and their family has been considered as part of the design. Revisions and recommendations that have been highlighted in this paper should be used to develop a more refined method for categorising stove safety into the IWA tier system.

### Acknowledgements

The authors gratefully thank Hestian who contributed a Chitetezo Mbaula stove for testing. This work was made possible by the Department for International Development, the Department of Energy and Climate Change and the Engineering and Physical Sciences Research Council's joint grant EP/L002639/1: "Understanding the Barriers to the Introduction and Uptake of Clean/Improved Cookstoves in Sub-Saharan Africa".

### References

- Adkins E, Tyler E, Wang J, Siriri D, Modi V. Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy Sustain Dev* 2010;14:172–85.
- Albertyn R, Bickler SW, Rode H. Paediatric burn injuries in Sub Saharan Africa—an overview. *Burns* 2006;32:605–12.
- Ashden. *Case Study: Burn Manufacturing, Kenya* [Online]. [https://www.ashden.org/files/case\\_studies/Burn,%20Kenya.pdf](https://www.ashden.org/files/case_studies/Burn,%20Kenya.pdf); Ashden; 2015 [Accessed 29/09/2015].
- Bailis R. *Controlled Cooking Test (CCT)* [Online]. <http://www.pciaonline.org/node/1050>; Winlock International; 2004 [Accessed 10/08/2015].
- Bailis R, Smith KR, Edwards R. *Kitchen Performance Test (KPT)* [Online]. <http://cleancookstoves.org/technology-and-fuels/testing/protocols.html>; United Nations Foundation; 2007 [Accessed 12/08/2015].
- Bryden M, Still D, Scott P, Hoffa G, Ogle D, Bailis R, et al. *Design Principles for Wood Burning Cook Stoves* [Online]. <http://www.ewb-usa.org/files/2015/05/PrinciplesWoodBurningCookStoves.pdf>; Aprovecho Research Centre; 2005 [Accessed 14/08/2015].
- Burn. *Our Stoves* [Online]. <http://www.burnstoves.com/stoves/>; Burn; 2015 [Accessed 06/04/2015].
- Christoffel T, Gallagher SS. *Injury Prevention and Public Health: Practical Knowledge, Skills, and Strategies*. Jones & Bartlett Learning; 1999.
- Clioma. *Chitetezo Mbaula Specifications* [Online]. <http://www.clioma.org/home/home/Item%202.aspx>; Clioma; 2013 [Accessed 14/08/2015].
- Curtis DO. Solar cooking and health. *Boiling Point* 2006;52:30–2.
- Desai M, Mehta S, Smith K. *Indoor Smoke from Solid Fuels: Assessing the Environmental Burden of Disease at National and Local Levels*. Geneva: World Health Organisation; 2004.
- Global Alliance for Clean Cookstoves (GACC). *IWA Tiers of Performance* [Online]. <http://cleancookstoves.org/technology-and-fuels/standards/iwa-tiers-of-performance.html>; United Nations Foundation; 2012 [Accessed 14/08/2015].
- Global Alliance for Clean Cookstoves (GACC). *Biomass Stove Safety Protocol Guidelines* [Online]. <http://cleancookstoves.org/technology-and-fuels/testing/index.html>; United Nations Foundation; 2015a [Accessed 12/08/2015].
- Global Alliance for Clean Cookstoves (GACC). *Country Profiles* [Online]. <http://cleancookstoves.org/country-profiles/>; United Nations Foundation; 2015b [Accessed 06/08/2015].
- Global Alliance for Clean Cookstoves (GACC). *Our Mission* [Online]. <http://cleancookstoves.org/about/our-mission/>; United Nations Foundation; 2015c [Accessed 01/09/2015].
- Golshan A, Patel C, Hyder AA. A systematic review of the epidemiology of unintentional burn injuries in South Asia. *J Public Health (Oxf)* 2013;35:384–96.
- Hyder AA, Kashyap K, Fishman S, Wali S. Review of childhood burn injuries in sub-Saharan Africa: a forgotten public health challenge: literature review. *Afr Saf Promot* 2004;2:43–58.
- Johnson N. *Risk Analysis and Safety Evaluation of Household Stoves in Developing Nations*. Master of Science, Iowa State University; 2005.
- Johnson NG, Bryden M. Direct contact hazards of cookstoves: burns, cuts and scalds. *Boiling Point* 2006;52:14–5.
- Johnson NG, Bryden KM. Field-based safety guidelines for solid fuel household cookstoves in developing countries. *Energy Sustain Dev* 2015;25:56–66.
- Jones DB. The World Health Organization has spoken—improved cookstoves are not clean enough. *Energy Sustain Dev* 2015;24:86–7.
- Justin-Temu M, Rimoy G, Premji Z, Matem G. Causes, magnitude and management of burns in under-fives in district hospitals in Dar es Salaam, Tanzania. *East Afr J Public Health* 2008;5:38–42.
- Kammen DM. Cookstoves for the developing world. *Sci Am* 1995;273:72–5.
- Kshirsagar MP, Kalamkar VR. A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. *Renew Sustain Energy Rev* 2014;30:580–603.
- Kurmi OP, Semple S, Simkhada P, Smith WCS, Ayres JG. COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis. *Thorax* 2010;65:221–8.
- Lofthouse V. Ecodesign tools for designers: defining the requirements. *J Clean Prod* 2006;14:1386–95.
- L'orange C, Defoort M, Willson B. Influence of testing parameters on biomass stove performance and development of an improved testing protocol. *Energy Sustain Dev* 2012;16:3–12.
- Mock C, Peck MD, Juillard C, Meddings D, Gielen A, Mckenzie L, editors. *Burn Prevention: Success Stories Lessons Learned*. Geneva: World Health Organization; 2011.
- Mock C, Peck MD, Peden M, Krug E, editors. *A WHO Plan for Burn Prevention and Care*. Geneva: World Health Organization; 2008.
- Ndiritu S, Ngum Z, Nyaim O. Burns: the epidemiological pattern, risk and safety awareness at Kenyatta National Hospital, Nairobi. *East Afr Med J* 2006;83:455–60.
- O'brien C. Introducing alcohol stoves to refugee communities; a case study from Kebrebehay, Ethiopia. *Boiling Point* 2006;52:16–8.
- Outwater AH, Ismail H, Mgalilwa L, Temu MJ, Mbembati NA. Burns in Tanzania: morbidity and mortality, causes and risk factors: a review. *Int J Burns Trauma* 2013;3:18–29.
- Peden M, Oyegbite K, Ozanne-Smith J, Hyder AA, Branche C, Rahman A, Rivara F, Bartolomeos K, editors. *World Report on Child Injury Prevention*. Geneva: World Health Organization; 2008.
- Raftery J. *CleanCook Ethanol Stove* [Online]. [http://www.appropedia.org/CleanCook\\_ethanol\\_stove](http://www.appropedia.org/CleanCook_ethanol_stove); Appropedia; 2009 [Accessed 06/04/2015].
- Sesan T. Navigating the limitations of energy poverty: lessons from the promotion of improved cooking technologies in Kenya. *Energy Policy* 2012;47:202–10.
- Simon GL, Bailis R, Baumgartner J, Hyman J, Laurent A. Current debates and future research needs in the clean cookstove sector. *Energy Sustain Dev* 2014;20:49–57.
- Tertinger DA, Greene BF, Lutzker JR. Home safety: development and validation of one component of an ecobehavioral treatment program for abused and neglected children. *J Appl Behav Anal* 1984;17:159–74.
- Thomas E, Wickramasinghe K, Mendis S, Roberts N, Foster C. Improved stove interventions to reduce household air pollution in low and middle income countries: a descriptive systematic review. *BMC Public Health* 2015;15:1–15.
- Urmee T, Gyamfi S. A review of improved cookstove technologies and programs. *Renew Sustain Energy Rev* 2014;33:625–35.
- World Health Organisation (WHO). *WHO Air Quality Guidelines for Indoor Air Quality: Household Fuel Combustion*. Geneva: World Health Organization; 2014.
- Zwi KJ, Zwi AB, Smettanikov E, Söderlund N, Logan S. Patterns of injury in children and adolescents presenting to a South African township health centre. *Inj Prev* 1995;1:26–30.