THE UNCONTROLLED COOKING TEST: MEASURING THREE-STONE FIRE PERFORMANCE IN NORTHERN MOZAMBIQUE

J. Robinson[1,2], M. Ibraimo[2,3], C. Pemberton-Pigott[1]
[1] SeTAR Centre and [2] Dept. of Geography, Env. Management & Energy Studies, University of Johannesburg,
[3] Dept. of Physics, Eduardo Mondlane University, PO Box 257, Maputo, Mozambique

ABSTRACT

The assessment of cooking system performance in developing countries is a continued area of interest, with laboratory testing methods often being unrepresentative of real world use, and field based methods tending to be resource intensive with high levels of variability. This paper presents the *Uncontrolled Cook Test* (UCT), a relatively low cost field testing protocol that assesses the task-based performance of the system when cooking any meal and operated as per local conditions and practice. A total of 29 UCTs were conducted in households in a study village in rural northern Mozambique, all on wood-burning three stone fires. The UCT proved a capable method for the assessment of cooking system performance and, critically, returned a data set with less variation than is typically reported by existing field test methods, so offering the potential to use fewer resources to detect a statistically significant difference between baseline and 'improved' stove results.

Keywords: Uncontrolled Cooking Test, CCT, KPT, firewood, three stone fire, Mozambique

1. INTRODUCTION

The domestic collection and use of biomass in many developing countries is a continued area of interest for researchers, policy makers and businesses alike. In Mozambique, where biomass accounts for over 80% of consumed energy [1] and 71% of the population lives in rural areas [2], there is the need to better characterize the energy baseline of rural villages in order to design and implement more effective technologies and policies.

In January 2008 a socio-economic study[1] [3] was carried out in Muculuone village, located in the Muecate district in north-eastern Nampula province, Mozambique. Using the main energy related findings from this study, a research programme was devised and in May 2010 a team of researchers from the University of Johannesburg and Eduardo Mondlane University returned to the village to conduct a performance assessment of the most commonly used cooking systems. For Mozambique, as is the case for much of sub-Saharan Africa, this is the three-stone fire burning locally collected firewood. Although the assessment of a particular cooking system can take place in either the laboratory or in-situ in a household, the nature of the three-stone fire means that user behaviour (i.e. lighting and tending of the fire) can have a significant impact upon performance [4]. Therefore, the method adopted for this study is a revised in-situ testing protocol based on the Controlled Cooking Test (CCT) [5] but that assesses the task-based performance of the system when cooking any meal and operated as per local conditions and practice. The aims of the research are to: measure baseline cooking energy patterns in the study village; and provide data and experience to feed-back into the development of the protocol.

2. METHODOLOGY

2.1 OVERVIEW OF STOVE PERFORMANCE TESTING

Of the suite of testing methods available for the assessment of cook stove performance, three commonly used are the: Water Boiling Test (WBT), a more technical task-based test where stove performance is measured in a systematic and repeatable way through the boiling and simmering of water in a standard pot [6]; Controlled Cook Test (CCT), in which task-based performance is assessed through the cooking of a local representative meal [5]; and Kitchen Performance Test (KPT), a more wide ranging field based methodology where both quantitative and qualitative surveys of households are used to measure fuel consumption as well as broader issues such as stove acceptability [7].

All three methods vary in their cost, location, accuracy, degree of repeatability, and overall relevance to the real-world performance of a cooking system - in terms of the stove, fuel, pot and operating method. In general there is a trade-off between variability and relevance. The WBT is conducted under controlled laboratory conditions and so generating repeatable results, but results that may not necessarily reflect how the stove will behave in a village household [8,9,10,11]. Conversely, in measuring actual household energy use, the KPT provides a more 'authentic' view of stove performance but with more aggregated results[2] that can show a high degree of variation and so be potentially limiting in their findings. For KPT's the Coefficient of Variation (CoV), a ratio of standard deviation to mean, is typically between 30-50% [7,8,12]. Occupying a position between these two methodologies, the CCT employs the logic that in

[1] A broader survey was developed by the VW Biomodels team as part of a regional study of rural biomass use, which was then adapted for conditions in Mozambique.

[2] For instance, wood fuel measured daily for a period of 3-7 days, or the use of standard adult equivalence factors to produce a per capita fuel consumption.

cooking exactly the same meal a number of times, a result can be achieved that is both repeatable and representative of real-world use, with CoVs typically of 10-30% [8,13]. However, the choice of prescribed meal, in terms of cooking method, food types and fuel quantities, represents a 'snap-shot' of system performance and as such may omit key system behaviour away from this point [9].

2.2 THE UNCONTROLLED COOKING TEST

In order to gain a better understanding of the performance of a cooking system over a wider range of variables, the University of Johannesburg SeTAR Centre has adopted and further developed a method here called the *Uncontrolled Cooking Test* (UCT). In this method the meal is not constrained and the cook is free to prepare what they want, how they want, with the only measurements being that of the firewood used and the final mass of food cooked as part of an actual household meal. When compared with the CCT method, this should give a stronger and more representative data set with a better measure of the inherent variability as determined by real world differences in user behaviour, local firewood etc. In providing a profile of stove performance across a range of conditions (meal size), the UCT protocol is fundamentally different from other task-based assessments which analyse a single task, the cooking of a specific meal, in repeated tests. Compared with the KPT, this method also has the potential to offer a rapid[3] and more cost-effective way of assessing the energy savings delivered by a new technology as part of a carbon-offset or development programme. Although still under development, it is thought that in studying a baseline cooking energy system in this way, with less control over test conditions and a greater interest in the variance shown in the data, a better picture can be gained of the way people actually cook.

A crucial question of the UCT method is: Can it provide test results that show less variance than existing field assessment methods and in doing so use the same or less resources? The objective being to detect a significant difference between a baseline and 'improved' stove scenario, but by using a method that allows you to sample fewer households. For example the KPT protocol [7,14] recommends that, in the absence of any pre-test data, per-capita fuel consumption CoV can assumed to be 40% and that a reasonable fuel reduction to try and detect between data sets is 30%. For a cross-sectional study this means that a total of 28 households would need to be sampled for the difference to be statistically significant at the 95% confidence level. However, if the CoV could be reduced to 30% then only 16 household would need to be sampled for the result to be valid.

[3] If a cluster of 2-3 houses is covered each day, a team of two people can conduct tests at midday and evening meal time (and possibly breakfast), resulting in 4-6 tests per day. Teams can consist of a trained tester and a local resident/translator.

2.3 UCT PROTOCOL

For a wood-burning three stone fire, the testing protocol is as follows: Once a suitable household has been identified and consent given, the UCT is conducted during the cooking of a number of everyday household meals. Prior to the test, any existing fire is extinguished and the cooking area is cleared of char and wood. The cook is asked to identify the pots to be used during the meal and these are cleaned, dried, measured and weighed without lids (if used). Selecting sufficient wood for the meal, the cook is asked to place this in a pile next to the fire and use only this fuel for the duration of the test. A fuel sample is taken (for species identification and moisture analysis) and the pile is then weighed on a mass balance. Fireplace dimensions, location and ambient conditions are noted.

The test begins with the cook being asked to make and light a fire as they normally would, with method and start time noted and lighting materials weighed. The cook is then left to prepare the meal with method, timings and food types briefly noted. Care should be taken to ensure that only wood from the pile is used. When the cook has finished preparing the meal the time is noted and the food is quickly weighed in the pots (with no lids), photographed and then removed from the cooking area. The cook is free to start serving the food. The fire is then knocked-out and any burning wood is extinguished by blowing on the end, and the remaining char knocked off. All char is then placed in a heat proof container and weighed (no ash). Any burnt wood is also weighed, with the number and length of wood pieces briefly noted. Any remaining unburned wood in the pile is also weighed. Questions on cooking, fire management practice and socio-economic issues can also be asked.

Results are then processed to give a Specific Fuel Consumption (SFC), a ratio of total energy consumed [MJ] to cooked food mass [kg], and a Fuel Burn Rate (FBR), a ratio of total energy used [MJ] to cooking time [minutes]. Equipment required for testing includes an electronic mass balance (preferably min. 10 kg, ± 1 g resolution), stop watch, hot wood/char handling equipment, digital camera, and for fuel sampling some sealable plastic food bags and a small field mass balance (resolution ± 0.1g).

2.4 SAMPLING

With the village field survey [3] reporting some 92% of households using firewood as their main cooking fuel, the performance testing was limited to the three-stone fire. A total of 29 *Uncontrolled Cooking Tests* were conducted over a four day period on a variety of meals in 24 households, with one household being tested three times, and three households being tested twice. Three tests were removed from the data set due to mistakes made during the testing process. The 24 households tested represent some 17% of the field survey households. The testing was conducted in May 2010, during the dry season and prior to any rains. The village is located at the following coordinates: Latitude 14.943˚S, Longitude 39.415˚E.

2.5 FUEL ANALYSIS

For each meal cooked as part of the UCT a representative fuel sample of 200-400g was taken and weighed using a set of small field mass balance. The samples were then taken back to the laboratory where they were oven-dried at 5˚C above local boiling point for approximately 24 hours and then re-weighed using the same calibrated mass balance. The two results were then used to calculate percentage moisture content (wet basis) or MC_{wet}. For reasons of cost the fuel samples did not undergo an ultimate and proximate analysis, instead typical hardwood properties have been assumed with a higher heating value (HHV) of 19.5 MJ kg^{-1} [15] and a composition of ash 0.76%, sulphur 0.01%, hydrogen 5.87%, carbon 49.09% oxygen 43.97% and nitrogen 0.30% on a dry basis. For each test conducted the moisture content, HHV and ash content were used to generate an as received ash free (ARAF) lower heating value (LHV). Post cooking, any burned wood was assumed to have the same MC_{wet} as unburned wood[4]. The energy in remaining char was assumed to be 29.5 MJ kg^{-1}.

3. RESULTS AND DISCUSSION

3.1 GENERAL OBSERVATIONS

Although not measured in every household in the study village, a typical wood-burning fireplace consisted of three angular/oval-shaped stones of approximate dimensions 200 mm high by 200-250 mm diameter, each set 250-300 mm apart from the other. When placed on the stones, the base of the round-bottomed pot was roughly 160 mm from ground level. All households used dry roof grass to light the fire, with ignition mainly by an ember from an existing fire in the home or from a neighbour. Wood used was typically of diameter 15 to 30 mm and length 0.5 to 1.0 m. Fire management was similar in most households observed, with 3-4 sticks of wood being placed radially outwards in each of the 3 spaces between stones. As it burned, each stick was pushed towards the fire, with power level being controlled by pushing in or removing the sticks from the fire. All 26 respondents indicated that they re-used any partially burned wood in subsequent fires but disposed of any remaining char.

Some 20 households (77%) cooked a meal using two pots sequentially, and all of these cooked a staple food, frequently Xima (made from maize flour, also known as Nsima, Sadza, Ugali or Pap in sub-Saharan Africa) on a 'standard' round bottomed pot made of cast/beaten aluminium and of approximately 250 mm diameter, 150-180 mm depth and 1.5-2.0 kg mass. Of those that used two pots, 12 (60%) households used a second smaller round bottomed pot made of clay, with the remainder using small metal round/flat bottom pots. Beans were cooked during five tests, and other side dishes/relish included vegetables, tomatoes, fish, chicken and eggs. During the UCT some 11 (58%) households cooked indoors, although it is thought that the presence of testing staff led to a preference for households to cook outdoors for reasons of space and/or privacy. An average of 5.0±1.6[5] people lived in a study household. Of potential interest to other studies is that prior to starting the fire a cook tended to over-estimate the wood required for that meal, with only 40%±20% of the initial wood pile being used in the fire. However, the UCT requirement to stop the fire immediately after cooking would have had some impact on the 'true' amount of wood used[6] for the meal, as would the cook ensuring she did not run out of fuel.

3.2 FUEL PROPERTIES

The moisture content (wet basis) for each test sample is shown in Table 1. Most wood sampled was relatively dry even though it appeared that most had been recently harvested by cutting, reflecting the local seasonal dry period. Due to the use of local names, not all samples could be identified. For an average MC_{WET} of 13.1% this resulted in an LHV (ARAF) value of 16.7 MJ kg^{-1}.

Table 1: Moisture Content of UCT Samples

Wood Type			Moisture Content (% Wet Basis)	
Local Name	**Latin Name**	**# Tests**	**Avg.**	**Std Dev**
Mixed	n/a	7	11.9%	4.2%
Rocossi	Diplorhynchus condylocarpon	5	16.9%	7.3%
Mukoi	Uapaca nitida	3	12.7%	6.4%
Mpacala	Julbernardia globiflora	3	12.6%	1.7%
Ncadjo	Anacardium	3	11.1%	2.0%
Nipovera	Newtonia buchananii	3	15.8%	3.6%
Cochokore	Uapaca zanguebarica	1	11.0%	n/a
Muhuquiniqui	*Not identified*	1	9.2%	n/a
Muleua	*Not identified*	1	13.3%	n/a
Nkiriwerre	*Not identified*	1	11.8%	n/a
Xinama	*Not identified*	1	10.8%	n/a
Total		**29**	**13.1%**	**4.6%**

3.3 UNCONTROLLED COOKING TESTS

Given the unconstrained nature of the UCT, where cooks could prepare any meal they wanted, both the Cooked Food Mass and Total Time varied greatly with averages

[4] An analysis of moisture content in two pieces of burned wood, with char removed, indicated that only the first 50 mm section (fire end) of each sample had an MC_{WET} that was lower than the rest of the sample prior to burning.

[5] Data is presented as an average ± 1 standard deviation.

[6] Ibraimo [3] reported 22% of households extinguished the fire immediately after cooking.

of 2.9±1.3 kg and 62±32 minutes respectively, and CoVs of 50% (Table 2). Following from the observation that all households disposed of any post-fire char rather than reusing it, so utilising the available energy, the key UCT metrics are presented in two conditions: the 'no char' case, reflecting the real world fuel consumption pattern; and the 'with char' case, representing the technical performance of the fire. As can be seen the 'no char' case results in a Specific Fuel Consumption of 12.1±3.0 MJ energy consumed per kg cooked food, some 21% greater than the 'with char' value of 10.1±2.8 MJ kg^{-1}, highlighting an important reason for reflecting real world use in stove performance analysis. The 'with char' case also reported a Fuel Burn Rate of 0.60±0.18 MJ min^{-1}.

Table 2: Results of Uncontrolled Cooking Test (n = 26)

Metric	Avg.	Std Dev.	Coef. Var.
Total Time [min]	60.7	31.9	53%
Cooked Food Mass [kg]	2.89	1.29	45%
LHV (ARAF) [MJ kg^{-1}]	16.9	0.8	4%
No Char			
Total Energy Consumed [MJ]	34.8	18.0	52%
Specific Fuel Consumption [MJ Fuel / kg Food]	12.1	3.0	25%
With Char			
Total Energy Consumed [MJ]	29.2	15.8	54%
Specific Fuel Consumption [MJ Fuel / kg Food]	10.1	2.8	28%
Fuel Burn Rate (Energy) [MJ min^{-1}]	0.60	0.18	31%

Crucially the UCT protocol, as tested in this one case, returned a CoV in the Specific Fuel Consumption metric of 25-28%, showing that this method is a viable alternative to the KPT, which typically results in a variation of 30-50%. In order to test the validity of sampling more than once in the same household, one family undertook three UCTs and the results showed an SFC of 12.9±2.7 MJ kg^{-1}, very close to the whole sample average, and with a CoV of 21% compared with the whole sample value of 25%, thus justifying this approach. There was no significant difference between Specific Fuel Consumption data sets depending on cooking location (inside or outside), two or one pot use, and food type. It was however more likely that cooking beans led to a heavier meal that took longer to cook but this did not impact upon SFC. Similarly, a simple one pot meal would take less time to cook but did not display any difference in SFC.

Exploring the Specific Fuel Consumption metric in greater detail, Figure 1 displays a linear regression analysis between the Cooked Food Mass and Total Energy Consumed variables for all 26 tests conducted. The two variables showed a strong correlation, with a Coefficient of Determination (R^2) of 0.79 for the 'no char' case, a feature not expected by the authors and greater than reported in other studies [16]. Of interest is the variance around the 'best-fit' line that appears to be constant and not proportional to the Cooked Food Mass as might be expected, an interesting observation that requires further investigation. In this case the relationship between the two variables is linear, but this may not be the case for all stove/fuel combinations, especially thermally massive stoves, leading to the rejection of a simple one-number fuel consumption figure in favour of a broader algorithmic description.

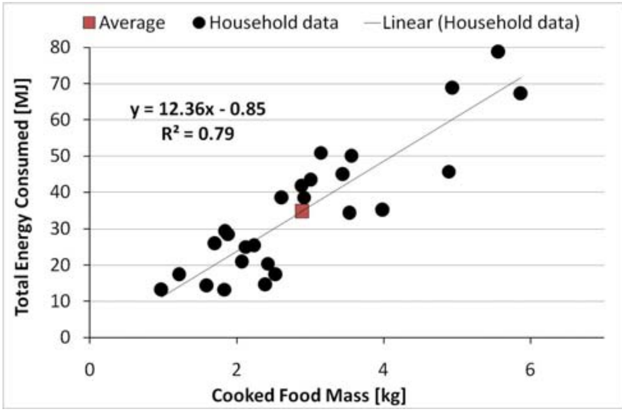

Figure 1: Specific Fuel Consumption (no char case) – the relationship between Total Energy Consumed and Cooked Food Mass

A regression analysis was conducted on each of the other key metrics and results are presented in Table 3 below. The Specific Fuel Consumption 'with char' returned a slightly lower R^2 value than the 'no char' case, and the Fuel Burn Rate 'with char' gave an R^2 of 0.65, a weaker correlation than the SFC case.

Table 3: Regression analysis of key metrics (n=26)

Metric	Variables	Coef. Deter. (R^2)	Gradient Intercept
SFC (no char) [MJ Fuel / kg Food]	Dependent : Total Energy Consumed Independent: Cooked Food Mass	0.79	12.4x - 0.8
SFC (with char) [MJ Fuel / kg Food]	Dependent: Total Energy Consumed Independent : Cooked Food Mass	0.76	10.7x - 1.6
FBR (Energy) (with char) [MJ Min^{-1}]	Dependent: Total Energy Consumed Independent: Total Time	0.65	0.4x + 4.9

4. CONCLUSION

The UCT proved a capable method for the assessment of baseline cooking energy patterns in the study village in rural Mozambique. As well as informative observations of stove type and operation, the method captured key user behaviour with regards to fuel consumption that had a critical impact on reported performance results.

More importantly the UCT returned a data set with less variation than is typically reported by the KPT, achieving a Specific Fuel Consumption CoV of 25% - as measured in 26 household tests during their daily activities by using an in-situ testing protocol that assesses the task-based performance of the system when cooking any meal and operated as per local conditions and practice. This lower CoV offers the potential to use fewer resources to detect a statistically significant difference between baseline and 'improved' stove results, or conversely to obtain a stronger data set for the same testing outlay.

Compared to the CCT, the UCT covers a much broader range of variables including meal type and mass, duration, fuel type and moisture content, and user operation (ignition and tending of fire). This does result in a greater degree of variability, but gives a stronger data set with a better measure of the inherent variability determined by real world differences in cooking practise.

With a focus on testing the performance of the system (stove, fuel, pot and cook) in the household context, the Uncontrolled Cook Test procedure allows for a rapid but representative assessment of stove use in the cooking of any meal, and offers a viable alternative to existing CCT and KPT methods.

5. RECOMMENDATIONS

Although the study assessed the in-situ performance of the three-stone fire, possibly one of the most variable cooking systems due to the impact of user operation, irregular fuel etc, more stove/fuel combinations and cooking cultures need to be measure using the UCT in order to gain a better understanding of data variability and error. With this information a better understanding of the required UCT sample size can be determined.

More advanced statistical treatments may also be of benefit, including a more detailed analysis of variance as well non-linear correlations and the development of a broader algorithmic description of performance rather than the current simplified 'one-number' approach.

In addition, due to its more representative approach, this revised method offers the potential to better correlate the laboratory and field performance/emissions of cooking systems, a task that is of increasing importance given recent initiatives such as the Global Alliance for Clean Cook Stoves [17].

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8. AUTHORS

Principal Author: James Robinson is a basic energy specialist, laboratory manager and PhD student at the SeTAR Centre, University of Johannesburg. His research focuses on the relationship between the laboratory and field performance of cooking systems. He has a background in engineering with experience in small-scale energy projects in Africa and Asia as well as with renewable and fossil fuel electricity generation in the UK. jamesrobinson77@gmail.com

Co-author: Momade Ibraimo is a PhD student studying environmental and socio-economic impacts and energy modelling at the University of Johannesburg. He has conducted a socio-economic village survey of biofuel use and attitudes in northern Mozambique in order to define the energy performance baseline of a rural village. This data will then be used to guide the design of optimised cooking devices using computational fluid dynamics. He has been a lecturer for 10+ years at the Faculty of Sciences, Eduardo Mondlane University, Mozambique.

Co-author: Crispin Pemberton-Pigott has worked with dozens of Appropriate Technologies for 30+ years, designing stoves and labour-enhancing equipment. He won the DISA Chairman's Award 2004 for the Vesto Stove made by his company, New Dawn Engineering. A co-founder of the Eastern Cape Appropriate Technology Unit, the Renewable Energy Association of Swaziland and the Industrial Designers Association of South Africa, he presently he advises two Mongolian clean air projects and the SEET Laboratory. He is the senior technical advisor at the Sustainable Energy Technology And Research (SeTAR) Centre at the University of Johannesburg. He volunteers at ETHOS and SABS co-writing stove standards and test protocols and has advised engineering student projects at the Universities of Alberta (Edmonton) and Waterloo in Canada and Dartmouth College, USA.

Presenter: The paper is presented by James Robinson