

Fuel Use and Design Analysis of Improved Woodburning Cookstoves in the Guatemalan Highlands

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Abstract

This study examined the fuel use and design of an improved woodburning cookstove (*plancha*) in comparison to traditional cooking using an open woodfire in the Guatemalan Highlands. These cookstoves were introduced into a portion of study households that had previously used open woodfires. This research consisted of: (1) a 4-day Kitchen Performance Test (KPT) in 12 households to examine fuel use; and (2) single-day participant observation in 5 households to support understanding of efficiency and to examine stove design. In both parts of the study, *plancha* households were compared to households using open fires for cooking.

The results of the KPT do not show statistically significant differences in fuel use between the two cooking methods. Increased study power – through an increase in sample size, for example – may have resulted in a statistically significant difference; however these data suggest that any difference in fuel savings may not be of practical significance. The qualitative data provide useful insights into the fuel use characteristics of the cookstove and key elements of its usability. Practical and experimental recommendations for future stove fuel use studies are presented, as well as recommended directions for continuing work in this area.

Keywords

RESPIRE, wood fuel, fuel efficiency, kitchen performance test, participant observation

1.0 Introduction

Several hundred improved cookstove projects probably currently exist worldwide, ranging from local, NGO (non-governmental organization) projects to the one remaining nationwide initiative in Nepal [1]. These projects and associated research commonly focus on reducing air pollution exposures and/or reducing fuel use, but there are also other important considerations, including time saving, household hygiene, and greenhouse emissions [2]. It is estimated that nearly half of the world population relies on biomass for household energy accounting for about 10% of all human energy use [3] and estimated to be responsible for approximately 1.5 million premature deaths annually in women and children through associated air pollution exposures [4].

Reduction in fuel use is perhaps the most compelling reason for consumers to adopt an improved stove. Thus, whether based on government and donor programs or commercial marketing, there is a need to understand the changes in fuel use of a proposed new stove as well as the performance of existing in-place stoves. In addition, such understanding is needed to evaluate the environmental benefits of stove introduction, particularly those related to pressure on deforestation from woodfuel gathering and the global warming pressure from products of incomplete combustion.

Reliable measurement methods are thus needed both for evaluating a new design in controlled non-cooking conditions

(“efficiency”¹ tests), controlled field conditions with cooking (“efficacy” tests), and in uncontrolled field conditions to determine the actual changes of fuel use in practice (“effectiveness” tests). These are part of a suite of tests investigating stove “performance,” which also include cooking speed, ease of ignition, turndown ratios, etc.

In light of the complex interaction between fuel parameters and stove design, reliable stove comparisons should be made on the basis of fuel-stove combinations even with efficiency tests [5].

Measuring and comparing cooking efficiencies for solid-fuel stoves is surprisingly difficult, however, particularly in the “effectiveness mode”. Several efficiency-related tests are recognized throughout the cookstove community, principally the water-boiling test (WBT, an efficiency test), the controlled cooking test (CCT, an efficacy test), and the kitchen performance test (KPT, an effectiveness test), which were originally developed by NGOs in the early 1980s [6]. Since then there have been a number of modifications to the WBT. For example, national versions were widely deployed during the Indian and Chinese improved stove programs, which ran from the early 1980s to the late 1990s. The KPT however, has undergone relatively little change and systematic evaluation, although there do exist ongoing efforts to improve it [7]. A search of the peer-reviewed literature revealed no published evaluations, although there are reports in the “grey” literature.

As part of RESPIRE (Randomized Exposure Study of Pollution Indoors and Respiratory Effects), a randomized trial of improved wood-burning chimney cookstoves to determine health effects of woodsmoke in women and children, we

conducted KPTs to evaluate the impact of the stove on household fuel use as compared to the traditional open woodfire. After describing the site and stove, we detail the implementation of the KPT and the results obtained with emphasis on a critical review of the method. A summary of research conclusions is provided, with a discussion of directions for future research.

The Site

Locally constructed *planchas* (see Figure 1) were installed in 500 households² in the western Guatemalan highlands during RESPIRE. The *plancha* was developed in Guatemala and has been constructed locally for over 25 years. It is a high-mass stove with an enclosed combustion chamber and a flue to remove smoke from the kitchen [5, 8]. A metal door provides access to the combustion chamber at one end of the stove; a flue with a damper, allowing the user to control airflow through the combustion chamber, is located at the opposite end (see Figure 2).



Figure 1: Shown are the *plancha* (clockwise, beginning at top left): combustion chamber; exhaust flue; work surface; and placement in a household kitchen.

¹ Here we keep to the strict engineering definition for efficiency as a unitless ratio of energy applied to useful energy obtained, in this case energy in the pot divided by energy in the fuel according to the First Law of Thermodynamics, i.e., not considering energy quality.

² Each of the 250 control households was offered a *plancha* at the conclusion of the study.

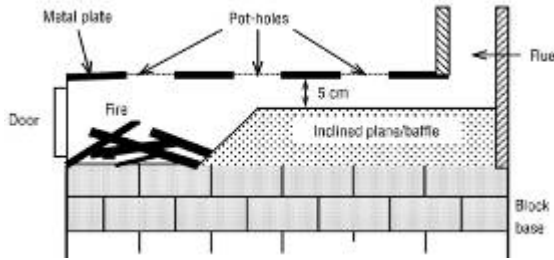


Figure 2: Cross-sectional view of the *plancha* taken directly from (Boy 2000). The designs evaluated in this study also contained a damper in the lower portion of the flue.

The cooking surface is constructed from a steel plate, measuring approximately 46cm x 92cm. Three holes are cut into this plate to allow for improved heat transfer from the combustion chamber to the pots. The holes are different sizes (approximately 28cm, 21cm, and 14cm); the largest is located near the fuel access door, and the smallest is located near the flue. The stove comes with metal disks and rings that accommodate different pot sizes, and can be used to cover the holes, creating a flat cooking surface.

The *plancha* body is constructed of cement blocks, fire bricks around the combustion chamber, and dirt insulation. The working surface surrounding the steel cooking surface is faced in tile. The *planchas* in this study were constructed at a cost of more than US\$100. Although the steel plate is an important cost element (approximately 25%), it is a critical part of the stove's attractiveness since it allows cooking of tortillas without smoke in the kitchen and provides a degree of space heating, which is desirable in the Guatemalan highlands.

The *plancha* in this study was compared to an open fire method of cooking, both using the same woodfuel. Although several households indicated that they cooked directly on the floor in the past, all of the open fire households in the study used an elevated stone hearth raised approximately 0.25-0.5m above the floor, locally called a *poyo*. These hearths are typically located in a corner of the kitchen.

Improved indoor air quality is the primary motivation driving RESPIRE, and considerable resources have been devoted to measuring the health benefits. Fuel performance in comparison to an open fire has yet to be conclusively determined, despite several studies [8, 9, 10].

Deforestation is not an immediate danger in the Guatemalan highlands, but restrictions against logging and the cost of fuel have a direct bearing on household livelihood as 56% of Guatemalans, and 76% of the indigenous population, lives in poverty [11]. 97% of households in rural areas depend on woodfuel for household uses [12]. This research was conducted in indigenous Mam regions of San Marcos, one of the poorest departments in the country. Although the specific impacts of stove fuel use may change depending on region and season, assessing fuel use accurately in field conditions is an integral component to cookstove evaluation.

2.0 Methods

The following sections of this article review the KPT and participant observation research methods. Information from both assessments was used to develop research conclusions.

2.1 Kitchen Performance Test: Methods

The KPT was selected over the water boiling and controlled cooking tests because it more accurately reflects the *in situ* fuel use of the stove. In the KPT the fuel use comparison relies on consumption data from households in which normal cooking for the family is done by the usual cook over several days. The relative advantages and disadvantages of each test are related to the control of variation. There is an inevitable trade-off, of course, between efforts to reduce variability and being able to interpret the results in terms of performance of the entire population of stoves. Transitioning from the WBT to the KPT brings an improvement understanding of actual practice, but also introduces an increase in variability. Further, [13] indicate that physical monitoring permits improved

estimates of fuel use at the household level when compared to estimates that rely solely on survey data.

The KPT conducted in this study was based primarily on the protocol published as part of the Shell Foundation, Household Energy and Health Project [7] and the previous pilot study conducted by [10]. It combined physical monitoring and surveying. The most significant difference was an increase in the number of days from four to five, and the provision of uniform firewood supplies to participant households.

This research consisted of: (1) a 4-day KPT in 12 households to examine fuel use; and (2) single-day participant observation in 5 households to elicit qualitative design and usage data. In both portions of the study *plancha* households were compared to households using open fires for cooking. An analysis of the quantitative and qualitative data was performed to reach a set of conclusions regarding: the advantages and challenges of implementing a KPT study; the fuel performance of the *plancha* with respect to open-fire methods; and evaluation of the *plancha* design.

The wood used in the study was acquired from local sellers in 2 large batches. Each batch was oak, the preferred wood type in the study communities. The first batch of wood was kept indoors and dried for more than 2 weeks prior to delivery. The second batch had a higher moisture content, and was delivered to households within 2 days of receipt.

Moisture affects the burn rate for wood and when moisture content is high enough can affect the ability to ignite. Moreover, fuel moisture has a complex interaction with the two components of stove efficiency: combustion efficiency and heat transfer efficiency [5]. However, electronic moisture meters were not used in this study because of their recognized inaccuracy outside of a tight, pre-specified range. In addition, the meter measurements are location-specific across the fuel specimen, and even though moisture content can vary significantly within a given piece of wood, there is no standard protocol to estimate overall

moisture content from a set of meter measurements. We therefore elected not to use it.

During recruitment, each participating household was asked to estimate their fuel needs. This estimate was increased by 25% to determine the approximate amount of wood to deliver each day.

On the first day of the study the initial supply of wood for each household was weighed and counted, and participants were reminded to only use the wood provided by the study for the remainder of the KPT. The wood was stored in a designated area in each household. On days 2-4 the delivered wood and the wood remaining from the previous day was weighed and counted (see Figure 3). In addition, a set of questions was asked in order to determine the number of meals served the previous day, and the age gender and number of people served at each meal.

On the final day, the remaining wood was weighed and counted, and questions were asked, however no wood was delivered. Participants were aware that they would be permitted to keep any wood remaining on the final day of the study thus providing some incentive to be as careful with its use as they would be with their own fuel supply. The primary tools and hardware used in the KPT were: two spring scales with 0-100 kg range and a 1 kg resolution; ropes and harnesses for wood transport; and bags for weighing up to 15 pieces of wood at once.



Figure 3: KPT daily delivery bundles (left) and in-home weighing process (right).

Over Over a two-week period, 6 open-fire and 6 *plancha* households each generated four fuel use data points, one per day. These data were averaged for each household, resulting in a total data set of $N = 12$. As the KPT included daily fuel use,

the number and age of people served at each meal, and the number of meals served, fuel use can be expressed in several ways. As consistent with the protocol, the metric reported here is kilograms of fuel per person-meal served (kg/PM). Comparisons are not significantly different using other common metrics. Person meals were scaled using an adult male as the reference, a child was weighted at 0.5, an adult female at 0.8, and a senior adult male at 0.8, as suggested by [14].

2.2 Participant Observation: Methods to Evaluate Design and Usage

One researcher and one fieldworker together conducted single-day participant observation study in 5 households in 2 communities (see Table 1). Three households used *planchas* and two used open fires. The fieldworker was fluent in both Mam and Spanish, while the researcher spoke Spanish only. There was need for Mam translation at 1 of the 5 observed houses.

Though other households in these communities had participated in the KPTs, none of the KPT households were included in this portion of the study. This eliminated biases that may have existed if a household

had participated in both studies. Participant observation typically spanned two complete meals per household. The goal was to gain an understanding of behaviors relevant to fuel use and *plancha* design. The 3 research questions guiding the participant observation were: (1) What behaviors impact fuel use?; (2) How do these behaviors differ between stove and fire households?; and (3) How do participants use different features of the cookstoves and fires?

Data collection consisted of informal, contextual interviews and direct observation. Photographs, surface temperature readings, and airborne particulate monitoring were used to supplement field notes. The unstructured nature of this portion of the study was critical to understanding fuel use and *plancha* design, as both were poorly understood prior to this study. In contrast, studies that utilize direct, structured observation often make assumptions about important behavior ahead of time [15].

Data analysis began with iterative codebook development [16] that resulted in 17 unique codes. This was followed by data reduction via coding; display of textual, numerical, and visual data; and conclusion-drawing [17].

Date	Community Code	Household type	Household size			Start time	End time
			Men	Women	Children		
Mon-25-Jul-05	TCH	open fire	2	2	5	06:00	16:30
Tues-26-Jul-05	TCH	<i>plancha</i>	1	1	4	06:05	12:30
Wed-27-Jul-05	TCH	open fire	0	2	3	12:50	19:00
Thurs-28-Jul-05	TCH	<i>plancha</i>	0	1	7	06:20	13:25
Fri-29-Jul-05	LCN	<i>plancha</i>	1	1	6	07:00	11:30

Table 1: Details of the five participant observation households

Household	Avg. Fuel Use (kg/PM)
Plancha1	1.81
Plancha2	1.21
Plancha3	0.936
Plancha4	2.02
Plancha5	1.29
Plancha6	0.903
Average	1.36
Deviation	0.459
Coeff. of Variance	0.337
OpenFire1	1.78
OpenFire2	1.69
OpenFire3	1.34
OpenFire4	1.00
OpenFire5	0.845
OpenFire6	0.785
Average	1.24
Deviation	0.431
Coeff. of Variance	0.348

Table 2: KPT data, *refacción* included.

3.0 Results

The entire KPT spanned two weeks. During the first week, it was noted that one of the spring scales was reading incorrectly and a correction factor was needed to account for measurements taken before the data was analyzed.

3.1 KPT Data Corrections

Data for the KPT were corrected to correct the data from the damaged scale. In addition, two sets of analyses excluding and including *refacción* were conducted. *Refacción* is preparation of snacks, which takes place in the mid-morning typically involving preparation of a hot beverage prepared from some of the following ingredients: milk, water, rice, corn, and sugar.

In order to correct the weights from the poorly operating scale, it was assumed, based on physical evidence, that the scale experienced an acute reduction in function, and that there was a linear relationship between measurements afterwards and those taken with an undamaged scale. Several weights of standard magnitude and units

were recorded for both the damaged and undamaged scales, and the erroneous data was mapped to the uncorrupted data.

Tables 2 and 3 present the corrected data for each household.

Household	Avg. Fuel Use (kg/PM)
Plancha1	2.31
Plancha2	1.19
Plancha3	2.51
Plancha4	1.28
Plancha5	1.70
Plancha6	1.13
Average	1.69
Deviation	0.604
Coeff. of Variance	0.357
OpenFire1	2.34
OpenFire2	1.85
OpenFire3	1.81
OpenFire4	1.21
OpenFire5	1.20
OpenFire6	1.04
Average	1.57
Deviation	0.497
Coeff. of Variance	0.316

Table 3: KPT data, *refacción* excluded.

3.2 KPT Fuel use Results

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As data from the participant observation and informal interviews of KPT households suggested that the amount of wood used to cook *refacción* varies only slightly with number served, analyses were conducted excluding and including this small meal. Considering *refacción* as a full meal could have biased the results.

Including *refacción*, the KPT data showed that the average consumption of the *plancha* was 1.36 kg/PM, while that of the open fire was 1.24 kg/PM; i.e., the *plancha* used approximately 10% more fuel than the open fire. Excluding *refacción*, the average fuel use of the *plancha* was 1.69 kg/PM, while that of the open fire was 1.57 kg/PM, representing an 8% increase in fuel use for the *plancha*.

To determine whether this difference in was statistically significant an independent means t-test was performed. This test was

selected because it applies to single factor, two-level, between-subjects experimental designs. In the analysis cooking method (open fire vs. *plancha*) is the independent variable, and fuel use (kg/PM) is the dependent variable. The significance of the measured differences in fuel use are summarized below in Tables 4 and 5. As the inclusion or exclusion of *refacción* only changes the p-value by 7%, the remaining analyses are applied to the data set in which *refacción* was excluded, producing more conservative conclusions that can be viewed as an upper bound.

Cooking Method	Average Fuel use (kg/PM)	t_{KPT}	$P(t > t_{KPT})$
<i>Plancha</i>	1.36	0.46	0.65
Open fire	1.24		

Table 4: Results of t-test: fuel use of *plancha* vs. open fire, *refacción* included.

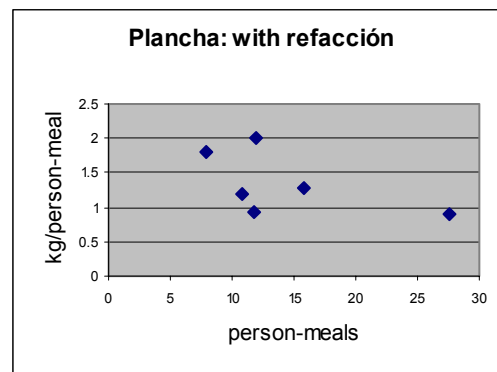
Cooking Method	Average Fuel use (kg/PM)	t_{KPT}	$P(t > t_{KPT})$
<i>Plancha</i>	1.69	0.38	0.72
Open fire	1.57		

Table 5: Results of t-test: fuel use of *plancha* vs. open fire, *refacción* excluded

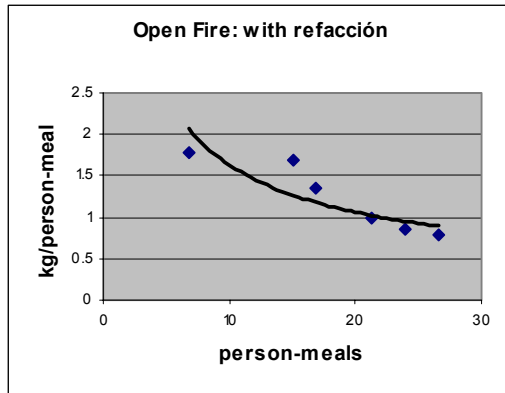
Cohen's effect size³ was calculated to gauge the magnitude of the observed difference in fuel usage. Convention holds that an effect size of 0.2 is 'small,' 0.5 is medium, and 0.8 is large [18]. In the KPT Cohen's effect size was approximately 0.23, representing a small difference in fuel use between the *plancha* and the open fire. Effect size can also be viewed as an indicator of the degree to which two data sets overlap. The effect size in the KPT

corresponds to roughly a 15% overlap. Finally, an effect size/power analysis was performed to determine the approximate number of households that would be required to detect an effect size of the magnitude found in the KPT. Assuming 10% significance and 80% power, 176 total households would be required to reach significance, assuming the effect estimate measured here was maintained.

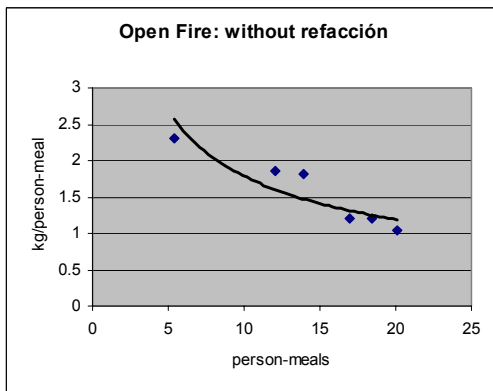
In addition to significance analysis further evaluations of the observed efficiencies are presented in Figures 4 and 5, where specific daily fuel consumption (kg/PM) is plotted versus the average number of person-meals cooked daily. Whether including or excluding *refacción*, the open fire households clearly exhibit an economy of scale in fuel consumption, as the kg/person-meal strictly decreases with increasing number of person-meals served. However, the data are not sufficient to determine whether the *plancha* households also exhibit economy of scale. The finding that an economy of scale exists has implications for eliciting meaningful data from the KPT, suggesting that matching households by size and/or using paired samples may be necessary. Should the nonlinearity reflected in the economy of scales prove significant, units of person-meal may be modified to eliminate the implication of a linear relationship.



³ Cohen's effect size is appropriate for analyses that use a t-test on means. It is defined as the difference between two means divided by the pooled standard deviation for those means.



Figures 4: *Plancha* and open fire specific daily fuel consumption as a function of average daily person-meals cooked, *refacción* included.



Figures 5: *Plancha* and open fire specific daily fuel consumption as a function of person-meals cooked, *refacción* excluded.

3.3 Participant Observation: Design and Usage Findings

The findings presented here are primarily from the households in the participant observation, yet they also draw upon observations and interviews in the 12

KPT households. This collection of observations formed a limited dataset and should be interpreted with care. In addition to showing that context-specific behaviors likely influence cookstove fuel use, it is anticipated that these findings will aid cookstove researchers in other parts of the world.

In the developing world, the most common form of open combustion consists of “three rocks or brick holding the pot above an open fire” [5]. In our study’s households, 2-3 concrete blocks were used around open fires.



Figure 6: Left, an open-fire household uses concrete blocks and a metal rack to support pots. Right, cooking of tortillas.

Open-fire houses universally used a *comal* solely for cooking corn tortillas (Figure 6). The *comal* is a round, flat earthen or metal pan. As with the *plancha*, a solution of lime and water is applied to the surface prior to use to clean and to prevent the (dough) from sticking.

On a typical day the first fire begins around 6 AM, independent of season. *Plancha* households maintain different schedules for cleaning the flue and the combustion chamber despite specific maintenance instructions from the RESPIRE project. The combustion chamber is not cleaned daily, but when it is, it is usually cleaned by hand before the first fire.

In both open-fire and *plancha* households, matches are used to light kindling or a small candle is used in place of kindling. In *plancha* households, the fuel is placed inside the combustion chamber via the door and the pot hole closest to the door. In both household types significant bellowing is often required to start the fire, suggesting similar exposure to pollutants

during this brief period for both cooking methods.

Breakfast is cooked between 6-8 AM and is followed by *refacción* about an hour later, and lunch is started just before noon. Some households cook food for tortilla dough or for the animals only in the afternoons, while others do so while preparing other meals for the family. Dinner preparation begins around 6 PM and the fire is extinguished at approximately 8 PM. Some *plancha* households maintain a fire for much of the day, effectively “warm-starting” the *plancha* (see Figure 7). At least one household let the fire die out completely after each meal. Such differences in cold-starting and warm-starting can confound fuel use data since much of the heat generated by fuel combustion is lost into the mass of the stove.

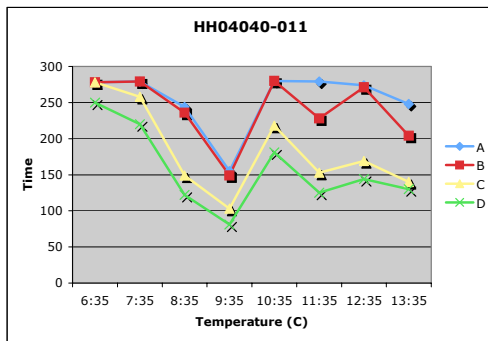


Figure 7: *Plancha* temperature measured hourly at four different points on the cooking surface (A is closest to access door, D is closest to flue) for a household with “warm-starting” behavior. Between the early-morning and mid-morning meals, the *plancha* surface never fully cools.

To measure the presence of harmful airborne particulates for the intervention, sensors were installed in participating households. This data permits identification of cooking events via increased levels of ionization, where ionization is an indicator of harmful particulates. Figure 8 contains a plot that reflects the ionization for one household, from approximately 10:30AM to midnight.

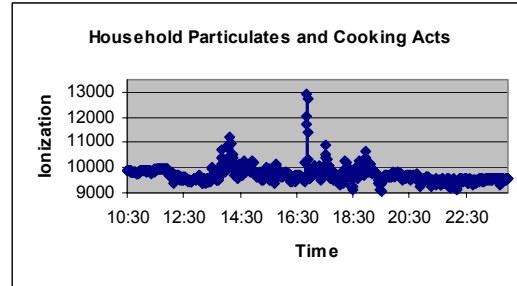


Figure 8: Airborne household particulates as an indication of cooking events.

Several of the findings from the observation portion of this research are replicated in the plot, reinforcing the validity of the observational results. The fact that breakfast is cooked from 6-8AM cannot be seen, since the data begins at 10:30AM. However the plot indicates a cooking event at approximately 1:30 PM, in agreement with the observations that approximated a noon lunchtime. The observations also noted that dinner began around 6:00 PM and that the fire is generally distinguished by 8:00PM. The data in the plot reflects similar timing. Beginning with the initial spike at approximately 4:45PM, there are two more peaks, ending at approximately 7:30PM., when the fire was distinguished. The initial spike is attributed to the pre-meal “stoking” of the fire, with the stove door open. The two peaks at roughly 5:00 and 7:00 likely indicate the shuffling of pots on the stove surface throughout the meal, permitting smoke to escape through the potholes.

Finally, the plot in Figure 8 yields information regarding hot and cold-starting of fires throughout the day. Notice that the baseline ionization level is roughly 950. This baseline is seen just before the lunchtime meal, just before the dinner meal, and for several hours after the dinner. Since the level of particulates just before meals is the same as that some four hours after the fire has been extinguished, it I concluded that this family uses a cold start method of cooking.

Heating, and to a lesser degree lighting, usage are important aspects of cookstove design. In the study communities, cooking

and lighting tasks were independent. The kitchen was typically in a separate structure from the living quarters, so the *plancha* and open fire did not contribute to lighting or heating the home. A handful of homes used electric bulbs, albeit sparingly. The remaining houses used homemade lamps constructed from a glass bottle, wick, and kerosene.

The *plancha* and open fire are not used directly for heating, yet heating still plays a role. Participants were witnessed sitting near the open *plancha* door in order to warm themselves. In this same household, the fire was used to heat towels to warm a newborn child. Based on the study observations, modifications to the *plancha* design that affect the ability to heat, by reducing thermal losses or changing the location of the access door, might affect the acceptability and ultimate adoption of the technology.

Based on the results of a fuel survey undertaken in the RESPIRE study area (Naumoff & Kaisel, 2003), we asked questions about wood usage and acquisition behaviors. Though issues concerning self-reporting on a sensitive topic as wood acquisition remain, the data provided by participants suggest a combination of acquisition methods including purchasing and illegal tree felling. Such activities are economically motivated, yet require significant investment of time, effort, and resources. This implies that a stove that significantly decreases fuel use would be attractive.

Vigilant tending of an open fire can drastically alter fuel performance (Smith, 1987). Data suggest that behavioral effects on include: selective placement of wood during open-fire burning, parallel management of cooking tasks, and saving partially burned wood for future use. Study participants from both household types often indicated a perception that the *plancha* is more efficient than the open fire, most often citing the ability to conduct more tasks in parallel.

A surprising variety of wood-drying techniques were observed in the study

households. One participant indicated that she dried wood by placing it in the sun. Another simply stored the wood in a dry location. Other techniques included above-fire rafter storage, placing wood very near the fire, and placing wood on the *plancha*. Different practices are expected to drastically alter the moisture content of the wood, which in turn affects fuel combustion and emissions, and time to burn. The KPT did not measure time of cooking tasks, but others have established that the *plancha* takes longer than the open fire for standardized tasks (McCracken & Smith, 1998; Boy et al., 2000).

Use of specific features of the *plancha*, was also observed. The damper was not often used, and in one case had been lost for several months. The door, though perforated, was left open for most of the day in every observed household. Multiple participants echoed the sentiment that the fire doesn't burn if the door is closed, especially with "green" wood. When closed the metal door became extremely hot, which is potentially dangerous, as the door is located at the head height of a 3-5 year old child.

At times, mispositioned pots allowed visible quantities of smoke to enter the kitchen through the pot holes. Cracks in the tiles at the edges of cooking surfaces and one water-rotted flue also allowed smoke to enter the kitchen. Such wear and damage on these relatively new stoves (all less than 3 years) suggest that differing physical conditions could have negatively affected stove performance, unlike the (Boy et al., 2000) study that screened out participants whose *planchas* had defects.

The tiled worksurface surrounding the cooking surface was used frequently and was viewed by participants as a key advantage over the open fire. In keeping with previous consensus, the *plancha* was highly desirable and accepted across all study households. The primary reasons cited were the reduction in smoke, the increased space for cooking tasks, and the comfort of cooking while standing.

4.0 Discussion

The inability to control variables in this effectiveness test led to moderately high coefficients of variation (0.30-0.35), which in turn contributed to the inability to reach statistical significance in the comparisons between KPT and open-fire fuel use. These included differences in moisture content, low-quality scales, and an economy of scale for open fire households. Given the variance in the data and the small difference in fuel use measured, 12 total households was not sufficient to bring the comparison to 10% statistical significance. A simple statistical power calculation shows that for the small effect size observed in the KPT, roughly 175 households would be required to reach 10% significance and 80% power. On the other hand, the small difference in fuel use obtained in this sample simply may not be high enough to motivate household changes or substantial donor funding.

Interestingly, in interviews household reported that the plancha was noticeably more efficient than traditional methods. This discrepancy is potentially due to the fact that participating households were reluctant to offer negative feedback to the researchers. It might also be due to the fact that there is an implicit assumption that contained fires are more efficient than open fires, or the fact that the significance values were low.

While the participant observation provided useful behavioral and technological insights regarding fuel performance, the findings are only based on a small number of households in two communities. This work could be strengthened by a micro-analysis of the actual cooking events, focusing on time-to-cook and cooking subtasks. Such a micro-analysis would have relevance both to performance (understanding utilization) and design (e.g. enclosed cookstoves with 2 instead of 3 pot holes have been shown to be much more efficient (Baldwin, 1987).

5.0 Conclusions

Although these studies were conducted in a very specific location and community we believe there are lessons for evaluating

fuel consumption of wood-fired cookstoves in diverse environments.

The measures taken to reduce the variance in data (equality in wood fuel, time of daily wood distribution, person-meals counts, etc.) seemed fairly successful, resulting in coefficients of variance of only about one-third. Any further reduction would likely require measures that would reduce the applicability of the results to target communities. Overall, however, the variance in consumption within households using the same cooking method was large compared to the variance between households with different cooking methods, which is a common problem with household measurements. An economy of scales between fuel consumption and number of people served was identified in larger households, certainly contributing to the variance in consumption within households with the same cooking method. In addition to household size, individual differences in cooking practices are thought to have contributed to the uncertainty in the experimental results.

Although the KPT is difficult to control, leading to data with a high variance, it has the advantage of reflecting the *true* fuel consumption in study households as they proceed with their everyday cooking activities. Laboratory-based investigations such as the water boiling test can be employed as a screening procedure to identify inefficient stove designs early on, yet should not be relied upon as the only method of efficiency assessment. Therefore it is worthwhile to consider changes in the KPT protocol that could be adopted to generate results of higher significance.

In order to better control the sources of uncertainty inherent in the KPT, it is recommended that the protocol be revised to reflect a more careful consideration of the households participating in the study. The simplest means of reducing variance in the data is to match study participants based on household size, thus mitigating the economy of scales effects. In addition to matching households based on size, it is recommended that the protocol be changed from a

between-subjects design to a within-subjects design. Each household in the study should use both cooking methods rather than being restricted to one method, if possible.

This would reduce variance by comparing differences in fuel consumption for individual households, rather than grouping households with the same cooking method for direct comparison to households using another method. This data pairing requires that each household have access to both methods of cooking, implying that the KPT be performed both before and after implementing the cookstove intervention. Further, cookstove users should be well-acquainted to the particular method of cooking. This was a limitation of the KPT⁴ performed by Boy et al.: *plancha* users who were unaccustomed to cooking with open fire were asked to use open fire for cooking.

Given seasonal variations in temperature, fuel usage, and cooking, the test should be performed under uniform seasonal conditions. In conjunction with the within-subjects recommendation, this may require that the study be conducted during the same season in different years. This is the ideal experimental case based on the results of this study, and is acknowledged to pose logistical challenges. A reasonable alternative is to use simpler household matching based on household size and community characteristics.

6.0 Future Work

The most important future work is related to the above recommendations regarding statistically significant and pragmatic KPT results. Several other potential projects are engendered by this work. Quantifying the effects of local drying practices on reducing moisture content would help researchers understand the relevance of moisture testing during the KPT and would provide a better understanding of how different drying

⁴ Boy et al. did not refer to their 5-day cooking test as a KPT; however, the methods used were sufficient to indicate that it was indeed a KPT.

practices impact fuel combustion and emissions.

The combined effects of differences in *plancha* design and wear of key components on indoor particle levels, as well as stove performance could be examined. Finally, future research might survey *plancha* design and usage patterns across different regions of the country. This research would permit the formulation of a set of design recommendations to improve stove dissemination and/or marketing.

Acknowledgement

The authors would like to thank Professor Kirk Smith's Brian and Jennifer Maxwell Endowed Chair in Public Health for providing funding for this research in its entirety. Our work would not have been possible without the assistance of the RESPIRE project, in collaboration with the Center of Health Studies, at Universidad del Valle de Guatemala, which was funded by the National Institute of Environmental Health Sciences.

The assistance of the following people in the RESPIRE randomized trial at the site was invaluable to our project: Anaité Díaz Artiga, Mayari Hengstermann, Eduardo Canú Castro, and Vicente Tema López. We also appreciate the help and advice of Lisa Thompson, Alisa Jenny, and Yu Kuwabara of UC Berkeley and John McCracken at the Harvard University School of Public Health. Finally, the authors are very grateful for the generosity and openness of the participating households, without whom this study could not have taken place.

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