BERKELEY AIR
MONITORING GROUP

Bangladesh Stove Trial: Fuel Efficiency and Usage

Prepared for WASHplus

With guidance from FHI360 and Winrock International

Berkeley Air Monitoring Group

FINAL: July 2013

Authors and Acknowledgments

Authors
Berkeley Air Monitoring Group
Kirstie Jagoe
David Pennise, Project Manager +1-510-649-9355 dpennise@berkeleyair.com
Dana Charron

Field Teams
Berkeley Air Monitoring Group
Todd Wofchuck, Field Team Leader

Village Education Resource Center (VERC)
A K M Anowar Hossain Mollah
Syeda Hosneara Akter
Shajahan Mia
Laila Ishrat Jahan Ruen
Dinabondhu Shikder
Bakul Hossain

Women Development Program
Mizanur Rahman

Esho Jati Gorhi
Ilias Hossain

Siddique Sanitation
Kazi Nurul Alam

Institute of Development Affairs (IDEA)
Zahid Bhuyan

The authors wish to thank the following individuals and organizations for their support and assistance with tl

Elisa Derby, *Winrock International*
Lizi Feng, *Berkeley Air Monitoring Group*
Maneet Kaur, *Berkeley Air Monitoring Group*
Ajay Pillarisetti, *Berkeley Air Monitoring Group*

Table of Contents

Abbreviations

Abbreviation	Meaning
CO	Carbon monoxide
HH	Household
HAP	Household air pollution
g	Gram
kg	Kilogram
KPT	Kitchen Performance Test
LPG	Liquefied petroleum gas
m	Meter
mg	Milligram
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
ppm	Parts per million
SA	Standard adult
SD	Standard deviation
SUMS	Stove use monitoring system

Executive Summary

This report presents the findings from two technical sub-studies that were incorporated into formative research activities in Bangladesh conducted under the USAID-funded WASHplus project, in which five improved wood-burning cookstoves were compared to the traditional technology. The primary activity was to measure stove efficiency through a direct-measurement protocol, entitled the Kitchen Performance Test, in a total of 140 homes in two locations. Consumption of wood and other household fuels was measured over three full days in 22-24 homes using each of the five intervention stove models and in 24 control households using traditional cookstoves. Additionally, temperature-logging sensors were used to track cookstove usage. A secondary sub-study focused on measuring health-related indicators, including air pollution in household kitchens and exposure of the cooks and their young children to carbon monoxide.

Key Results

- Data from usage sensors (SUMS) suggested that all intervention stoves were frequently used by the study households, but none of them fully displace the use of the traditional stoves. During the fuel-use monitoring period, average uses per day for the intervention stoves were between 2.1 to 3.3 and 1.3 to 1.9 for the traditional stove.
- Once the field teams stopped visiting the test homes daily to take fuel measurements, all stove groups, including the traditional stove 'control' homes, showed a marked reduction in the use of any stoves, both intervention and traditional. The largest decline was seen in the use of the intervention stoves.
- All intervention stoves except one used on average 16-30% less fuel per household per day and 5-18% less per standard adult per day compared to the traditional stove group.
- In a very limited snapshot of indoor air pollution, all of the intervention stoves were seen to reduce kitchen concentrations of carbon monoxide and fine particulate matter, although not to what are considered to be health-protective levels.
- The pilot measurements of 24-hour exposure to carbon monoxide revealed low exposure levels that were not health threatening, even in homes with traditional stoves.

1 Introduction

1.1 Study Background and Objectives

WASHplus' current work aims to assess the interest of Bangladeshi cooks in having more choice in the improved stove market and their willingness to pay for these.

Pilot research being conducted by FHI360 and Winrock International under the current WASHplus project activities in Bangladesh focuses on household trials of five improved wood-burning cookstoves. The components of this research undertaken by Berkeley Air are composed of three discrete efforts:

- a broad qualitative household survey aimed at documenting the user's immediate experience and exploring their perceptions, needs, and willingness to pay;
- cookstove fuel efficiency and usage measurements, conducted in a subset of homes using the kitchen performance test (KPT) protocol and temperature-logging stove-use monitors; and
- feasibility testing of several health-related indicators for household air pollution (HAP) concentrations and exposure in a limited illustrative subsample.

The household survey was conducted using a before/after paired study design, whereas a cross-sectional approach was employed for the KPT and HAP components. After the baseline survey, improved stoves were installed in homes for 3-4 weeks, during which the KPT and HAP modules were carried out. Full training on the use of the stove was given to the main cook upon dissemination.

Capacity building is a key component of the WASHplus cookstove activities in Bangladesh. The in-field fuel efficiency testing provided an ideal opportunity to develop national cookstove monitoring capabilities. To achieve this goal, Berkeley Air Monitoring Group led a two-day classroom training session for a group of field workers comprised of staff from Village Education Resource Center (VERC), plus four other NGOs and small stove manufacturers. The classroom training was followed by two weeks of fieldwork during which time the Berkeley Air field team leader was able to guide and support the local field teams through a complete KPT cycle.

The objective of the health-related sub-study was to leverage the presence of experienced field personnel in Bangladesh to collect preliminary data on household air pollution and exposures. Kitchen concentrations and exposure of women and children to fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) were monitored in the kitchens of a small subset of homes. The resulting snapshot of the indoor air pollution levels associated with the use of these improved cookstoves will allow the feasibility and value of a larger in-depth, more robust study to be gauged by program staff.

1.2 Overview of Project Stoves

Six study groups were included in the KPT monitoring. Five groups of households, each with one of the five different wood-burning improved stoves (intervention stoves), and one group of households (control households) that had only their traditional cookstove, the type most frequently used in the study communities. Figure 1 shows the intervention and traditional stoves used by the study households.

Figure 1: Study group stoves.

1.1 Traditional stove

1.2 Envirofit Z3000

1.3 Prakti Chimney Stove

1.4 Eco Chula

1.5 Greenway Smart Stove

1.6 EcoZoom Dura

2 Methods

2.1 Overview of Study Design

The study was carried out using a cross-sectional study design. 24 households who had not already received an intervention stove were included in the study as control households, along with 22-24 households for each of the five intervention stove models. This gave an overall sample size of 140 households. The sample size (20 in each group) was chosen to be able achieve statistically significant differences in fuel use given an estimated 35-40% reduction in fuel use by the intervention stoves compared to the traditional stove and a variability in fuel use measurements typically seen in KPT studies (coefficient of variation in the 0.4-0.45 range). Such reductions in fuel use have been demonstrated for some of these and other similar intervention stoves in previous KPT studies from various parts of the developing world. Laboratory test data on these intervention stoves suggested even greater percent fuel savings, as is often the case. Of course, budget and logistical considerations also factored into the sample size choice, especially given the desire to study six different stove types in two locations.

WASHplus local partner NGOs, DESH GORI from Barisal and IDEA from Sylhet, selected the study villages. In Barisal the villages were Billobari, Bihangal, Ichakathi, and Gonpara; in Sylhet the villages selected for the study were Jangail, Kewa, Tilargaon, and Kunarchor. Households were originally selected because they fit the basic criteria of primarily using wood for cooking, having at least four people in the household with at least one child under 5, and being willing to participate in the study. Unfortunately, around 20 smaller households made it past the household selection screening into the study, as the families included members who do not live full time in the house.

Monitoring was carried out during the dry season in two locations of Bangladesh - Barisal, located in Southern Bangladesh, and Sylhet, in the Northeast of the country. The primary cooking fuel in both locations was fuel wood, although at the time of the survey, the use of dried leaves in combination with wood was prevalent in these communities. There was no predominant method of fuel procurement within the study group with just under 30% gathering all fuel and just under 50% of households buying all or most of their fuel.

After being randomly assigned an intervention cookstove, the participants were trained in its use following manufacturers' instructions and then asked to "try out the stoves under normal conditions" for a three week period.

2.2 Fuel Efficiency Assessment

Fuel efficiency was measured using a 3-day KPT (version 3.0, www.pciaonline.org/testing). The KPT is widely acknowledged as the best currently available method for accurately estimating daily household fuel consumption (Bailis et al. 2007; Smith et al. 2007; WHO 2008).

All household fuels to be used (wood, crop residues, charcoal, kerosene, etc.) were weighed at the beginning and end of each of the three 24-hour monitoring periods using Salter Brecknell (Fairmont, MN) ElectroSamson digital hand-held scales (25 kg maximum with a resolution of 0.02 kg).

Wood moisture was measured daily in each household using a dual pin, electrical resistance style moisture meter (Extech MO120) at three points on three randomly selected sticks in the woodpile.

A short questionnaire was also administered daily to record information about cooking stove and fuel usage, the number and type of meals prepared, and the number of people cooked for (see Appendix 1 for a copy of the survey form). The households were asked to maintain their typical cooking patterns for the duration of the survey.

2.3 Stove Use and Adoption

Two approaches were used to measure the extent to which households adopted the new stoves and the manner in which they integrated them into their cooking and kitchen management practices: the use of stove use monitoring sensors (SUMS) and reported use of stoves at the end of each 24-hour KPT monitoring period. The SUMS temperature-logging sensors were affixed to the stoves to collect data on how often the stoves were "turned on" (i.e. lit). The sensors were iButton model DS1922T, manufactured by Maxim Integrated, USA. Figure 2 shows the placement of the SUMS iButtons on the traditional and Envirofit Z3000 stoves, as an example.

Figure 2: SUMS iButton placements.

Figure 2.1. SUMS iButton placement on traditional cooking stove	Figure 2.2. SUMS iButton placement on Envirofit Z3000 stove
	

These approaches are summarized in Table 1.

Table 1: Stove use and adoption assessment methods.

Method of Data Collection	Method Details	Resulting Usage Information
Stove use monitoring sensors (SUMS)	SUMS placed on all intervention stoves, all traditional stoves in the control group, and on the traditional stoves in a subset (51%) of the intervention homes. SUMS were also placed in 10 kitchens to measure ambient temperature. Stove temperatures were recorded for at least 10 days starting when the KPTs were begun.	Measured number of stove uses each day throughout the 10-day monitoring period.
Technical questionnaire administered daily during the 3-day KPT period	Cooks were asked about their household energy practices for the previous 24 hours throughout the 3-day KPT. Details about stove use, fuel use, and numbers cooked for were recorded.	Self-reported number of stove uses by stove type each day for the 3-day KPT period

The SUMS recorded the stove temperature every 10 minutes for a total of approximately 10 days (data was recorded in some households for slightly longer periods due to a delay in gaining access to the kitchen to remove the buttons). The resulting temperature profiles were then analyzed to determine the frequency of "cooking events" (i.e. number of times the stoves were lit) per day.

2.4 Household Air Pollution Monitoring Methods

The impact of the interventions on household air quality was explored during the KPT monitoring in a subset of seven homes (two households from the traditional stove group and one household from each of the five intervention stove groups.). There were a total of four households monitored in Barisal and three in Sylhet. This limited sample size was selected with the goal of demonstrating the feasibility of measuring health-related indicators in household energy projects in Bangladesh and collecting some illustrative results; it was not expected to generate statistically significant results.

Small particles ($PM_{2.5}$) and carbon monoxide (CO) are the most commonly measured pollutants in wood smoke, as they are widely accepted to be the source of the majority of the ill-health resulting from solid-fuel use. Instruments for measuring these pollutants were placed in the kitchen at one meter from the stove and 1.5 meters above the floor, a standardized location meant to represent the approximate breathing zone of a woman standing near the stove.

Minute-by-minute kitchen concentrations were recorded using real-time data-logging instruments in the same seven households where the personal exposure monitoring was performed. $PM_{2.5}$ was measured with the UCB-PATS (Berkeley Air Monitoring Group, Berkeley, CA, USA), and carbon monoxide (CO) was primarily measured using the GasBadge Pro. In addition, Drager CO Diffusion Tubes were co-located with the GasBadge monitors in the kitchen to establish a relationship between the CO readings from the GasBadge Pro and the Drager tubes.

Environmental and contextual information that might impact indoor air quality, such as kitchen volume, was also collected during the studies.

2.5 Personal Exposure Monitoring Methods

The impact of the interventions on women and children's exposure was explored in the same subset of seven homes used for household air pollution monitoring, described in section 2.4.

2.5.1 Exposure of the main cook

The cook's 24-hour exposure to CO was measured using a portable, datalogging GasBadge Pro Single Gas Monitor (Industrial Scientific), which the participant wore on a lanyard around her neck. Participants were asked to wear the monitor as continually as possible and to keep it close by when they were sleeping or bathing. The GasBadge Pro measures CO in the 0-1,500 ppm range in 1 ppm increments.

Exposures were also assessed using Drager Carbon Monoxide Diffusion Tubes 50/a-D (50-600 ppm*h, Dräger, Lübeck, Germany). Tubes were placed on the cooks using plastic tube holders and clips. Analysis was carried out on the average of two readings taken immediately after collection. To increase the resolution of the tube readings and reduce error, the stain length was measured in millimeters, and then converted to ppm.

2.5.2 Exposure of the child

24-hour exposure to CO was measured on one child less than 5 years of age in six of the seven households where the adult exposure was monitored (one household did not have a child under 5 available). Exposures were assessed using the Drager carbon monoxide diffusion tubes. Tubes were placed on each child's shirt using plastic tube holders and clips. The same procedure was used for reading the CO tube measurements as with the cooks.

2.6 Quality assurance

To ensure consistent comparable readings of fuel consumption, each surveyor used the same scales throughout the KPT study. All scales were calibrated before deployment with NIST traceable calibration weights at the Berkeley Air laboratory to ensure accurate readings.

The field supervisor reviewed the survey and KPT data at the end of each day for consistency and completeness. Any discrepancies were addressed as soon as possible.

Prior to deployment in the study, the UCB-PATS were calibrated with wood smoke in the Berkeley Air laboratory against gravimetric (pump and filter) measurements of $PM_{2.5}$ (the standard method), and the GasBadge Pro CO monitors were calibrated with NIST-traceable CO gas (50 ppm).

3 Results

3.1 Stove Use and Adoption

Although the SUMS monitoring period was restricted to 10 days due to the limited timeframe of the monitoring effort, the results do provide a useful snapshot of how the stove was being used two to three weeks after its introduction to the households.

Monitoring was carried out during the time of the KPT and then for 8-10 days after. Figure 3 shows the mean estimate of traditional and intervention stove uses per day for the different stove groups both during the time of the KPT (blue shaded columns) and then for the time after the field staff had ceased the daily home visits required by the KPT (green shaded).

SUMS measured usage rates for all intervention stoves were between 2.1 (Envirofit) and 3.3 (Eco Chula) uses per day during the KPT monitoring, with all groups using the traditional stove as part of their cooking systems between 1.3 (Prakti stove group) and 1.9 (EcoZoom stove group) times per day. These usage patterns during KPT monitoring suggest the intervention stoves were commonly used by the study households, but in all cases, did not fully displace the use of the traditional stoves.

The post-KPT stove use estimates were consistently different, however. Once the KPT had finished and the field staff had left the home, all stove groups, including the traditional stove 'control' homes, showed a marked reduction in stove use (See Figure 3).

Figure 3: Traditional and intervention stove use monitored using SUMS during and after the KPT monitoring period.

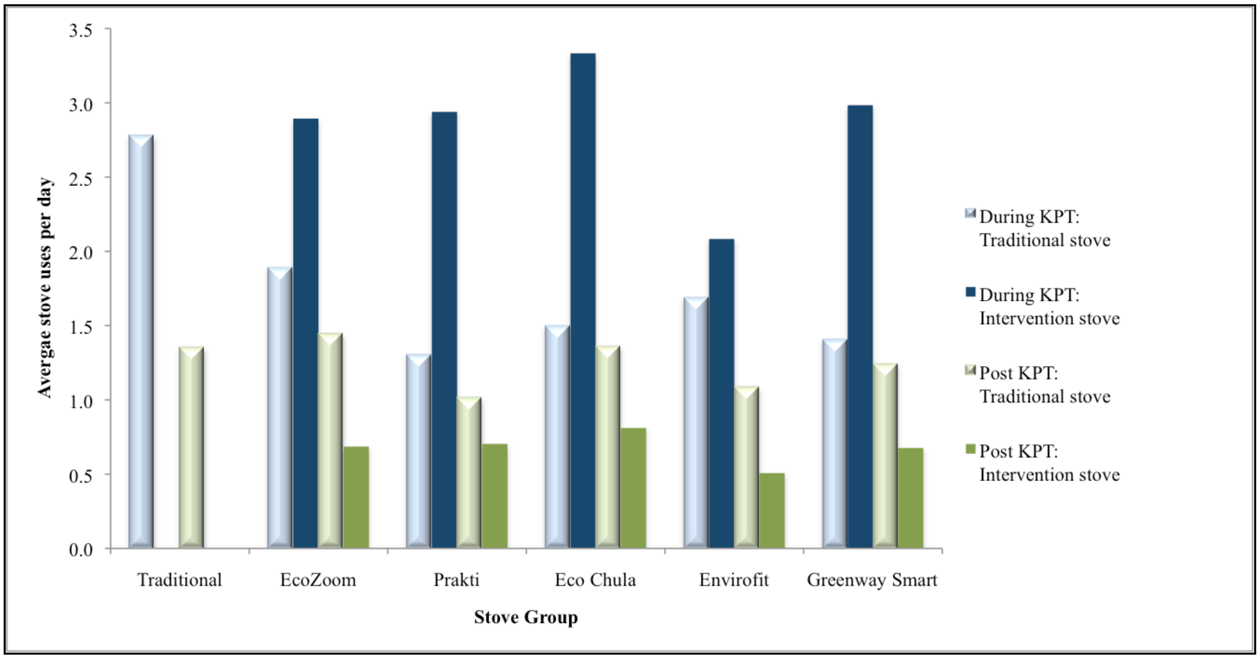


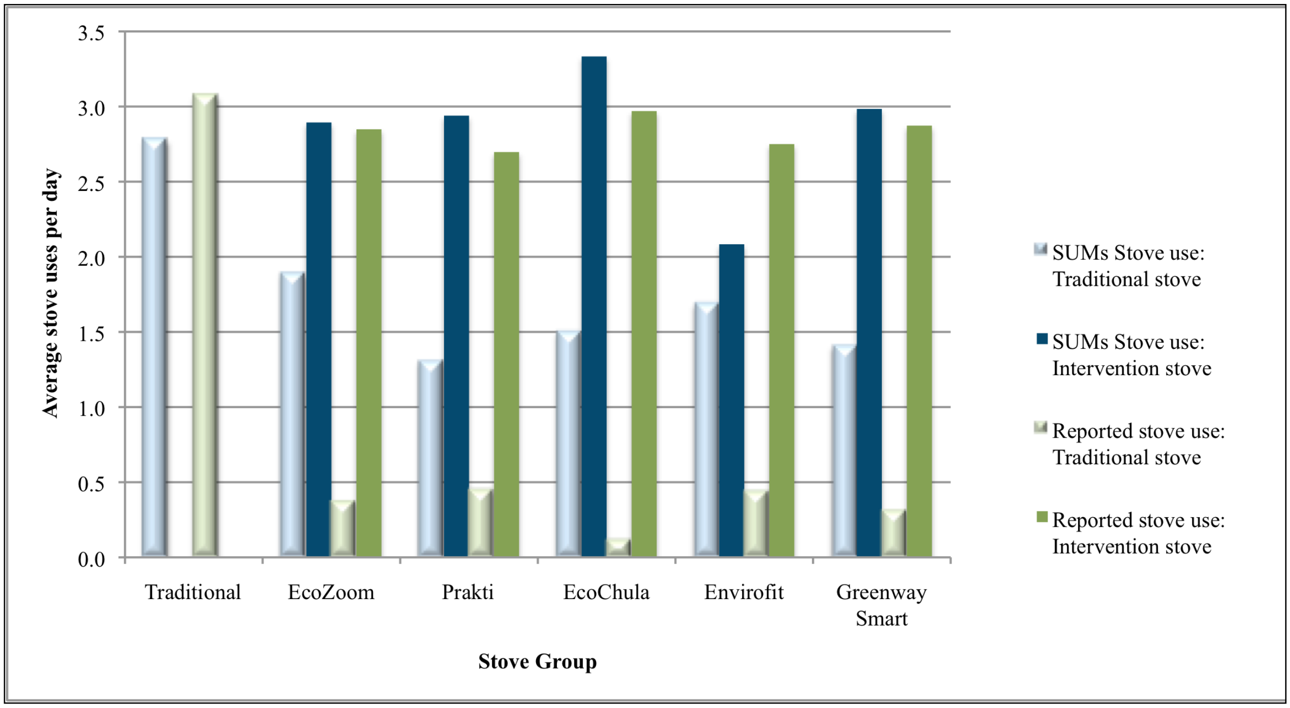
Table 2 shows the average number of times a stove (traditional or intervention) was used per day during and after the KPT monitoring. In all study groups it can be seen that the stove use decreased dramatically once the KPT monitoring was finished. The biggest reduction was, however, in the use of the intervention stove, with most groups showing a reduction of about 75-80% compared to during the KPT monitoring.

Table 2: Average (mean) number of stove uses per day for all stoves.

Average number of stove uses per day- all stoves		
	During KPT	Post KPT
Traditional	2.8	1.4
EcoZoom	4.8	2.1
Prakti	4.2	1.7
Eco Chula	4.8	2.2
Envirofit Z3000	3.8	1.6
Greenway Smart	4.4	1.9

The stove use rates reported at the end of each day of KPT monitoring were compared to the SUMS data from the same period. The data in Figure 4 indicate that the cooks with an intervention stove were likely to underreport use of the traditional stove but reported use of the intervention stove with relative accuracy.

Figure 4: Traditional and intervention stove use during the KPT monitoring: reported verses monitored with SUMS



Between 43 and 67% of stoves in each intervention study group had both traditional and intervention stove use monitored using SUMS (See Table 3). The proportion of total recorded cooking events performed by the intervention stoves was examined in these households. Once again there is a significant difference in stove use patterns during and then after the KPT monitoring. During the KPTs the intervention stove was contributing to between 60-73% of the recorded cooking events. Whereas once the field team had left the communities, this fell to between just under 30% (Envirofit) and just over 45% (Eco Chula group).

Table 3: Proportion of all recorded cooking events performed by the intervention stove (by stove group).

	% Stove group with traditional stove data	% Cooking performed on ICS: During KPT	% Cooking performed on ICS: Post KPT
EcoZoom	41%	65%	34%
Prakti	50%	72%	43%
Eco Chula	50%	73%	46%
Envirofit Z3000	67%	60%	29%
Greenway Smart	43%	69%	30%

3.2 Fuel Consumption Measurements

The KPT was carried out in 140 households. After removal of inaccurate or missing data, there was a final sample size of 134 (Barisal: 65 HH and Sylhet: 69 HH). Table 4 shows the final sample size by stove group.

Table 4: Sample size for KPT monitoring by stove

Traditional stove	n=23
EcoZoom Dura	n=22
Prakti	n=22
Eco Chula	n=22
Envirofit Z3000	n=24
Greenway Smart Stove	n=21

All households in each stove group used wood as their main cooking fuel during the monitoring period, with a small number of homes in Barisal reporting the use of crop residue (in the form of dried leaves) as a secondary fuel (9.0%, n=12).

Approximately 79% (n=106) of the households reported to be using less wood fuel at the time the survey was carried out compared to other times of year (Barisal: 80%, n=52; Sylhet: 78%, n=54).

Figure 5 shows the responses given by location and stove group. The majority of households in all intervention stove groups across both locations report using less wood at the current time of year. The main exception can be seen in the traditional stove group in Sylhet where, although the majority still report using less wood than their average, it is a significantly reduced proportion within the group compared to all others.

Figure 5: Relative wood fuel use at time of KPT monitoring compared to other times of year by stove group and location.

Figure 5.1: Sylhet

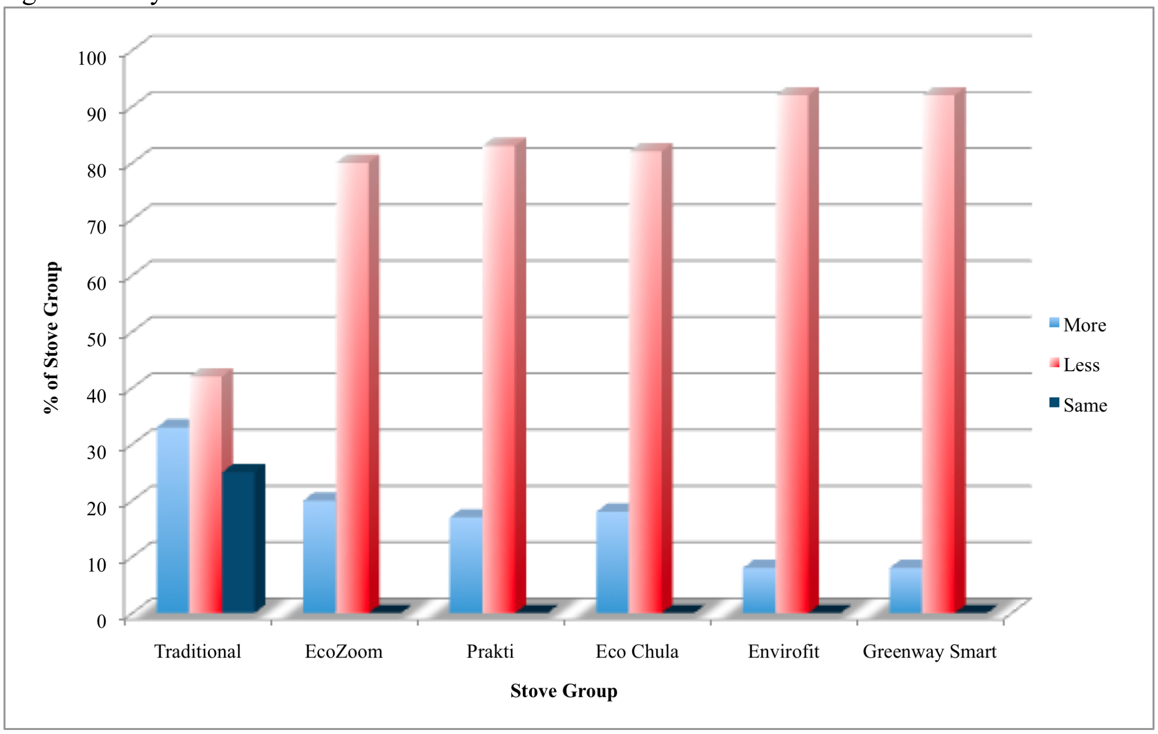
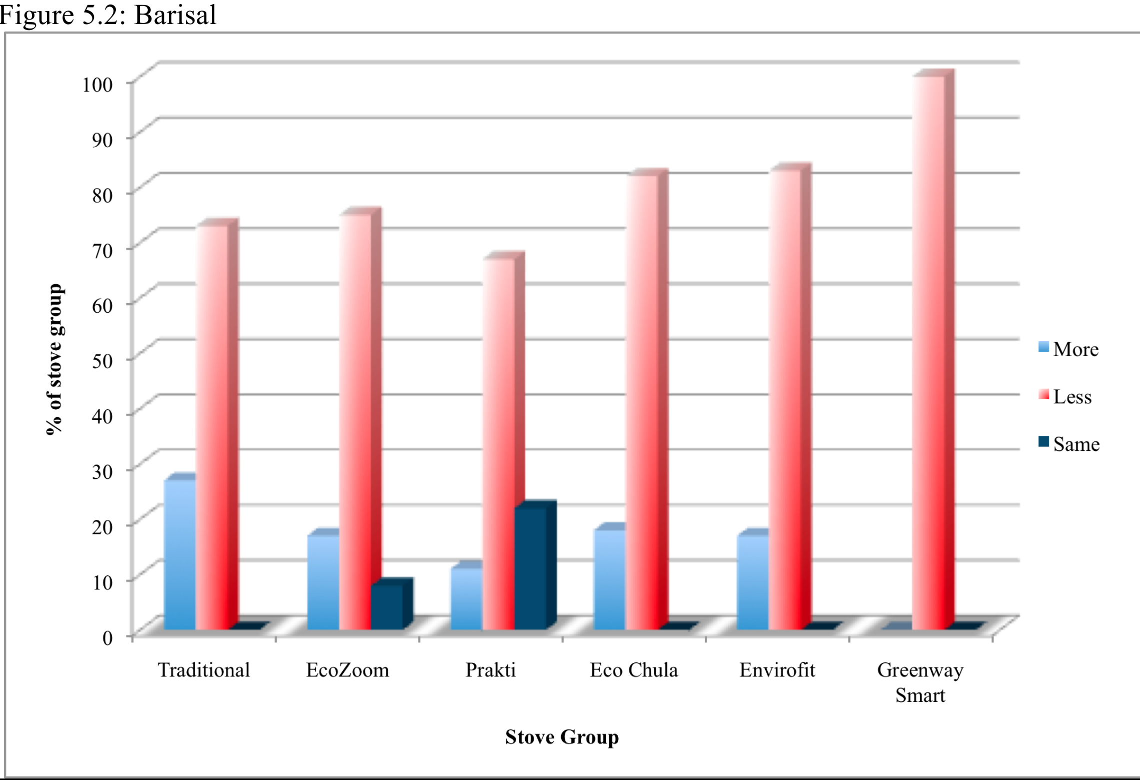


Figure 5.2: Barisal



Reasons for the seasonal change in the amount of wood fuel consumed were explored. The fact that wood is dry (n=80, 70% of group reporting less wood used) and the availability of agricultural residues (leaves, see Figure 6) (n=24, 21% of group reporting less wood fuel) were the most frequent answers in both locations across all stove groups.

Figure 6: Dry leaves used as cooking fuel

Table 5 shows the wood fuel consumption estimates (kg/SA/day) for the homes by stove group and location. It can be seen that there was no statistically significant regional difference in fuel consumption across the two locations for any stove group except for the groups using the traditional stove, which showed a lower consumption per standard adult in Sylhet compared to Barisal (p=0.034).

Table 5: Mean daily fuel consumption estimates, reported as kg per standard adult (SA)[1] per day for stove and location group. ± represents 1 standard deviation.

Stove Group	Location	Wood (kg/SA/day)	P value*
Traditional stove	Barisal (n=11)	0.86 ± 0.21	0.034
	Sylhet (n=12)	0.60 ± 0.32	
EcoZoom Dura	Barisal (n=12)	0.66 ± 0.18	0.122
	Sylhet (n=10)	0.53 ± 0.19	
Prakti	Barisal (n=10)	0.78 ± 0.58	0.261
	Sylhet (n=12)	0.58 ± 0.18	
Eco Chula	Barisal (n=11)	0.66 ± 0.25	0.506
	Sylhet (n=11)	0.59 ± 0.21	
Envirofit Z3000	Barisal (n=12)	0.76 ± 0.31	0.249
	Sylhet (n=12)	0.99 ± 0.58	
Greenway Smart Stove	Barisal (n=9)	0.70 ± 0.25	0.225
	Sylhet (n=12)	0.65 ± 0.34	

** Comparing mean fuel consumption between location within stove group. Equal variances assumed in all cases.

Table 6 shows the daily wood fuel consumption by stove group and in comparison to the traditional stove group. The estimates show that wood consumption in all intervention stove groups except the Envirofit Z3000 (see outlier discussion below) was on average 16-30% lower per household per day and 5-18% lower per standard adult per day compared to the traditional stove group. None of these differences show statistical significance, however.

[1] "Standard adult" equivalence factors defined in terms of sex and age (from Guidelines for Woodfuel Surveys, for F.A.O. by Keith Openshaw cited in (Joseph, 1990)). Gender and age fraction of standard adult: child 0-14 years = 0.5; female over 14 years = 0.8; male 15-59 years = 1; and male over 59 years = 0.8.

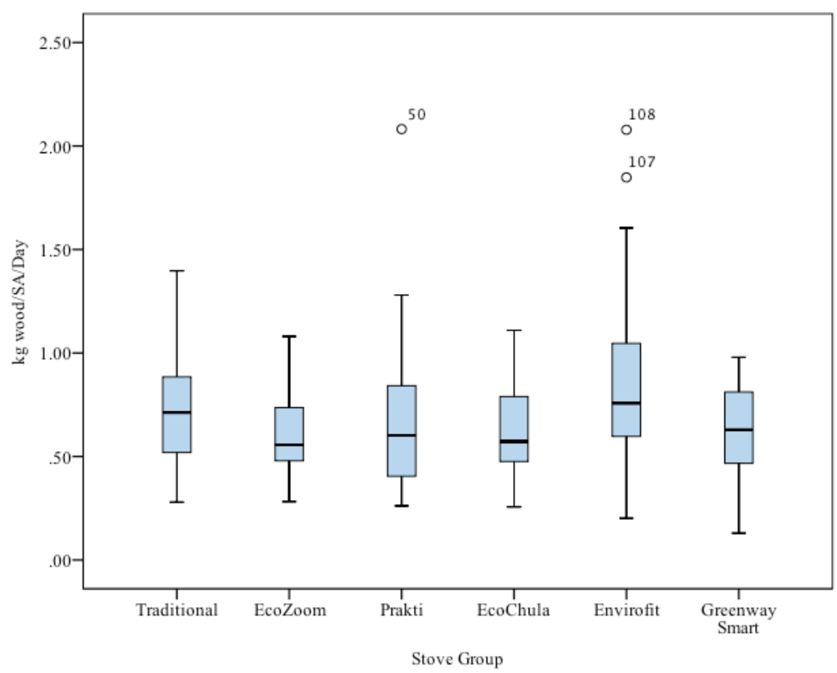
Table 6: Mean daily fuel consumption estimates, reported as kg per standard adult (SA) per day and by household (HH) per day. ± represents 1 standard deviation.

	Wood (kg/HH/day)	% savings compared to trad stove	Wood (kg/SA/day)	% savings compared to trad stove	P value*
Traditional stove (n=23)	3.09 ± 1.69	-	0.73 ± 0.30	-	-
EcoZoom Dura (n=22)	2.39 ± 0.77	22.7	0.60 ± 0.19	17.8	0.106
Prakti (n=22)	2.58 ± 1.16	16.5	0.69 ± 0.41	5.5	0.746
Eco Chula (n=22)	2.19 ± 0.79	29.1	0.63 ± 0.23	13.7	0.223
Envirofit Z3000 (n=24)	3.63 ± 1.24	-17.4	0.87 ± 0.47	-19.2	0.214
Greenway Smart Stove (n=21)	2.32 ± 0.94	24.9	0.62 ± 0.22	15.1	0.217

* Comparing intervention stove with traditional stove for (kg/SA/day value). Equal variances assumed in all cases.

A box plot of the kg wood/SA/day by stove group was examined for the presence of outliers that might have an impact on the sample mean. Figure 7 below identifies (denoted as circles) one outlier[2] in the Prakti stove group and two in the Envirofit Z3000 group.

Figure 7: Box plot showing fuel consumption by stove group (kg/SA/day).



[2] Outlier defined as 1.5 times the inter-quartile range (IQR) from the third (75th) quartile.

Removal of these data points changes the mean wood fuel consumption for the Prakti stove to 0.63 **kg/SA/day** (SD 0.28 n=21). This estimate is 13.7% lower than the wood fuel consumption in the traditional stove households (vs. a 5.5% reduction when the data point is included). Removal of the two outliers in the Envirofit stove group would reduce the fuel consumption to 0.77 **kg/SA/day** (SD 0.34 n=22), an increase of 5.5% compared to the traditional stove estimates (vs. a 19.2% increase when the outliers are included).

The data from these outliers was examined for any error or unusual characteristics that might warrant its removal. It was found that all three households cooked for more people during the KPT than they had reported to be their usual number cooked for. This 'usual number cooked for' was used to determine the number of standard adults (SA), and so cooking for more people than usual during the KPT results in an unrepresentatively high kg/SA/day value for that household. However, the overall mean number of 'standard adults' reported to be usually cooked for was slightly lower than the actual numbers cook for during KPT (SA mean = 4.26, mean people cooked for during KPT= 5.07, p=0.000), we could therefore expect that many households might have been affected in this way, and although they did not show up as outliers, they could be contributing to an overall elevation of the mean kg/SA/day. However as this increase is most likely to be randomly spread across all stove groups, it is unlikely to be causing any bias and distorting of comparative results.

Considering this and the fact that the results in these three households do not look like an error, it is recommended that they are not removed and the kg/SA/day presented in Table 6 are taken as the final fuel consumption estimates.

3.3 Household Air Pollution and personal exposure

3.3.1 Household air pollution

The kitchen concentrations of $PM_{2.5}$ and CO are reported in Table 7. This limited data "snapshot" shows that kitchen concentrations in all the homes with intervention stoves were lower than those recorded in the two traditional stove households. This exploratory data should be seen only as an indicative pilot, however, as there is only one household per stove type (two in the traditional stove group). Without a larger sample size, the comparison of household air pollution levels can be misleading, as many of the factors that affect pollution levels vary from home to home. Factors include ventilation rates, the size and type of kitchen, the mix of stoves and fuels used, the number of people cooked for, lighting, and other indoor sources of pollution, such as incense and cigarettes.

Table 7: Mean 24-hour air pollutant concentrations in the kitchen.

	$PM_{2.5}$ (µg/m³)	CO (ppm)
Traditional stove_1	11,017	31.5
Traditional stove_2	2737	14.1
EcoZoom Dura	1744	2.8
Prakti	626	9.1
Eco Chula	2587	7.8
Envirofit Z3000	1343	0.9
Greenway Smart Stove	1472	3.2

3.3.2 Personal exposure monitoring

The mean 24-hour CO exposure concentrations for the women and children are reported in Table 8. All women's exposure levels were low, between 0.4 and 1.9 ppm CO, and the child exposures were even lower, between 0.2 and 0.7 ppm CO. As with the household air pollution monitoring, there was only one exposure measure per stove type (two in the traditional stove group), thus this data can only be seen as providing indicative, pilot information. Comparing exposure levels is even more complicated than comparing kitchen air pollution levels, as not only are exposure levels affected by all of the kitchen factors, but also where and when the participants spend their time throughout the monitoring period and the air pollution levels associated with those areas.

Table 8: Mean 24-hour exposure of woman and child.

	Description of kitchen	CO woman[1] (ppm)	CO child[2] (ppm)
Traditional stove_1	Separate building to house/ enclosed	0.9	0.7
Traditional stove_2	Separate building to house/ enclosed	0.5	0.4
EcoZoom Dura	Enclosed room in main house	1.6	0.7
Prakti	Separate room in main house/enclosed	0.6	0.4
Eco Chula	Separate room in main house/enclosed	0.6	No child
Envirofit Z3000	Separate room in main house/semi-open	1.9	0.2
Greenway Smart Stove	Separate building to house/ semi-open	0.4	0.2

1- Reading taken from GasBadge Pro
2- Reading taken from Drager carbon monoxide diffusion tubes

3.3.3 Compliance with equipment

There was a high level of compliance with wearing the monitoring equipment. All women were wearing the GasBadge Pro and the Drager carbon monoxide diffusion tubes when the field team arrived at the home, and all claimed to have worn it for the full duration of the 24-hour monitoring period. Additionally, all children monitored were wearing the diffusion tube on arrival, and the mother reported that they had worn it for the full duration of the monitoring period.

3.4 Stove perceptions

Collection of information on the users' perceptions of the intervention stoves was not a key outcome for this component of the research activities. However, the fieldworkers documented interesting and useful information given to them during casual conversations with the participants. The most frequently reported perceptions are presented by intervention stove in the Table 9 below.

Table 9: Perceptions of the intervention stove provided on an informal basis.

Stove used	Feedback/issues raised
EcoZoom Dura	• Would have liked it to be a bigger size so that it could take larger pots and cook more food. • It was felt that cooking takes longer with the EcoZoom stove. • There was some difficulty in cutting the wood to use on the stove.
Prakti	• Several homes reported that they could not get sufficient heat from the second burner. One noted "better that both mouth of the stove have same heat" • The stove was described as too small to be able to cook all of the food easily with one household saying "Stove uses regularly; Stove size is not enough for heavy meal" • Some households felt the stove would be helpful to them and they felt 'good to use' it. • Increase in cooking time when using the Prakti was reported by some.
Eco Chula	• The need to prepare wood in small pieces was the most frequently reported disadvantage with the Eco Chula. • As with other stoves some households some participants felt they could cook less food on the Eco Chula compared to their traditional stove. • One household did say that "She is happy to cook with this stove"
Envirofit Z3000	• There was some mixed report from the homes using Envirofit. Some homes reported using less wood while others reported more wood fuel was required compared to the traditional stove. • There was more agreement in that their cooking took longer on this stove compared to their traditional stove. • One participant reported "This stove cooks well but need stand". [Note: We believe this is referring to a fuel support]
Greenway Smart stove	• Some participants felt that they can cook less food on the Greenways compared to their traditional stove "Main hole of this stove is very small it is very difficult to cook more". One home used the "intervention stove for light cooking; stove for heavy meal cooking required" • "Heavy smoke" was reported on lighting the stove in one home. • One participant was reporting to be cooking regularly with the stove and was "feeling happy".

The reoccurring perception that the stove was not large enough to meet all of the cooking requirements was also a theme that came out during the wider qualitative study using the TIPs (Trials of Improved Practices) methodology.

3.4.1 Reasons for refusals to take part in KPT

Three households selected to take part in the KPT monitoring refused to participate. All were located in Barisal. The reasons given for refusal provide some further insight into user perceptions and fuel use patterns in these communities.

"Not enough space for two pot on the Prakti - too much time to cook with Prakti - also takes a lot of time to clean the ash out - has a child and does not want to deal with Prakti - takes too much time to cook / maintain" [Prakti Stove]

"Takes too long to cook on, a lot of smoke - too much fuel - very difficult to light - does not have patience for this stove" [Greenway Smart stove.]

"House does not use wood - use leaves and sawdust" [Eco Chula]

4 Discussion

4.1 Study limitations

There are several factors that should be considered when interpreting these results.

Sample sizes

One of the strengths of this study is its relatively broad scope, assessing 6 stoves in 2 regions of the country, and thus building a knowledge base about household energy that is widely relevant across Bangladesh. This wide-angle view is particularly appropriate for the type of formative programmatic investigation that WASHplus has undertaken in Bangladesh. In fact, with limited resources, it could be argued that funding larger sample sizes for the assessment of cookstoves that have not yet been accepted by the local population would be irresponsible.

Nevertheless, the limitations of this broad approach are evident in the current results, which did not result in any statistically significant differences between the fuel consumption in the homes with and without the intervention stoves. This fact is telling in its own right because it suggests that the intervention stoves were not performing well under these typical Bangladeshi household conditions, especially when compared to lab test results. The sample size calculations were based on a minimum fuel savings of 35% over the traditional stove, which was clearly not achieved in the majority of homes.

Impact of fuel mixing

Results from the wider qualitative survey suggest that there is typically extensive use of leaves for cooking fuel during the time of year during which the KPTs were conducted. Many households burn this fuel in 'leaf-burning mud stoves' that they construct outside in the open courtyard. This could have potentially influenced the extent and nature of wood fuel consumption in both the control and intervention stove households.

However it is reported that the KPT team did not see many houses using leaves during the three days of the KPT monitoring. The team weighed the leaves whenever the household used them, whether used in their outside stove or in the traditional stove in their house. 12 of the 134 total households had leaves weighed during the KPT, and all 12 of these households were in Barisal. This fact is in line with the field team reports that leaves are used as a cooking fuel in addition to wood in Barisal due to the abundance of trees at that location, while in Sylhet, where trees are less abundant, leaf use was much less common. Only one of these 12 leaf-using households was a control household.

It is possible that some degree of leaf use was not measured during the KPT. Any time a fuel is both procured and used in between the daily field worker visits, it is very difficult to quantify its use during a KPT. We do not, however, have any strong evidence to indicate that this occurred for leaves in this KPT or that it occurred more so for leaves than for wood (e.g. small sticks and twigs). Also this 'leakage' in the measurement of leaves is likely to have had a similar impact across all stove groups including the control households.

The intervention stoves use only wood fuel and do not function well with leaves. Some households in Barisal reported to be using wood during the KPT when they would normally be using leaves for some or possibly all of their cooking at this time of year and found this to be a disadvantage of the intervention stove.

> One surveyor noted, "[Cook reports] regular use [of] this stove but she feel unhappy to use fuel wood in dry season." Another noted that one home had restricted their use of the intervention stove as it did not use leaves: "She prepares breakfast and lunch in the traditional stove with leaf and only dinner prepare with Prakti."

This suggests that families who shifted their cooking to the intervention stoves depended more heavily on wood fuel than they normally would have if they only had access to their traditional stove with a leaf/wood combination. However, this shift to wood fuel is only likely to have occurred in Barisal, as leaf use appeared to be minimal in Sylhet. Furthermore, some intervention stove households in Barisal did continue to use leaves in their traditional stove. Finally, as only one control household had leaves weighed during the KPT, it suggests that the controls might have also shifted to using more wood in some way during the KPT.

There is also the possibility that the process of monitoring influenced the way the households used their stoves and fuels (known as the observer-expectancy effect). If the control households perceived the main focus of the KPT to be wood fuel (even though they had been asked to show all fuels to be weighed), they could have altered their habits to use more wood and less leaves for the period of the KPT. The SUMS data supports this hypothesis in that there was a reduction in traditional stove use in the control households after the end of the KPT monitoring. This suggests that the may have moved from the traditional wood burning stove, which had the SUMS unit placed on it, to the leaf burning stove that did not get monitored due to fears of security issues as the stove was located outside. Or, they may have had more stove use during the KPT than is their typical practice.

Barisal had the higher wood fuel consumption and the greater use of leaves in this KPT compared to Sylhet, which might suggest that leaves are complementary rather than a replacement fuel. The extent to which leaf use reduces wood use is not clear.

It is likely there was some shift from leaves to wood in both intervention and control homes in Barisal and less so (if at all) in Sylhet during the period of the KPT monitoring. We cannot, however, be certain of the extent of this shift and, therefore, how it might impact wood fuel consumption in the new stove households relative to the traditional stoves, if at all. Any shift from leaves to wood use likely occurred similarly across all of the intervention stove groups and thus would exert a similar effect on each group. It is therefore unlikely that there is a large effect on the differences in wood fuel consumption between the traditional stove households and the intervention stove households as a result of fuel mixing.

Envirofit stove results

Data from the households with the Envirofit stove suggested higher fuel consumption than in the control households using traditional stoves.

As described in Section 3.2 two outliers were identified in this group. Outliers are defined as data points that are greater than 1.5 times the inter-quartile range (IQR) from the third (75th) quartile, and those that are 3 times the IQR are deemed to be extreme outliers. The data from these outliers were investigated to establish if the results were in fact erroneous. As Section 3.2 outlined, this was not found to be the case and the data looked consistent and within the bounds of reasonable fuel consumption for this population. In view of the fact that the outliers are not considered to be ‘extreme’ and without any evidence to show that these households had any unique characteristics to suggest they were not representative of this selected population, it was decided to include these households in the analysis.

However, there are factors that should be considered when interpreting these results. The sample sizes for each individual stove group are relatively small (n=24 for the Envirofit stove). Outliers such as those seen in the Envirofit stove group (and to a lesser extent the Prakti stove group) can have an influence on the estimated sample mean when the sample size is small. It is possible that a mean from a larger group might not have been so influenced by extreme values.

Although the stove allocation was random, it could be that the Envirofit group included two households that were high users of wood and would continue to be such regardless of the stove type used. However, this can only be investigated and subsequently controlled for by using a paired / before and after study design.

4.2 Comparison to stove performance standards

Although there are not yet any globally accepted stove performance standards, an ISO International Workshop Agreement for cookstove performance was agreed in 2012. The IWA provides a system for categorizing stoves based on several performance metrics, including two metrics related to efficiency, from tier 0 representing traditional stoves to tier 4 representing aspirational gas technologies. Currently, however, the IWA tiers only provide comparative classification for stoves based on lab tests.

All of the stoves selected for this study had achieved a tier 2 or higher rating for their efficiency metrics in the laboratory. And all of the stoves except the Envirofit Z3000 showed reductions (though not statistically significant) in wood fuel consumption compared to the traditional stoves in the field. While it is not yet possible to compare the field performance results using the IWA structure, it is fair to say that the fuel savings were not as strong in the field as in the lab.

4.3 Comparison to household air pollution health standards

The pilot measurement of health-related household air pollution concentrations and exposures suggested that all of the intervention stoves were reducing harmful emissions of CO and $PM_{2.5}$. The 24-hour $PM_{2.5}$ levels were, however, still several fold higher than the World Health Organization (WHO) annual interim-I guideline of 35 $\mu g/m^3$ (WHO, 2006). Three of the five intervention stove homes achieved 24-hour CO levels below the WHO 24-hour guideline of 6 ppm (WHO, 2010) and two nearly achieved that level, with the traditional stove homes averaging 22.8 ppm.

The personal exposure measurements suggested cookstove emissions might not be a dominant source of CO exposure for Bangladeshi women and their young children. All women's exposure levels were low, between 0.4 and 1.9 ppm CO, and the child exposures were even lower, between 0.2 and 0.7 ppm CO. All were well below the WHO 24-hour guideline of 6 ppm (WHO, 2010). It is much more challenging to measure personal exposure to particulates, and these measurements were not attempted for this study, even though they would be relevant, as Bangladesh has a high rate of respiratory infections and other diseases related to household air pollution.

These preliminary health-related measurements in combination with the usage data suggest that an in-depth study of indoor air pollution concentrations and exposure could be worthwhile if an improved wood-stove was found to perform well in field tests and displace a substantial fraction of traditional stove cooking. In this case, it would be important to invest the resources necessary to measure exposure to particulate matter.

4.4 Future study considerations

Questions remain regarding the nature and extent of the leaf use in these communities at the time of year the study was conducted and the level of impact this might have had on the use of the intervention stove and the wood fuel consumption. One way to resolve these questions would be to conduct a similar study outside the 2-month period when leaves are available as a cooking fuel.

It would also be valuable to add a truly aspirational stove to this study, even if it is not affordable or viable in the marketplace, in order to provide a solid reference point for a high level of adoption and usage.

5 References

Bailis, R. et al., 2007. Performance testing for monitoring improved biomass stove interventions: experiences of the Household Energy and Health project. Energy for Sustainable Development, 11(2), pp.57–70.

Smith, K.R. et al., 2007. Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: conclusions from the Household Energy and Health Project. Energy for Sustainable Development, 11(2), pp.5–18.

WHO, 2006. WHO guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide (Geneva: World Health Organization Press).

WHO, 2008. Evaluating household energy and health interventions: a catalogue of methods, World Health Organization. Available at: http://www.who.int/indoorair/publications/methods/en/index.html.

WHO, 2010. WHO guidelines for indoor air quality: selected pollutants (Bonn: World Health Organization Regional Office for Europe).

6 Appendices

Fuel Consumption Survey: Bangladesh

A. Background Information: Visit #1						
A1.Date (dd-mm-yy)				A2 Time (hh:mm) (24hr time)		
A3. Surveyor ID 1 2 3 4 5 6 7 8 9				A4. Household ID		
A5. Study Group	1.Traditional stove	2. EcoZoom Dura	3. Prakti	4. Eco Chula	5.Envirofit Z3000	6. Greenway Smart Stove
A6. IAP measurement household? 1. Yes 2. No				A7. Study location. 1. Barisal 2. Sylhet		
A8. Name of main cook				A9. Telephone number		
A10. Address						
A11. Primary stove type [*Note this is the stove the household was using most of the time before receiving the intervention stove*]: 1. Traditional wood burning chula 2.						
A12. Secondary stoves: [*Note this any other stove the household was using* ***at least once per week*** *before receiving the intervention stove- please circle as many as apply]* 3. Charcoal 4. LPG 5. Paraffin 6. Other_____________						
A13. Photos: House______ Kitchen______ Stove1______ Stove 2_____ Stove3______						
A14. How many people eat in this household normally per day?						
A15. # of children of age 14 or younger in home?				A16. # of females of age 15 and older in home?		
A17. # of men aged 15-59 years in home?				A18. # of men above 59 years in home?		

B. Seasonal patterns: Visit #1	
B1. Do you currently use more, less or the same amount of **wood** fuel per day as you do at other times of the year?	1= More [*answer B2*] 2= Less [*answer B3*] 3= Same [*Go to C1*]
B2. For what reasons do you currently use **more** wood fuel at this time of year?	1= To heat the room(s) 2= The wood is wet 3= Cook different types of food 4= Cook for more people 5= There is no/little agricultural residue 6=Other please describe:____
B3. For what reasons do you currently use **less** wood fuel at this time of year?	1= Do not need to heat room(s) 2= The wood is dry 3= Cook different types of food 4= Cook for less people 5= There are agricultural residues 6=Other please describe:____
C. Fuel measurements: Visit #1	

C1. New charcoal total (kg)		C2. New wood total (kg)	
C3. New LPG total (kg)		C4. New paraffin total (kg)	
C5. New crop residues (kg)		C6. New dung (kg)	
C7. New 'dung stick' (kg)			
C8. Wood moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
C9. Wood moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
C10. Wood moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3
C11. Crop moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
C12. Crop moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
C13 Crop moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3

D. SUMS Monitor: Visit #1		
D1. How many SUMS ibuttons in total are placed in this household?		
D2	Please fully describe the location of all of the **stove SUMS** monitors so they can be easily located on the next visit.	
	SUMS 1	
	SUMS 2	
	SUMS 3	
D3	Please fully describe the location of the **ambient air SUMS** monitor so it can be easily located on the next visit.	
D4.Notes/ observations from visit 1.		

Visit #2 **Household ID**____________ **Name of main cook**________________		
E1. Date (dd-mm-yy)	E2.Time (hh:mm)	E3.Surveyor ID: 1 2 3 4 5 6 7 8 9
E4. Unused charcoal total (kg)	E5. Unused wood total (kg)	
E6.Unused LPG total (kg)	E7. Unused paraffin total (kg)	
E8. Unused crop residues	E9. Unused dung	
E10. Unused 'dung stick' (kg)		
E11. New charcoal total (kg)	E12. New wood total (kg)	

E13.New LPG total (kg)		E14. New paraffin total (kg)	
E15. New crop residues		E16. New dung	
E17. New 'dung stick' (kg)			
E18. Wood moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
E19. Wood moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
E20. Wood moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3
E21. Crop moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
E22. Crop moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
E23. Crop moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3

E24-30. What have you used your stove for since the last visit? Please include all tasks such as heating, warming bath water, brewing drinks, re-heating food etc as well as all cooking events.
[*Check if they use only one stove for each activity-If they use more stoves please record all*]

Codes for events				Codes for stoves			
Breakfast	1	Heating water	6	Three wood chula	1	Paraffin	5
Lunch	2	Roasting [meat/maize]	7	Other traditional stove	2	Other_____________	6
Dinner	3	Space heating	8	Charcoal stove	3	Intervention stove	7
Tea/hot drinks	4	Other	9	LPG	4		
Re-heating food	5						

	E24	E25	E26	E27	E28	E29	E30
Event							
Stoves used							
# of people							

E31 Notes/observations (explain other types of stove use events here).	
E32 Was the amount of **wood** fuel you used since our last visit more, less or the same that you usually use in a day?	1= More 2= Less 3= Same [*Go to F1*]
E33 Please describe the reasons why you used more/less wood fuel than you usually do.	1= Had visitors 2= Prepared food for other days this week 3= Brewed beer 4= Roasted food 5= Celebration 6= Heated bathing water 7= Did not eat at home 8= Less people than usual to cook for 9= Other [*please describe*] ________________________________

F. SUMS Check and notes: Visit #2
F1. Referring to the notes in section D please check that all SUMS monitors are still insitu and securely fastened. Record any issues below and report to the field manager.
F2.Notes/ observations from visit 2.

Visit #3 Household ID____________ Name of main cook________________

G1. Date (dd-mm-yy)	G2.Time (hh:mm)	G3.Surveyor ID: 1 2 3 4 5 6 7 8 9

G4. Unused charcoal total (kg)	G5. Unused wood total (kg)
G6.Unused LPG total (kg)	G7. Unused paraffin total (kg)
G8. Unused crop residues	G9. Unused dung
G10. Unused 'dung stick' (kg)	
G11. New charcoal total (kg)	G12. New wood total (kg)
G13.New LPG total (kg)	G14. New paraffin total (kg)
G15. New crop residues	G16. New dung
G17. New 'dung stick' (kg)	

G18. Wood moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
G19. Wood moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
G20. Wood moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3
G21. Crop moisture sample 1	a) Reading 1	b) Reading 2	c) Reading 3
G22. Crop moisture sample 2	a) Reading 1	b) Reading 2	c) Reading 3
G23. Crop moisture sample 3	a) Reading 1	b) Reading 2	c) Reading 3

G24-30. What have you used your stove for since the last visit? Please include all tasks such as heating, warming bath water, brewing drinks, re-heating food etc as well as all cooking events.
[*Check if they use only one stove for each activity-If they use more stoves please record all*]

Codes for events				Codes for stoves			
Breakfast	1	Heating water	6	Three wood chula	1	Paraffin	5
Lunch	2	Roasting [meat/maize]	7	Other traditional stove	2	Other______________	6
Dinner	3	Space heating	8	Charcoal stove	3	Intervention stove	7

Tea/hot drinks	4	Other	9	LPG	4		
Re-heating food	5						
	G24	G25	G26	G27	G28	G29	G30
Event							
Stoves used							
# of people							

G31 Notes/observations (explain other types of stove use events here).	
G32 Was the amount of **wood** fuel you used since our last visit more, less or the same that you usually use in a day?	1= More 2= Less 3= Same [*Go to H1*]
G33 Please describe the reasons why you used more/less wood fuel than you usually do.	1= Had visitors 2= Prepared food for other days this week 3= Brewed beer 4= Roasted food 5= Celebration 6= Heated bathing water 7= Did not eat at home 8= Less people than usual to cook for 9= Other [*please describe*] ________________________________
H. SUMS Check and notes: Visit #3	
H1. Referring to the notes in section D please check that all SUMS monitors are still insitu and securely fastened. Record any issues below and report to the field manager.	
H2.Notes/ observations from visit 3.	

Visit #4 Household ID____________ Name of main cook________________

J1. Date (dd-mm-yy)	J2.Time (hh:mm)	J3.Surveyor ID: 1 2 3 4 5 6 7 8 9

J4. Unused charcoal total (kg)	J5. Unused wood total (kg)
J6.Unused LPG total (kg)	J7. Unused paraffin total (kg)
J8. Unused crop residues	J9. Unused dung
J10. Unused ‘dung stick’ (kg)	

J11-17. What have you used your stove for since the last visit? Please include all tasks such as heating, warming bath water, brewing drinks, re-heating food etc as well as all cooking events.
[*Check if they use only one stove for each activity-If they use more stoves please record all*]

Codes for events				Codes for stoves			
Breakfast	1	Heating water	6	Three wood chula	1	Paraffin	5
Lunch	2	Roasting [meat/maize]	7	Other traditional stove	2	Other_____________	6
Dinner	3	Space heating	8	Charcoal stove	3	Intervention stove	7
Tea/hot drinks	4	Other	9	LPG	4		
Re-heating food	5						

	J11	J12	J13	J14	J15	J16	J17
Event							
Stoves used							
# of people							

J18 Notes/observations (explain other types of stove use events here).	
J19 Was the amount of **wood** fuel you used since our last visit more, less or the same that you usually use in a day?	1= More 2= Less 3= Same [*Go to K1*]
J20 Please describe the reasons why you used more/less wood fuel than you usually do.	1= Had visitors 2= Prepared food for other days this week 3= Brewed beer 4= Roasted food 5= Celebration 6= Heated bathing water 7= Did not eat at home 8= Less people than usual to cook for 9= Other [*please describe*] ________________________________

K. SUMS Check and notes: Visit #4
K1. Referring to the notes in section D please check that all SUMS monitors are still insitu and securely fastened. Record any issues below and report to the field manager.
K2.Notes/ observations from visit 4.