Indoor Air Pollution Monitoring Summary

for

Gaia Association-Ethiopia's CleanCook Stove Tests

in the Bonga Refugee Camp
Gambella Regional State
Ethiopia

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and

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Purpose of Study

For the last two years Gaia Association (GA) has been collecting indoor air pollution (IAP) data under the guidance of University of California–Berkeley's Center for Entrepreneurship in International Health and Development (CEIHD). High levels of IAP contribute to a myriad of health issues. These high levels of IAP are prevalent in refugee camps throughout Ethiopia and in the homes of Addis Ababa, largely as a result of the burning of solid biomass fuels and kerosene for cooking.

Background of Gaia Association – IAP study in Addis Ababa, Ethiopia

The Gaia Association initiative (Project Gaia Research Studies) was created over four years ago with the purpose of promoting alcohol fuels for household and refugee use in Ethiopia. The association seeks to replace existing traditional fuels such as firewood, kerosene, charcoal, and dung, which have been shown to produce soot and other products of incomplete combustion that are harmful to human health. The vehicle for this change is the CleanCook stove, which is fueled in this study by ethanol.

For a three-month period Gaia collaborated with UNHCR (The United Nations High Commission for Refugees) and ARRA (Administration of Refugee and Returnee Affairs) in a pilot study to test the CleanCook stove at Bonga Refugee Camp in the Ethiopian Regional State of Gambella. Twenty stoves were tested during this time period. Each of the participants was given a two-burner CleanCook stove and 10 liters of ethanol for a 10-day period.

During the study Bonga Refugee Camp accommodated 17,000 refugees. Bonga presented the IAP team with a very unique cooking environment. Traditionally, the Sudanese refugees cook outside their homes. The traditional porridge (Genfo) that is prepared requires a very large pot and can only be cooked on a three stone fire. This contributes to low IAP in both the before and after studies. However, during the night they burn a three stone fire to keep snakes and mosquitoes from entering their homes.

The purpose of this pilot study was to test the impact of the CleanCook stove and to take IAP samples from the participating households. At the end of the three-month study, narratives were done to document the experience the participants had with the CleanCook stove and what type of impact it had on their lives.

Methods

The study was conducted in a total of 12 households in Bonga Camp. The format of the study consisted of monitoring indoor air quality in homes for 24 hours both before and after the introduction of the CleanCook stove. Monitoring equipment was positioned in kitchens in accordance with the standard placement protocols given by CEIHD.

The requirements were:

1. 100 cm from the edge of the stove (combustion zone)
2. 140 cm above the floor
3. 150 cm from any openable door or window, where possible

The devices were placed for a 24 hr period in accordance with the above noted requirements. After the devices were placed in the refugee camp households, sketches were made of the placement of the equipment and the kitchen and photographs were taken.

The CO concentrations in the room were measured with the HOBO CO logger (model # H11-001, Onset Computer Corporation, Bourne, MA, USA), which was set to record a concentration reading every minute. Fine particulate matter was measured by the University of California Berkeley Particle Monitor (UCB PM), which uses a photoelectric detector (Litton et al., 2004; Edwards et al., 2006; Chowdhury et al., 2007). The UCB PM measured the $PM_{2.5}$ concentration every minute (reported in units of milligrams per cubic meter of air, mg/m^3).

Six HOBO CO loggers were used in the study. These loggers were purchased by Gaia Association and calibrated at the Indoor Air Pollution Lab at the University of California-Berkeley using CO standard gas of 5 and 60 ppm. Before the start of the 'Before' and 'After' sampling, a CO-location calibration check was performed in the Gaia Association office kitchen to test whether or not the six HOBO loggers were working properly. The six HOBO loggers were tested against a seventh HOBO logger, which was called the "Gold Standard" (and was not otherwise used). This protocol was followed after each of the devices was used six times.

The UCB particle monitors were produced and calibrated in the IAP Lab at UC-Berkeley before they were used in Addis Ababa. The photoelectric chamber of each of the devices was cleaned with isopropyl alcohol after every five uses.

The above monitoring equipment was launched and downloaded on the premises of the camp. The data was then organized and analyzed at the Gaia Association office in Addis Ababa.

Pre and Post–Monitoring Questionnaires

A pre-monitoring questionnaire was used to measure the structure of the cooking areas. At the end of the 24 hr testing period, a post-monitoring questionnaire was administered to the 12 participating households. Also at this time, the monitoring equipment was taken down and end times recorded.

During the post-monitoring questionnaire, the main cook of each household was asked a series of questions to determine what the household conditions were like throughout the monitoring period. The questionnaire contained a total of 39 questions. These questions were designed to help interpret the IAP data collected during the 24 hr period. Questions such as what type of fuel was used and for how long the participating family cooked help explain why there may have been higher or lower levels of CO and PM recorded during the study.

Household Selection

The households were selected by our partner organization ZOA and the refugee committee of Bonga before our arrival to the camp. These two organizations created a list of 20 homes that would participate in this study. There were no confounding factors that would effect the selection of the homes. The reason for this is that each household is constructed in the same manner. The food that is cooked and condition of the homes are similar in nature.

Results

Indoor Air pollution Concentrations.

The following results are for the 24-hour concentration measurements of $PM_{2.5}$ and CO in Bonga Refugee Camp Kitchens. The 12 households selected for the study used a three stone traditional and a modified traditional wood stove as their primary stove (Table 1). In the After study (AS), the CleanCook stove was introduced (Table 2).

In addition to the mean, minimum, and maximum PM concentrations recorded during each monitoring period, the UCB PM software calculated the highest, second highest, and third highest 15-minute average PM concentration. Each of these three metrics is a consecutive 15-minute period, and none of the three periods overlap. All values are displayed in Tables 1 and 2.

Table 1. Results of the 24-hour kitchen concentration measurements of $PM_{2.5}$ and CO in 12 households using modified wood stoves and charcoal stoves (Before).

HH ID	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)	
	# of records	Mean	Min	Max	Highest 15-min Ave	2nd Highest 15-min Ave	3rd Highest 15-min Ave	HOBO Mean	HOBO Max
BG 001	1429	0.34	0.05	13.12	4.61	4.30	2.05	9.3	57.4
BG 002	1432	1.31	0.03	39.40	25.85	13.75	9.22	24.0	184.6
BG 003	1437	0.16	0.06	2.07	0.66	0.62	0.62	2.2	14.9
BG 004	1406	2.19	0.06	51.43	18.30	16.70	16.10	57.3	270.5
BG 005	1358	0.27	0.04	5.69	2.65	2.49	2.34	9.8	63.7
BG 006	1353	1.11	0.08	31.05	17.47	11.11	9.77	16.7	135.7
BG 007	1528	0.36	0.04	10.56	2.78	2.48	2.27	16.5	145.5
BG 008	1520	0.12	0.04	4.62	1.14	1.14	0.97	5.3	33.9
BG 009	1479	2.18	0.03	40.21	15.90	9.85	7.83	58.4	167.0
BG 010	1439	0.56	0.04	27.19	4.35	4.19	3.59	NA	NA
BG 011	NA	NA	NA	NA	NA	NA	NA	18.1	119.4
BG 012	1466	1.32	0.05	74.50	29.02	13.06	12.11	25.8	241.2

Table 2. Results of the 24-hour kitchen concentration measurements of $PM_{2.5}$ and CO in the same 12 households using the CleanCook stove (After).

HH ID	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)	
	# of records	Mean	Min	Max	Highest 15-min Ave	2nd Highest 15-min Ave	3rd Highest 15-min Ave	HOBO Mean	HOBO Max
BG 001	NA	NA	NA	NA	NA	NA	NA	6.4	51.0
BG 002	1255	0.07	0.03	9.51	2.58	0.10	0.08	3.2	15.9
BG 003	1304	0.22	0.03	7.64	2.65	2.01	1.85	4.8	45.7
BG 004	1283	0.09	0.03	5.25	1.61	1.05	0.88	5.9	25.6
BG 005	1221	0.08	0.07	0.91	0.28	0.21	0.15	2.1	13.4
BG 006	1231	0.09	0.05	16.59	0.40	0.25	0.16	1.2	9.0
BG 007	1421	0.10	0.05	3.16	0.82	0.79	0.67	7.8	36.4
BG 008	1401	0.05	0.04	0.79	0.18	0.15	0.14	3.8	8.5
BG 009	1442	0.20	0.03	11.85	3.24	2.73	1.45	12.1	98.9
BG 010	1441	0.24	0.06	4.05	2.26	2.20	1.64	12.4	64.2
BG 011	1390	0.10	0.05	6.79	1.59	0.70	0.27	2.2	47.1
BG 012	1391	0.40	0.06	25.96	6.35	6.13	4.75	11.6	182.6

Table 3 shows the means of the PM and CO data for the households in the Before and After monitoring, along with the standard deviations. The percent differences are also shown, comparing the Before and After averages (the Before values were used as the denominator). Finally, the p values resulting from T-tests for significance of the differences are also shown. Note that only the households with pairs of valid final data (both Before and After) were included in the analyses in Table 3. As can be seen in Tables 1 and 2, there were 10 such households for PM, as households BG 001 and 011 were excluded due to missing PM data. Similarly, there were 11 valid households for CO, with household BG 010 being excluded due to missing data (in the Before phase).

Table 3. Average Kitchen Concentration and Percent Changes

	Before, Average	**Before, Std Dev**	**After, Average**	**After, Std Dev**	**Percent change**	**T-test (p value)**
PM: Average (mg/m^3)	0.96	0.79	0.15	0.11	-84	0.010
PM: Minimum (mg/m^3)	0.05	0.02	0.05	0.02	-4.3	0.78
PM: Maximum (mg/m^3)	28.67	23.61	8.57	7.88	-70	0.007
PM: Highest 15-min average	11.81	10.77	2.04	1.88	-83	0.011
PM: 2^{nd} Highest 15-min average	7.54	5.98	1.56	1.87	-79	0.010
PM: 3^{rd} Highest 15-min average	6.48	5.29	1.18	1.42	-82	0.009
CO: Mean, HOBO (ppm)	22.1	19.1	5.6	3.7	-75	0.010
CO: Maximum, HOBO (ppm)	130.3	83.1	48.6	51.6	-63	0.006

The average of the set of 10 24-hour average kitchen $PM_{2.5}$ concentrations went down from 0.96 mg/m^3 in the Before (Charcoal stove) phase to 0.15 mg/m^3 in the After phase, when the households were using the CC stove. This is a significant, 84% reduction ($p = 0.010$). For comparison, a Wilcoxon Signed-Rank test of significance gave a p value of 0.0074 for the difference in the average $PM_{2.5}$ concentrations. The average minimum or baseline $PM_{2.5}$ concentrations were the same in both phases: 0.05 mg/m^3. The average maximum $PM_{2.5}$ concentration dropped by 70% in the After sampling, relative to the Before phase (also significant, $p = 0.007$). The highest, second highest, and third highest 15-minute average $PM_{2.5}$ concentrations were also significantly lower after the introduction of the CC stove, by 83%, 79%, and 82%, respectively.

Similarly, the average of the set of 11 24-hour kitchen CO concentrations measured by the HOBO CO logger dropped from 22.1 ppm in the Before phase to 5.6 ppm in the After phase, a statistically significant reduction of 75% (T-test p value of 0.010, Wilcoxon

Signed-Rank test p value of 0.0063). The average of the maximum CO concentrations was reduced from 130.3 ppm to 51.6 ppm (63%, p = 0.006).

Post-Monitoring Questionnaire Results

The important findings of the Post-Monitoring Questionnaire are described below. The survey was administered to the main cook at the end of the monitoring session. Ten of the 10 participants used a traditional three stone wood fire stove. All 10 households used the CC stove as their primary stove during the After sampling phase while 2 households used three-stone stove as their secondary stove. Lastly, the number of people cooked for in each household was essentially the same in the Before and After phases (overall averages of 5.5 Before and 5.5 After). This is shown in Table 4 below.

Table 4. The number of people cooked for on the days of IAP sampling in the Before and After studies.

HH ID	**Before, Number of people cooked for**	**After, Number of people cooked for**
BG 001	4	4
BG 002	7	7
BG 003	5	4
BG 004	6	6
BG 005	9	9
BG 006	5	5
BG 007	5	5
BG 008	3	5
BG 009	2	2
BG 010	10	10
BG 011	5	4
BG 012	5	5
Average	5.5	5.5

Discussion

Comparison of Kitchen Concentrations to International Standards

The World Health Organization (WHO) sets air pollution guidelines to offer guidance in reducing the health impact of air pollution (both indoor and outdoor) based on current scientific evidence. The WHO recently set new Air Quality Guidelines (AQG) for $PM_{2.5}$, ozone, nitrogen dioxide, and sulfur dioxide, along with interim targets that are intended as incremental steps in a progressive reduction of air pollution in more polluted areas (WHO, 2005). The guideline for carbon monoxide was set in 2000 (WHO, 2000).

The results of the IAP monitoring in the 10 households are compared to the World Health Organization's AQG and interim target-1 (WHO, 2005) in Table 5 below. Note that the CO concentrations reported above in parts per million (ppm) were converted to mg/m^3 to match the unit used by WHO (by multiplying the gram molecular weight of CO, 28, and dividing by the conversion factor of 24.45).

Table 5. Comparison of kitchen concentrations to WHO guidelines.

	Before (charcoal and kerosene stove)	After (CleanCook stove)	WHO interim target-1	WHO Air Quality Guideline
$PM_{2.5}$	960 ug/m^3	150 ug/m^3	75ug/m^3 (24-hr mean)[1]	25 ug/m^3 (24-hr ave)[1]
CO	25.3 mg/m^3	6.4 mg/m^3	NA	10 mg/m^3 (8-hr ave)[2]

[1] WHO, 2005.
[2] WHO, 2000.

The average PM concentration in the kitchens was reduced after the households began using the CC stove (from 960 to 150 ug/m^3), a very significant improvement in indoor air quality. Thus, the households moved much closer to the WHO interim target-1 of 75 ug/m^3 for $PM_{2.5}$ (and the Air Quality Guideline of 25 ug/m^3) in the After phase. The average CO kitchen concentration in the traditional stove case (Before) was 25.3 mg/m^3 and dropped to 6.4 mg/m^3 with the CC stove, below the WHO guideline of 10 mg/m^3.

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