INDOOR AIR POLLUTION MONITORING IN GHANA

Project Reference Number: 21341

Start Date: 15 February 2005
Finish Date: 31 December 2006

THIRD PROGRESS REPORT

Submitted to:

THE SHELL FOUNDATION

April 2006

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Purpose

Indoor air pollution monitoring activities were undertaken by EnterpriseWorks-Ghana, with training and support from the Center for Entrepreneurship in International Health and Development (CEIHD), for the purpose of documenting the impact of the Gyapa wood stove on indoor air quality in households in Accra, Ghana compared to traditional cooking stoves.

Methods

Indoor Air Pollution Sampling. Fine particulate matter and carbon monoxide (CO), the two most important and most studied pollutants associated with biomass combustion smoke, were measured in study households both before and after the introduction of the Gyapa wood stove (a "Before-After" study design, without controls). Valid PM and CO data (pairs of "Before" and "After" measurements) were collected for thirty six households. Baseline indoor air pollution (IAP) monitoring (the Before sampling) took place from April 1 through May 4, 2005. Thirty four of these households used a traditional clay wood stove (mokyia) for cooking, while the other two used a three-stone open wood fire. Monitoring after the introduction of the Gyapa wood stove was performed in the same households from September 19 through October 14, 2005.

The particulate and CO measurement devices were placed on the wall of the kitchen for 24 hours according to the following criteria:

1. Approximately 100 cm from the edge of the combustion zone (this distance away from the stove approximates the edge of the active cooking area)
2. At a height of 125 cm above the floor (this height relates to the approximate breathing height of a standing woman)
3. At least 150 cm away (horizontally) from doors and windows, where possible

All three devices were co-located (placed next to each other) and placed in a relatively safe location to minimize the risk of interrupting normal household activities or being disturbed or damaged. Detailed kitchen sketches were made during the initial visit of the Before sampling, so that the sampling location could be duplicated in the After monitoring phase.

Fine particulate matter was measured in each of the households using the University of California-Berkeley Particle Monitor (UCB PM) with a photoelectric detector. The UCB PM measured and logged the fine PM concentration every minute (in units of milligrams PM per cubic meter of air, mg/m^3). The monitor measures particles of aerodynamic diameter less than approximately 2.5 microns (called $PM_{2.5}$) (Litton et al., 2004; Edwards et al., 2006). The monitors were produced and calibrated in the Indoor Air Pollution Laboratory at the University of California-Berkeley (UC-Berkeley) prior to their use on the ground in Accra. The photoelectric chamber was cleaned with isopropyl alcohol after every five 24-hour uses.

Carbon monoxide was measured in each of the households with the HOBO CO logger (model #H11-001, Onset Computer Company, Bourne, MA, USA: http://onsetcomp.com/), which recorded the CO concentration every minute (in units of parts CO per million parts of air, ppm). The seven loggers used in this study were purchased new and calibrated at the Indoor Air Pollution Lab at UC-Berkeley using CO standard gas cylinders of 5 and 60 ppm. Also, in the middle of the sampling campaign, before the start of the After sampling, a co-location calibration check was run, where the six routinely used loggers were compared to the seventh ("gold standard") logger which was only used for such co-location calibration checks.

In addition, as a backup, CO was also measured by a CO diffusion tube (model #810-1DL, Gastec Corporation, Japan; http://www.gastec.co.jp/) in each of the 36 households. By design, these tubes yielded one average (or integrated) concentration of CO for the 24 hour monitoring period, also in recorded in ppm.

The protocols for the three measurement methods used in this study, along with the HOBO CO Calibration Check Protocol and the Sampling Data Forms, are included in the Appendix. Updated versions of the three protocols can be found at CEIHD's website: http://ceihd.berkeley.edu/heh.IAPprotocols.htm (Indoor Air Pollution Team, 2005).

Post-Monitoring Questionnaire. At the end of each 24-hour IAP sampling session, a Post-Monitoring Questionnaire was administered to the main cook of the household. The questionnaire contained 47 questions and was designed to document the cooking and other activities that may have affected the indoor air pollution levels in the kitchen during the monitoring period. The Post-Monitoring Questionnaire is included in the Appendix.

Household Selection. Neighborhoods of Accra heavily dependent on fuel wood for their household energy needs were targeted for this IAP study. A Screening Questionnaire was used by field staff upon their first visit to each household to ensure that the household was suitable for and amenable to the study. If the head of the household agreed to be involved in the study, the field staff administered a Consent Form at that time. The combined Screening Questionnaire/Consent Form is included in the Appendix.

Results

Indoor Air Pollution Concentrations. Tables 1 and 2 below shows the results of the 24-hour concentration measurements of $PM_{2.5}$ and CO in the kitchens of the 36 households while using a traditional wood stove (Before, Table 1) and after the introduction of the Gyapa wood stove (After, Table 2).

Table 1. Results of the 24-hour kitchen concentration measurements of $PM_{2.5}$ and CO in 36 households using traditional wood stoves (the Before sampling).

HH #	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)		
	N records	Mean	Min	Max	Highest 15-min Ave	2nd highest 15-min Ave	3rd highest 15-min Ave	HOBO Mean	HOBO Max	Tube Mean
001	1478	2.01	0.037	77.14	28.81	23.03	17.27	34.7	186.5	28.4
002	1447	1.60	0.039	61.33	22.28	16.65	8.35	45.6	303.7	> 32
003	1426	0.67	0.029	34.66	8.53	8.26	4.39	11.1	62.3	9.5
004	1440	0.64	0.130	27.05	6.60	6.19	6.18	9.5	69.1	5.9
005	1441	0.50	0.019	56.51	15.66	6.94	2.74	9.1	82.8	5.2
006	1452	0.08	0.024	7.18	0.86	0.80	0.54	4.2	56.4	2.2
007	1483	0.25	0.023	12.37	2.73	1.46	1.45	7.9	89.6	3.3
008	1477	0.91	0.020	63.63	20.97	8.07	7.86	13.0	84.7	4.2
009	1468	1.47	0.024	61.30	41.19	24.60	15.73	13.2	107.2	11.6
010	1681	0.51	0.024	72.60	18.58	10.62	5.98	11.7	208.0	4.1
011	1396	0.30	0.022	45.99	5.41	2.53	1.31	6.1	94.0	3.0
012	1462	0.21	0.029	13.51	3.38	2.36	1.80	2.9	26.6	1.9
013	1478	0.29	0.021	18.33	3.93	3.78	2.88	11.6	155.3	7.1
014	1501	0.55	0.023	49.88	14.10	7.93	7.39	8.4	151.4	5.7
015	1509	1.20	0.022	65.02	13.77	11.63	7.20	22.1	161.1	10.5
016	1512	1.30	0.026	76.04	34.19	24.34	23.67	32.9	432.6	> 31
017	1520	0.17	0.019	34.13	3.09	2.64	1.66	5.9	80.3	6.3
018	1509	0.44	0.022	18.89	5.77	4.11	2.88	20.0	170.9	17.8
019	1532	0.48	0.022	28.01	7.55	5.04	2.42	12.8	126.0	8.1
020	1445	0.22	0.020	14.51	3.35	3.26	2.19	4.4	57.4	2.9
021	1402	0.55	0.022	49.27	9.33	8.49	7.65	13.0	149.4	7.4
022	1517	0.16	0.022	17.32	2.96	1.48	1.20	5.7	58.3	3.2
023	1482	0.68	0.030	43.06	12.94	12.50	7.14	9.7	75.9	5.2
024	1524	0.16	0.022	25.10	4.14	3.29	1.26	5.1	99.4	2.1
025	1463	0.33	0.021	30.10	10.48	6.88	4.08	4.9	126.0	3.8
026	1467	0.72	0.023	33.06	10.90	7.54	5.60	9.4	114.5	3.8
027	1448	0.59	0.022	49.98	13.62	6.47	5.68	7.7	67.1	4.8
028	1459	0.93	0.023	45.17	10.21	10.19	8.04	10.8	62.7	8.5
029	1437	1.10	0.022	48.98	19.86	18.11	12.08	5.8	93.5	5.4
030	1450	0.40	0.021	36.19	12.25	3.51	3.35	4.8	49.6	2.5
031	1423	1.47	0.020	73.91	32.17	20.88	17.76	26.2	317.4	12.8
032	1544	1.37	0.050	72.18	16.87	7.02	5.06	28.1	147.5	18.4
033	1566	0.27	0.024	56.26	15.79	1.63	1.35	4.1	114.0	2.4
034	1427	0.34	0.021	45.69	9.02	8.17	4.55	4.7	58.3	3.0
035	1481	0.19	0.023	20.21	2.53	2.19	1.70	7.7	196.3	6.4
036	1484	0.46	0.024	28.61	5.23	3.91	3.87	8.4	56.4	4.2

Table 2. Results of the 24-hour kitchen concentration measurements of $PM_{2.5}$ and CO in the 36 households using the Gyapa wood stove (the After sampling).

	$PM_{2.5}$ Concentration (mg/m^3)							CO (ppm)		
HH #	N records	Mean	Min	Max	Highest 15-min Ave	2nd highest 15-min Ave	3rd highest 15-min Ave	HOBO Mean	HOBO Max	Tube Mean
001	1532	0.37	0.033	28.89	6.23	3.89	3.37	9.5	69.1	6.8
002	1503	0.23	0.037	18.80	5.32	5.30	3.51	3.4	33.4	2.8
003	1477	0.31	0.077	46.62	12.86	1.36	1.19	6.8	225.6	3.7
004	1440	0.10	0.024	5.62	1.74	1.00	0.64	1.8	44.7	1.3
005	1491	0.19	0.021	40.01	8.51	5.34	0.94	3.1	33.4	1.8
006	1485	0.11	0.025	24.91	4.67	1.22	0.33	1.2	57.4	0.9
007	1480	0.73	0.025	39.81	8.40	6.86	5.91	19.9	210	6.4
008	1528	0.38	0.027	45.54	10.34	5.78	4.94	7.7	116.9	5.6
009	1508	0.18	0.024	28.03	4.77	3.38	2.57	2.7	59.3	1.8
010	1485	0.24	0.024	34.72	4.18	3.67	2.18	14.3	497.1	7.7
011	1468	0.33	0.022	38.77	7.00	4.89	3.28	7.1	57.4	9.5
012	1445	0.50	0.025	48.92	11.47	9.25	5.32	7.2	69.1	4.5
013	1461	0.28	0.021	17.89	3.63	2.99	1.99	18.8	210	10.8
014	1468	0.52	0.026	74.15	12.21	10.88	7.72	6.9	167	3.8
015	1446	0.25	0.021	28.94	4.62	3.55	1.56	3.2	68.1	1.9
016	1524	0.07	0.023	30.37	4.21	0.11	0.11	1.2	32.5	1.8
017	1446	0.31	0.025	10.16	3.72	3.33	3.27	19.6	231.4	24.3
018	1476	0.17	0.021	13.21	2.88	2.16	1.52	5.1	67.1	2.9
019	1448	0.34	0.027	36.89	8.55	4.37	3.46	6.3	68.1	4.8
020	1441	0.30	0.050	36.74	8.70	3.49	2.90	3.2	48.6	2.6
021	1435	0.17	0.025	41.16	8.85	2.79	1.02	3.4	35.9	2.2
022	1522	0.19	0.027	19.55	3.71	2.75	1.03	7.1	104.2	3.6
023	1405	0.24	0.024	13.82	2.99	2.17	1.78	7.4	63.7	5.5
024	1516	0.54	0.026	72.91	13.42	12.16	5.65	14.6	497.1	6.3
025	1518	0.71	0.043	58.68	18.71	9.89	7.46	9.3	69.1	5.7
026	1521	0.08	0.029	5.96	2.48	0.65	0.50	3.5	63.7	1.8
027	1445	0.38	0.020	51.11	14.40	6.09	2.29	6.0	155.3	3.8
028	1412	0.18	0.026	20.64	4.88	2.45	1.81	2.5	31	1.4
029	1488	0.13	0.036	11.29	3.19	1.40	1.16	1.1	11.5	0.9
030	898	0.07	0.025	5.96	2.54	0.35	0.15	1.0	28.3	0.4
031	1463	1.29	0.026	57.77	20.33	18.00	12.14	26.0	411.1	20.5
032	1590	0.23	0.041	26.67	5.69	3.83	2.83	12.1	256.8	6.0
033	1587	0.13	0.025	12.04	3.25	1.45	1.11	3.6	45.7	2.3
034	1439	0.24	0.021	17.49	4.12	3.51	2.98	6.5	88.1	4.3
035	1438	0.19	0.023	13.37	2.64	1.98	1.18	4.2	53.5	3.0
036	1445	0.70	0.023	50.43	14.66	11.25	6.47	8.8	62.7	6.4

The UCB PM software calculated the highest, second highest, and third highest 15-minute average PM concentration during each monitoring period, displayed in Tables 1 and 2. Each of these metrics is a consecutive 15-minute period, and none of the three 15-minute periods overlap.

Table 3 shows the means of the PM and HOBO CO data for the 36 households in the Before and After monitoring, along with the standard deviations. The percent differences are also shown, comparing the After averages to the Before averages (the Before values were used as the denominator). The Student's T-Test was used (paired, 2-tailed) to determine whether or not the means of those PM and CO concentration statistics were statistically significantly different in the Before versus After phases. The results (p-values) of these tests of significance are also shown in Table 3. A p-value is the probability (chance) of claiming that there is a significant difference between the means when there truly is no difference. Based on standard practice, a p-value of 0.05 (5%) or less indicates that the two means are significantly different.

Table 3. Average Kitchen Concentrations, Percent Changes, and T-Tests for Significance

	Before, Average	Before, Std Dev	After, Average	After, Std Dev	Percent Change	T-Test (p-value)
PM: Average (mg/m^3)	0.65	0.49	0.32	0.24	-52%	0.0006
PM: Minimum (mg/m^3)	0.027	0.019	0.028	0.011	+3.3%	0.80
PM Maximum (mg/m^3)	42.0	20.5	31.3	18.4	-26%	0.021
PM: Highest 15-min ave	12.5	9.75	7.22	4.79	-42%	0.0053
PM: 2nd Highest 15-min ave	8.24	6.74	4.54	3.89	-45%	0.0065
PM: 3rd Highest 15-min ave	5.95	5.35	2.95	2.58	-50%	0.0031
CO: Mean, HOBO (ppm)	12.3	9.9	7.4	6.1	-40%	0.013
CO: Maximum, HOBO (ppm)	124.8	84.6	120.7	125.1	-3.3%	0.86
CO: Mean, Tubes (ppm)	6.8	5.6	5.0	5.0	-27%	0.18

The average of the set of 36 24-hour average kitchen $PM_{2.5}$ concentrations went down from 0.65 mg/m^3 in the Before (or traditional wood stove) phase to 0.32 ug/m^3 in the After phase, while the households were using the Gyapa wood stove. This 52% reduction in $PM_{2.5}$ levels was a statistically significant (the p-value of the T-Test was 0.0006). There was no difference in the average minimum $PM_{2.5}$ concentrations, because background conditions were similar enough in the Before and After periods, as expected (p=0.80). The average maximum $PM_{2.5}$ concentrations dropped by 26% (significant, p=0.02) in the After sampling, relative to the Before phase. The highest, second highest, and third highest 15-minute average $PM_{2.5}$ concentrations were also significantly lower after introduction of the Gyapa wood stove, by 42%, 45%, and 50%, respectively.

Similarly, the average 24-hour kitchen CO concentrations measured by the primary method, the HOBO CO logger, dropped from 12.3 ppm in the Before phase to 7.4 ppm in the After phase, a statistically significant reduction of 40% (p=0.01). The average of the maximum CO concentrations was not significantly different (124.8 versus 120.7 ppm). The secondary and less accurate CO monitoring method, the CO dosimeter tubes, showed that the average CO concentrations were 27% lower in the After phase, though this result was not statistically significant (p=0.18).

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 monitoring session. Thirty four of the 36 households used a traditional mokyia (clay) wood stove for cooking during the Before sampling phase, while two households used a traditional three-stone wood fire. All 36 households used the Gyapa wood stove during the After sampling phase. The amount of money the households reported spending on fuel wood for cooking dropped from 2500 cedis to 1700 cedis, a significant, 32% reduction (p=0.02). There was no significant difference in the average reported number of people cooked for, although it was lower (8.3 Before versus 7.5 After, p=0.54). Similarly, there was no difference in the reported number of hours the stove was lit for cooking (4.4 versus 4.1 hours, p=0.47). The average reported number of hours of kerosene use in lamps decreased from 1.1 hours to 0.5 hours, which was just significant (p=0.046). The number of households reporting rain or light rain at some point during the 24-hour sampling period increased from 3 to 8. These reported differences in kerosene lamp usage time and rain are not large enough to account for much, if any, of the differences in the kitchen IAP concentrations. Finally, there were no reported cigarettes smoked and no incense or mosquito coils burned in any of the kitchens; nor was any relevant garbage burning or any other nearby air pollution source reported during both phases of monitoring.

Discussion

Comparison of the kitchen concentrations to international standards. The World Health Organization (WHO) sets air pollution guidelines to offer guidance in reducing health impacts of air pollution (both indoor and outdoor) based on current scientific evidence. The WHO recently set new Air Quality Guidelines (AQG) for PM2.5, ozone, nitrogen dioxide, and sulfur dioxide, along with interim targets which 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 36 households are compared to the World Health Organization's AQG and interim target-1 (WHO, 2005) in Table 4 below. Note that the CO concentrations reported above in parts per million (ppm) were converted to mg/m^3 to match the units used by WHO (by multiplying by the gram molecular weight of CO, 28, and dividing by the conversion factor of 24.45).

Table 4. Comparison of kitchen concentrations to WHO guidelines.

	Before [traditional stove] (24-hr ave)	**After [Gyapa wood stove] (24-hr ave)**	**WHO interim target-1**	**WHO Air Quality Guideline**
$PM_{2.5}$	650 ug/m^3	320 ug/m^3	75 ug/m^3 (24-hr mean)[1]	25 ug/m^3 (24-hr ave)[1]
CO	14.1 mg/m^3	8.5 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 greatly reduced after the households began using the Gyapa wood stove (from 650 to 320 ug/m^3), a very significant improvement in indoor air quality. 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 was 14.1 ug/m^3, above the WHO Air Quality Guideline of 10 mg/m^3, but dropped below the guideline to 8.5 mg/m^3 in the Gyapa stove case, another significant improvement.

Extrapolation of the kitchen concentrations: health implications. The science of quantifying the human health effects of exposure to air pollution is extremely complex, but has advanced much over the past several decades. The best data for doing so come from large epidemiological studies of outdoor air pollution and health conducted over the past two decades spanning five continents. Such studies typically measure the effects of air pollution in terms of PM and have provided evidence of associations between PM and the following adverse health outcomes: mortality, hospital admissions for cardiovascular and respiratory disease, urgent care visits, asthma attacks, acute bronchitis, respiratory symptoms, and restrictions in activity (Ostro, 2004).

Bart Ostro's 2004 World Health Organization publication also provided relative risk functions for four health outcomes. Table 5 below is reproduced from that report (Ostro, 2004) and shows the four outcomes and the associated exposure metric ($PM_{2.5}$ or PM_{10}), the functions (equations) themselves including the suggested coefficient and the 95% confidence interval for that coefficient, and the subgroup to whom the outcome applies. The relative risk function allows one to quantify the risk of the outcome when people are exposed at one ambient (outdoor) PM concentration to the risk when they are exposed at another ambient PM concentration. This ratio of risks posed at the two different PM scenarios is called relative risk.

Table 5. Health outcomes and risk functions for air pollution exposure (reproduced from Ostro, 2004)

Outcome and exposure metric	**Source**	**Relative risk function**	**Suggested β coefficient (95% CI)**	**Subgroup**
All-cause mortality and short term exposure to PM_{10}	Meta-analysis and expert judgment	RR = exp[β (X-Xo)]	0.0008 (0.0006, 0.0010)	All ages
Respiratory mortality and short term exposure to PM_{10}	Meta-analysis	RR = exp[β (X-Xo)]	0.00166 (0.00034, 0.0030)	Age <5 years
Cardiopulmonary mortality and long-tern exposure to $PM_{2.5}$	Pope et al. (2002); R Burnett[a]	$RR = [(X+1)/(Xo+1)]^{\beta}$	0.015515 (0.0562, 0.2541)	Age >30 years
Lung cancer and long-term exposure to $PM_{2.5}$	Pope et al. (2002); R Burnett[a]	$RR = [(X+1)/(Xo+1)]^{\beta}$	0.23218 (0.08563, 0.37873)	Age >30 years

[a] Personal communication to the author of the original table (Ostro, 2004)

Though standard practice is to use these four relative risk functions for burden of disease calculations for populations exposed to outdoor air pollution, they can be applied, with much uncertainty, to individuals exposed to differing amounts of PM from either outdoor or indoor air. Here, the four relative risk functions were used to estimate the changes in health risk that result from the changes in kitchen $PM_{2.5}$ concentrations due to the introduction of the Gyapa wood stove. There were three major problems and sources of error in attempting this quantification of health risks.

The first is the problem of estimating the $PM_{2.5}$ exposure concentration of the household members, given only the kitchen concentrations. Personal monitoring was not performed in this study, no time-activity information was collected, nor did the household members spend their entire days in the kitchen where the monitoring occurred.

The second major problem is that the household members in this study were exposed, while in the kitchen, to air pollution ($PM_{2.5}$) concentrations that exceeded the outdoor concentrations involved in the epidemiological studies upon which the relative risk functions are based. The shape of the concentration-response functions are not known at the high exposure concentrations involved in this study. Also, whether there is a threshold concentration, a concentration above which the risk no longer increases, for any of these health outcomes is still unknown.

The third and least troublesome problem in attempting to quantify the health risks associated with the changes in IAP seen in this study of the Gyapa stove is that the first two risk functions are based on PM_{10} concentrations, not $PM_{2.5}$ (PM_{10} stands for particles of aerodynamic diameter less than 10 microns). Fresh wood burning emissions are almost entirely made up of particles less than 1.0 micron (Smith, 1987). Hence, this problem was addressed by assuming the PM_{10} concentration in the kitchens to equal the $PM_{2.5}$ measurements made. This is a conservative assumption in that the PM_{10} concentration can only be greater that of $PM_{2.5}$.

To attempt to work around the first problem, data was pulled from studies that measured both kitchen and exposure concentrations for household members. A recent IAP monitoring study in Mexico that included kitchen concentration measurement methods similar to those used here (i.e. the same instruments and same placement criteria were used), but also measured the 24-hour personal PM exposure concentration, found that the ratio of the personal $PM_{2.5}$ exposure concentration of the main cook of the household to kitchen $PM_{2.5}$ concentration (the cook/kitchen ratio) to be 0.21 to 0.26 (Johnson et al., 2005). Bruce et al., 2004 showed child/kitchen concentration ratios ranging from 0.42 to 0.79 in rural Guatemala, which seemed to increase with increasing level (quality) of the kitchens. That same trend was seen in a CEIHD study in Nicaragua (CEIHD, 2003) which found cook/kitchen concentration ratios of 0.56 and 0.73 for two groups using open fires and 0.79 and 0.92 for the same two groups when they upgraded to an improved stove with a chimney (the EcoStove). These three studies show the obvious, that the range in the ratio of personal exposure to kitchen concentrations is very large and dependent on the individual situation. Hence, attempting to assign such a ratio to a new situation, such as that in Accra, is not particularly accurate and introduces much uncertainty. Nonetheless, a personal/kitchen concentration ratio of 0.50 was used here as the "best" estimate. A "high" personal exposure case of 0.8 and a "low" exposure case of 0.25 were also considered.

Multiplying the "Before" (traditional) kitchen $PM_{2.5}$ concentration average of 650 ug/m^3 by the best estimate of 0.50 for the personal/kitchen concentration ratio yielded a personal exposure concentration estimate of 320 ug/m^3. Similarly, the "After" (Gyapa) kitchen $PM_{2.5}$ average of 320 ug/m^3 led to an estimate of personal exposure concentration of 160 ug/m^3. These two exposure concentrations were plugged into the risk functions in Table 4 to estimate the relative risks of going from the lower concentration scenario (Gyapa stove) to the higher concentration scenario (traditional). The same was done for the low personal exposure case (personal/kitchen = 0.25) and the high personal exposure case (=0.80). The resulting relative risk estimations are shown in the three columns on the left side of the table.

The right three columns of Table 4 show the estimated percent decrease in risk of each of the selected outcomes due to using the Gyapa wood stove versus using the traditional wood stove. The risk decrease fraction is equal to 1 – (1/RR). According to Table 4, the best estimate relative risk of all-cause mortality was 1.14 for the traditional (Before) versus the Gyapa wood (After) exposure cases of this study, which translated to an estimated 13% decrease in risk when going from the traditional to the Gyapa wood stove. Use of the Gyapa wood stove also had an estimated protective effect of a 13% reduced risk of respiratory mortality in children age <5 years (best estimate), a 11% lower risk of cardiopulmonary mortality in adults >30 years (for all three exposure cases), and a 15% reduced risk of lung cancer (all three cases) compared to use of the traditional wood stove. Note that the estimated relative risks differ only slightly between the three exposure categories for cardiopulmonary mortality and lung cancer, because those two risk functions are much less sensitive to differences in exposure concentrations.

Table 6. Estimated relative risks (Gyapa wood stove vs. traditional stove) and percent decrease in risks for using the Gyapa wood stove (showing best estimate, low, and high exposure categories)

Outcome	Relative Risk (RR) (traditional vs. Gyapa wood stove)			Percent decrease in risk (Gyapa wood stove vs. traditional stove)		
	low	**best**	**high**	**low**	**best**	**high**
All-cause mortality	1.07	1.14	1.24	7%	13%	19%
Respiratory mortality	1.15	1.32	1.57	13%	24%	36%
Cardiopulmonary mortality	1.12	1.12	1.12	11%	11%	11%
Lung cancer	1.18	1.18	1.18	15%	15%	15%

The estimations shown in Table 4 must be considered preliminary and extremely uncertain as they are based on many assumptions. Personal exposure measurements would improve these estimations. Further, data from on-going studies of indoor air pollution and health around the world should help reveal the exposure-response relationships necessary to more accurately make these estimations of relative risks and percent risk reductions.

Conclusions

The use of the Gyapa wood stove in place of traditional wood stoves in 36 households in Accra resulted in significant reductions in kitchen indoor air pollution concentrations. Twenty-four-hour $PM_{2.5}$ levels inside the kitchens were reduced by 52% (from 650 to 320 ug/m^3) while CO levels dropped by 40%. $PM_{2.5}$ levels were still higher than the WHO Air Quality Guideline (25 ug/m^3, 24-hr mean) and interim target-1 (75 ug/m^3, 24-hr mean), as expected for all unvented solid fuel stoves. When households used the traditional wood stove, the average 24-hour CO concentration in the kitchen was 14.1 mg/m^3, above the WHO guideline of 10 mg/m^3. The average CO concentration in those same kitchens dropped to 8.5 mg/m^3 after the households had switched to the use of the Gyapa wood stove. These results were obtained using well documented and accepted methodologies, and EnterpriseWorks can feel comfortable that publicizing them would not likely elicit significant challenge from the scientific community.

The health implications of these improvements in indoor air quality are difficult to quantify, as this study did not collect any information on the participants' personal exposure or health status. Furthermore, the tools to make such quantifications are not yet robust in the literature. Some preliminary methods to estimate the health benefits of the reduction in kitchen $PM_{2.5}$ concentrations were applied here. These methods, while subject to many assumptions and limitations, led to the following best estimates for the use of the Gyapa wood stove versus the use of the traditional stove: a 13% decrease in the risk of all-cause mortality, a 24% decrease in the risk of respiratory mortality in children under 5, an 11% lower risk of cardiopulmonary mortality in adults >30 years, and a 15% reduced risk of lung cancer. Although the methodology used to obtain these results relied partly on methods that have been published and promoted by the WHO, it is highly experimental and based on several assumptions that are still widely debated in the scientific community. Therefore, EnterpriseWorks should be prepared to respond to challenges from scientists and health policy makers when making these results public. In CEIHD's view, these results are still valuable, as long as they are presented together with the assumption upon which they are based, as a preliminary indication that remains to be proven through further research.

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Acknowledgements

The author would like to thank Jessica Higashiyama for processing much of the IAP data.

Appendix

Standard Operating Procedure:

UCB Particle Monitor

Collection, downloading, and storage of data from the UCB Particle Monitor

Protocol Contents

1. Statement of Purpose

This protocol describes launching, collecting, downloading and saving UCB particle monitor data, including zeroing in Ziploc bags immediately prior and after deployment in study houses.

1.1 Equipment requirements

- UCB particle monitor installed with UCB firmware version 5.3
- 1 cable with DB9 plugs for connection to COM port
- UCB particle monitor software installed on computer version 1.5
- CD-ROMs or disks to archive data
- Supply of 9 volt batteries

1.2 System requirements for Desktop

- Pentium 90 or higher with 24 MB of RAM running windows 2000 or later (minimum 486/66 MHz processor with at least 16 MB of RAM is required)
- At least 1 free COM port using 9-pin connector for serial communications (or adapter for 25 pin)
- Preferably a CD-ROM drive with write ability or some other means of backing up the data (for example, memory stick or floppy disk drive)

1.3 It is **essential that the clock on the UCB particle monitor is synchronized to the clock** on the computer so that the UCB monitor reflects real time. We use the atomic clock to set the time of the computer. This is checked at the start of every week.

Prior to going to the field, all wristwatches much be synchronized to the time on the computer used to launch the UCBs. This is done so that field calibration times and cooking events can be related to the UCB data.

2. Launching UCB Particle Monitor

Important Notes:

- Sampling intervals and sampling setup must be programmed prior to taking to the field.
- **Close other applications/tasks that require the COM port. For example, make sure hyperterminal is closed. These may be other monitoring devices that use the same communications port.**

2.1 Connect serial cable to COM port. Make sure the cable is installed properly.

2.2 Open UCB particle monitor device manager. A debugging screen and then a wizard interface should open.

2.3 Connect serial cable to UCB particle monitor.

2.4 Make sure the UCB particle monitor contains a 9-volt battery.

2.5 Click on "***show log***" and then select ***next***. (If there is a problem, first check the battery. If it is not above 7.5 volts in cold areas and 7.0 volts in temperate areas, replace the battery. If the battery is okay, close monitor manager and try again. If this doesn't work, reboot the computer and try again. If this doesn't work, launch the UCB using the PPPSD command in hyperterminal – refer to the hyperterminal instruction sheet. Additional troubleshooting tips are in Section 11. The green LED (blinking light) becomes red when UCB battery voltage is equal to or less than 7.5 volts.

2.6 Check 9 V battery status using the voltmeter (don't rely on the monitor manager software). For a 24-hour monitoring period ensure that the battery contains 7.5 volts minimum in cold areas and 7.0 volts in temperate areas. If you notice a problem with poor data collection using the voltage cut-off of 7.0, increase the voltage minimum to 7.5 volts according to field conditions.

2.7 Check that the firmware version number in the lower left panel shows "57d" (5.7d).

2.8 Check that the UCB ID appears in the lower left panel.

2.9 Check that humidity and temperature sensor readings display reasonable values (are not above 100). Also check sensors are updating (the values should vary slightly).

2.10 Select ***configure this device*. It's okay to delete data on the device but make sure you've downloaded the monitoring sample. You can confirm this by checking the UCB download data sheets.**

2.11 Select next

2.12 A configuration screen should then open.

2.13 Synchronize the UCB particle monitor clock with the computer clock by selecting ***synchronize***, select ok when complete – **THIS IS VERY IMPORTANT**. Make sure your watch is synchronized to the computer.

2.14 Select the date and time that the UCB monitor is to start. Set a time in the near future at a convenient interval with 00 seconds e.g. 12:15:00. Type the number of hours that you wish the logger to record data for in the next window. For a 48 hour monitoring period select 50 hours to allow for delays and transportation to and from the field.

2.15 Set ***logging*** **interval** to 1 minute (one value will be recorded every minute).

2.16 Set ***sample*** **interval** to 1 second.

2.17 Select filter depth to 2 (For your reference, filters address the amount of noise in a signal; a value of zero (0) means no filter, the maximum is a value of 4).

2.18 Select 'Launch Program.' In the launch confirm dialog box, check that the settings are correct.

2.19 Record launch information on UCB sampling data form.

3. Zeroing with Ziploc bag (PRE- & POST-CALIBRATION PERIODS (1 HOUR)

3.1 Locate a relatively clean environment for the calibration periods (for example, your guesthouse or hotel). If these locations are not available, conduct the calibration period in the study households.

3.2 Place launched UCB particle monitor in 1 liter Ziploc bag. Make sure the bag does not have holes. If it does, repair with some tape. Close Ziploc bag ensuring air remains in the bag. Place the bagged monitor in a location where it will not be moved or disturbed in any way.

3.3 Record time on sampling data form.

3.4 After a period of at least 60 minutes remove the UCB from the Ziploc bag and note time on UCB sampling data form; this will complete the pre-calibration period.

3.5 After sampling in the study household, place the UCB again in the Ziploc bag for at least one hour. While in the bag, the UCB should not be moved or disturbed in any way. It is best if the temperature of step 3.2 and 3.4 are as similar as possible. This will complete the post-calibration period.

3.6 It is essential to record the times so these can be used in data processing.

4. Installation of the UCB in field location

4.1 Approximately 100 cm from outside perimeter of stove.

4.2 Height approximately 125 cm above the floor.

4.3 At least 150 cm from doors and windows where possible.

4.4 If support plate has been placed on wall, place in support plate.

4.5 If the kitchen area is outdoors, attach the UCB to the stand provided.

5. Data Download

5.1 Connect serial cable to computer.

5.2 **Close other applications/tasks that require the COM port (for example, make sure hyperterminal is closed). These may be other monitoring devices that use the same communications port.**

5.3 Open UCB particle monitor device manager. A debugging screen and then a wizard interface should open.

5.4 Connect serial cable to UCB particle monitor

5.5 Select ***next***

5.6 Select ***offload data from this device***

5.7 A progress window will appear showing the progress of the download.

5.8 A graphical display of the data will appear in the window. Ensure that the box for leaving data on the device is selected. Select ***save as*** button. Select data directory for ***UCB new data*** and select ***save.***

NOTE: if an overflow error appears once the download is complete, select ***continue*** and a graphic with a red cross will appear. This will not affect your data. Select ***save as*** button. Select data directory for ***UCB new data*** and select ***save***.

5.9 Select ***next***. A confirmation window will appear confirming the data has been saved, the filename it has been saved under, and the settings for the measurement period. The data can be viewed by selecting ***open in data browser***. If this screen does not appear, repeat download

5.10 **Check that**:

- the sample period of measurement is okay (things that might be wrong include sample period finishing early, etc.);
- the data does not 'flat-line' across the graph;
- each of the sensors does not report unreasonably high or low values;
- the data does not appear abnormal in other ways.

If these things happen, select one of the back-up devices for the next sampling periods (make sure the problem is not a low voltage battery (lower than 7.5 volts or a circuit board that is not properly snapped into the UCB). Inform your field contact of the problematic device.

5.11 Check box on UCB sampling data sheet labeled ***check graph.***

6. Data File Processing

6.1 Open .ucbpm file (UCB particle monitor data file) in UCB data browser.

6.2 The UCB device manager will display a graph of the data downloaded.

6.3 Input the time for the calibration period prior to sampling in the box at the top. This value is obtained from the UCB sampling data sheet.

6.4 Enter the time period for the sampling period (does not include transportation or calibration periods). This value is also obtained form the UCB sampling data sheet.

7. Export Data as a Text File

7.1 Select ***file*** and ***export to CSV***. This will save the data file as a text file readable by other statistical programs (CSV = comma separated variables).

8. Save Statistics as a Text File

8.1 The UCB data browser will display statistics for the sampling period on the right hand side of the display. Selection of "save stats" will save these into a text file. When different sampling times (e.g. successive 24 hour periods) are selected the save stats button can be used to save the statistics for each time period selected.

9. Backup of Data files

9.1 At the end of each week measurement period the new data files should be saved. Each monitor will produce three files, the ucbpm file (approximately 26 Kb) and its corresponding comma separated variable file (approximately 40 Kb) and stats files. Back up the file on a labeled floppy disk or CD. Information on the label must include: 1) date, 2) HH ID numbers, 3) your initials. Additionally, if you have email access, you may want to email your files to a designated person as another method of backup.

9.2 Once new data files have been backed-up, the data files on the computer should be moved to the ***UCB backed-up data*** directory on the computer.

10. Cleaning the UCB Photoelectric Chamber

10.1 To ensure the photoelectric chamber (PE) remains clean and that mass calculations are as accurate as possible, the PE chamber must be cleaned every other week.

10.2 Gently remove the UCB lid and take out the circuit board from the base unit.

10.3 Remove the PE chamber lid, being careful not to lose/tear the net covering. If the net covering tears, make a note of it on the sample data form.

10.4 Swap out the interior of the PE chamber with cotton Q-tips and rubbing alcohol. If no Q-tips are available, use a small amount of tissue. Be careful not to leave any threads/etc in the chamber. Note any debris you find on the data sheet. Reseal the chamber.

10.5 Firmly snap the circuit board back into the UCB; this step is very important.

10.6 Replace the UCB cover.

11. Troubleshooting

11.1 The LED (blinking light) indicates:

- When detached from Monitor Manager:
    - Blinking green 1 per second: taking data, battery okay
    - Blinking red 1 per second: taking data, battery low (less than 7.5 volts)
    - Not blinking, either:
        - UCB is not within the time window for logging (before or after)
        - UCB battery is dead (less than 5 volts)

- When attached to and activated by Monitor Manager:
    - Green: battery voltage is greater than 7.5 volts
    - Red: battery voltage is equal to or less than 7.5 volts

The LED does not indicate other information, such as date/time device errors, signal out of range, etc.

11.2 Steps 11.2 to 11.5 describe what do to if you receive error messages when connecting the UCB to the Monitor Manager software. If you get a message "device error," the first step is to check the battery voltage. If the voltage is less then 7.5 volts (cold climate) or 7.0 climate (temperate climate), change the battery.

11.3 If the problem persists, close out of the monitor manager software, open the software and try again.

11.4 If the problem persists, close out of the monitor manager software, **reboot the computer** and try again.

11.5 If the problem continues, switch to using hyperterminal to download and launch the UCBs (see separate instruction document for using hyperterminal).

Standard Operating Procedure:

HOBO Carbon Monoxide Data Logger

Collection, Downloading, and Storage of Data

Protocol Contents

1.0 Statement of Purpose

This protocol describes procedures for launching, collecting, downloading, saving, and backing up data for the HOBO carbon monoxide (CO) data logging monitor.

1.1 Equipment requirements

- HOBO CO monitor
- 1 x CABLE-PC-3.5 (Logger to PC COM port cable)
- CD-ROM disks

1.2 System requirements for computer:

- Boxcar Pro software manufacturer recommends Pentium 90 or higher and 24 MB of RAM
- Windows 95/98/NT4 or later (minimum 486/66Mhz processor with at least 16 MB of RAM is required).
- The system requires at least 1 free COM port using a 9-pin connector for serial communications (or adapter for 25 pin)
- CD-ROM drive with write ability
- Install ***all*** software on desktop

2.0 Preparation of HOBO CO logger prior to placement in the field location

(the logger must be launched from a computer prior to placement in the field):

2.1 Connect the serial cable to the COM 1 serial port of the computer

2.2 Open ***Boxcar Pro*** software (double click on the icon on the desktop)

2.3 Connect the other end of the serial cable (the male "stereo" end) to the CO logger

2.4 Select "***Launch***" from the logger menu

2.5 Check the battery status

2.6 Select '***Enable/disable channels'***. Check the box next to 'Channel 1 (0-125 ppm)' and 'Channel 2.' Select ***'Apply.'***

2.7 In the '***Interval Duration***' menu, select '***1 minute.'***

2.8 Type in the label for sampling location (HOBO CO ID#_House ID#_Date)

2.9 Select the box with delayed start. In the boxes on the right, insert the date of sampling and the time that all monitors will be started.
(*Note: preferably at the top of the hour and with 00 seconds)

2.10 DO NOT select the box to 'wrap' the data (leave this box unselected)

2.11 Select '**S*tart'***

2.12 Select '***Continue***' from screen with enable channel reminder

2.13 Click '***OK***' for old data to be erased from logger

2.14 Detach the cable from the logger and then press '***OK***.' Note that the logger will now begin to log CO levels at the programmed time.

2.15 Check that the logger is switched 'ON' by looking at the LED light on the front face of the unit for several seconds. When the logger is switched 'ON,' the light will flash faintly every two seconds. When off, the logger LED will not flash.

3.0 Placement of CO logger in the field location

3.1 Approximately 100cm from the outside perimeter of the stove

3.2 Height: approximately 125cm above the floor

3.3 At least 150 cm from doors and windows, where possible

4.0 Downloading data

4.1 Connect the 9-pin plug of the cable (CABLE-PC-3.5) to the COM 1 serial port on the computer

4.2 Open ***Boxcar Pro*** software

4.3 Plug the cable (CABLE-PC-3.5) 'stereo' plug into the logger

4.4 Select '***Logger***' from the top menu of the ***Boxcar Pro*** software. When the drop down menu appears, select '***Readout***.'

4.5 A window will appear displaying '**connecting**' and then '**HOBO found**'. Another window will then appear saying '**offload**.' Wait for data to download to desktop.

4.6 Unplug the logger at the prompt and select '***OK***'.

4.7 A window will appear displaying '**save as**'.

4.7.1 At the top, select the data directory on the computer corresponding to new data for the CO logger (e.g. select the data directory '**HOBO CO – New Data**')

4.7.2 Check that the filename reads 'HOBO CO #_House ID#_Date'

4.7.3 Select '***save'***

4.8 The **Boxcar Pro** software will then display a graph of the data downloaded.

4.8.1 Check the sample period on the graph (make sure the final time is correct)

4.8.2 Check that the data does not 'Flat-line' across the graph. If the data does flat-line (e.g. display one constant value), check the cable connection in the logger to ensure that all 3 soldered connections are intact. If one of these connectors is not intact, the solder needs to be replaced,
****note that the data may still be retrieved from the logger once the soldered connection has been repaired - follow the steps above*** (beginning with 4.1)

4.8.3 Check that the data does not appear abnormal in any other way.

4.9 Check the box on sample sheet labeled '**CO Time series plot check'**

5.0 Backup of data files

5.1 At the end of each week of logger usage, the new data files should be saved to a CD-ROM, which will have a defined ID#.

5.2 Once the new data files have been saved to CD-ROM, they should be moved to the '**HOBO CO - Archived Data**' directory.

<u>Standard Operating Procedure:</u>

HOBO CO Logger Calibration Check Protocol

Version 5.1 (October 2005)

Indoor Air Pollution Team
and
Center for Entrepreneurship in International Health and Development (CEIHD)

School of Public Health, University of California-Berkeley

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NOTE: This protocol should be used only when standard CO gas cylinders are not available. If standard CO gas cylinders are available, the HOBO CO loggers should be formally calibrated with those standards.
***

1.0. Materials Required

- Field HOBO CO loggers: those loggers used routinely in homes throughout the IAP study
- Gold Standard HOBO CO logger: the one logger that stays in the office, is not used for routine sampling, and is used only for calibration checks

2.0. Frequency

- A calibration check should be performed after approximately every six 24-hour uses of the Field HOBO CO loggers

3.0. Procedure

3.1. Launch each logger to collect data once every minute (including all Field loggers and the Gold Standard logger). Be sure to enable Channels 1 and 2.

3.2. Place each of the Field loggers and the Gold Standard logger in a house that burns wood in an open fire stove without a chimney. The loggers should remain in the house during one cooking event, for a total time of about 1.5 hours. Note the time that the last logger was placed on the wall.

3.2.1. Place each logger next to each other in a row, all at the same height, spaced about 2 cm apart.

3.2.2. Place the Gold Standard logger in the center position of the row of loggers.

3.2.3. Locate the loggers in the house according the instrument placement protocol (***Installing IAP Instruments in a Home***):

- Approximately 100 cm from the outside perimeter of the stove
- Height: approximately 145 cm above the floor (Note: previous versions of this protocol suggested 125 cm above the floor)
- At least 150 cm from doors and windows, where possible

3.3. After the cooking event (after ~1.5 hours), retrieve all of the loggers from the house, noting the time the first logger was removed from the wall.

3.4. Download the data saved in each logger using the BoxCar Pro software. Inside of BoxCar Pro, create an Excel file of the data for each logger (File/Export/Microsoft Excel Spreadsheet…).

3.5. In each of the Excel files that were just created, copy the column of CO concentration data (Channel 1) for each of the Field loggers and paste it into the spreadsheet for the Gold Standard logger, being careful to match up the sampling times. Note: if any of the concentration values for any logger exceeded 125 ppm, use Channel 2 data for all of the loggers, instead of Channel 1 data.

3.5.1. Delete the data corresponding to the times before the last logger was placed on the wall in the house. Similarly, delete the data corresponding to the times after the first logger was removed from the wall of the house. This creates a set of data corresponding to the times that all of the loggers were placed in the house.

3.5.1. Create a XY (scatter) chart of the all of the concentration data for the first Field logger (the y values) versus all of the concentration data for the Gold Standard logger (the x values), again making sure that the sample times were aligned properly. Make one chart for each of the Field loggers, again using the Field logger data as the y values and the Gold Standard data as the x values.

3.5.2. For each chart, add a trendline by selecting Chart/Add Trendline from the main menu tab. Choose the trendline type to be linear. From the 'Options' tab in the Add Trendline box, check the boxes for 'Display equation on chart' and 'Display R-squared value on chart.'

3.5.3. Record the trendline equation and the r^2 value for each of the charts (one equation and one r^2 for each of the Field loggers).

Standard Operating Procedure:

Carbon Monoxide Passive Dosimeter Tubes (for area monitoring)

Protocol Contents

1. Statement of Purpose

This protocol describes the use of Gastec passive dosimeter tubes for carbon monoxide area monitoring. (Tube Model Number: 1DL– 0.4-400ppm).

2. Equipment Requirements for Each House

- 1 CO passive dosimeter tube holder
- Gastec passive dosimeter tube 1DL – 0.4-400ppm
- Office depot laser permanent adhesive white (self-stick) labels item #611-441 printed with sample ID.

3. Preparation of Passive Dosimeter Tubes (before going to field)

3.1 The sample identification number (state, district, village, HH) must be assigned to each tube, including the state, district, village and household codes where the sample is to be taken.

3.2 Each self-stick label should have the ID printed on it.

3.3 Stick the label around the transparent base of the 1DL – 0.4-400ppm CO tube between the blue stain inside the tube and the pointed end of the tube. ***The label should not obscure any of the granular material inside the tube. Do not put the label on the transparent section of tube that has a groove around the tube, as this will be detached. Place it on the transparent section with no groove.***

3.4 The tubes are now ready for transport to the sampling location.

4. Installation of Passive Dosimeter Tubes in Field Location

4.1 Place the dosimeter tube into the holder by placing the dosimeter tube along the top of the channel in the blue clip holder. The transparent end of the dosimeter tube with the groove should stick out past the end of the clip. The numbered scale on the tube should be facing upward. Press the tube firmly down into the channel using your thumbs. You should hear a click as the tube is seated correctly.

4.2 Holding the holder containing the dosimeter tube in one hand, use the other hand to snap off the other end of the tube using a sharp downward motion.

4.3 The dosimeter tube is now measuring CO levels.

4.4 Attach the holder in the same location as the kitchen UCB monitoring, using the clip on the holder, tape, or string to hold it in place. **The tube should be placed such that the open end of the tube is facing the combustion source.**

5. **Collection & Reading of Passive Dosimeter Tubes at the end of the Sampling Period**

   5.1 Remove the holder from the kitchen location.

   5.2 Press the dosimeter tube from the reverse side to release the tube from the clip holder.

   5.3 Using one of the red caps, tightly close the open end of the dosimeter tube.

   5.4 Immediately read the level of the stain on the tube. To do this, measure the spread of the stain (in mm) by placing the edge of a metal ruler at the base of the tube. The stain is a brown or black discoloration. The measurement should include both the length of the brown/black stain as well as the adjoining "gray specs." Placing the tube onto a white sheet of paper may help in reading the tube. Record this reading in the space on the sample sheet. A yellow stain is produced by sunlight and is not the correct endpoint; if you observe a yellow color and/or other unusual stains, make a note of this on the sample sheet. A calibration curve[1] will be used to transform the mm measurements in ppm-hr measurements.

   5.5 Place the capped tubes in a location where they will be shielded from direct sun, shock, and extreme heat or cold and transport to a refrigerator as soon as practical.

6. **Confirmation Reading of Passive Dosimeter Tubes after Return from the Field**

   6.1 Dosimeter tubes should be handed to the team leader upon return from the field without communicating the reading that was measured in the field. The team leader should then independently assess the reading of the dosimeter tube and write the reading down in the space on the sampling sheet.

   6.2 Store tubes in safe cool (refrigerator) location until the end of the data cleaning process when the data set is confirmed.

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[1] For a successful sample, all 1DL Gastec tubes should be from the same lot (mention this on the phone when ordering). The calibration curve is constructed by measuring (in mm) from the base to each ppm-hr marking. The mm measures are plotted against the ppm-hr values in Excel. Field measurements in mm can be converted to ppm-hr by using this calibration curve.

UCB Particle Monitor sampling data form

Household ID on Master Sheet	
Region Name	
District Name	
Village/town Name	
House Description	

Pre-Sampling Calibration Period (at least 1 hour)

UCB ID	Location (Office or other, specify)	Date (dd/mm/yy)	Start Time (hh:mm)	End Time (hh:mm)

Household Sampling Period

UCB ID	HH ID	Monitoring Start Date (dd/mm/yy)	Monitoring Start Time (hh: mm)	Monitor Height (cm)	Monitor Distance from Stove (cm)	Monitor Distance from ________________ (cm)	Monitoring End Date (dd/mm/yy)	Monitoring End Time (hh:mm)	**UCB ID**	HH ID

Post-Sampling Calibration Period (at least 1 hour)

UCB ID	Location (Office or other, specify)	Date (dd/mm/yy)	Start Time (hh:mm)	End Time (hh:mm)

Downloaded?	ucbpm File Name	Graph OK?	Initials
[ ] Yes [ ] No	RAWDATA (P3z00_ _ _) __-__-__ __-__ to __-__-__ __-__ _ _ _ # # # mm-dd-yy hh:mm mm-dd-yy hh;mm # # #	[ ] Yes [ ] No	

Note: Describe any disturbances to the UCB Particle Monitor in the household:

____

____

Note: Describe any errors that occurred while you were launching or downloading the UCB Particle Monitor data (note lowest value (mg/m^3):

____

____

HOBO CO sampling data form

HOBO CO Sampling Period										
HOBO ID	HH ID	Monitoring Start Date (dd/mm/yy)	Monitoring Start Time (hh: mm)	Monitor Height (cm)	Monitor Distance from Stove (cm)	Monitor Distance from ____________ (cm)	Monitoring End Date (dd/mm/yy)	Monitoring End Time (hh:mm)	**HOBO ID**	HH ID
#815 __ __ __									#815 __ __ __	

HOBO CO logger	Downloaded data/file information	Initials of data manager
Are there values of CO above 125ppm	[ ] Yes [ ] No	
Does the graph look ok?	[ ] Yes [ ] No	
File name on desktop/laptop computer	H815_ _ _ __-__-__ to __-__-__-_ _ _ # # # mm-dd-yy to mm-dd-yy # # #	
ID/name of back-up CD-ROM		

CO dosimeter tube sampling data form

CO Tube Sampling Period										
CO TUBE ID	HH ID	Monitoring Start Date (dd/mm/yy)	Monitoring Start Date (hh: mm)	Tube Height (cm)	Tube Distance from Stove (cm)	Monitor Distance from ____________ (cm)	Monitoring End Start (dd/mm/yy)	Monitoring End Time (hh:mm)	**CO TUBE ID**	HH ID

Length of brown stain in field #1 (mm)	Initials of reader #1	Length of brown stain in field #2 (mm)	Initials of reader #2	Supervisor's initials	Comments

Note: Describe any disturbances to the HOBO monitor or CO tube in the household:

____

____

Note: Describe any errors that occurred while you were launching or downloading the HOBO data:

____

____

Indoor Air Pollution: Post-Monitoring Questionnaire

Household ID on Master Sheet	
Region Name	
District Name	
Village/town Name	
House Description	
Person Interviewed	
Interviewer Name	
Date (dd/mm/yy)	
Day of the week for collection	
Monitoring period	[ ] 24h [ ] 48h

Make sure that the kitchen layout is the same and that the equipment is positioned at the same place as during the baseline.

Check the box when completed:____ [ ]

Note any discrepancies: ____

Make sure that the house layout is the same as during the baseline.

Check the box when examined: ____ [ ]

Note any discrepancies: ____

INSTRUCTIONS: Answer each question by circling and/or writing the appropriate number. Questions 1-7 are household (HH) observations, and can be completed before the IAP monitoring is finished. Questions 8-47 must be completed after the monitoring period is completed.

Beginning of Pre-Monitoring Questions

1. (Observe) How many walls does the kitchen area have?

one wall	1
two walls	2
three walls	3
four walls	4

2. (Observe) What type of kitchen walls?

solid wood	1
fence (porous, sticks, bamboo)	2
mud	3
concrete	4
other:	5

3. (Observe) What type of kitchen roof?

thatch	1
metal sheet	2
asbestos	3
other:	4
not applicable	0

4. (Observe) What is the length (longest dimension) of the kitchen? _____ **meters**
(0 if not applicable)

5. (Observe) What is the width (shortest dimension) of the kitchen? _____ **meters**
(0 if not applicable)

6. (Observe) What is the height of the kitchen? _____ **meters**
(0 if not applicable)

7. (Observe) Are there open eaves between the walls and the roof of the kitchen area?

no	1
partially (less than 1 foot)	2
yes (more than 1 foot)	3

End of Pre-Monitoring Questions

Beginning of Post- Monitoring Questions

8. (Observe) What was the primary stove used during the monitoring period for both cooking and boiling water:

three stones	1
mokyia (clay)	2
metal mokyia	3
gyapa wood (improved)	4
coal pot (for charcoal)	5
rim charcoal stove	6
gyapa charcoal (improved)	7
ahibenso (improved)	8
kerosene	9
gas stove (LPG, biogas)	10
electric stove	11
other:	12

NOTE: If the household did not use the appropriate stove for this section of the study, make sure this questionnaire and data sheets are marked accordingly and that data managers are notified.

9. (Observe) How many windows are in the kitchen?

number	

10. (Ask) Were the windows in the kitchen open during the monitoring period?

not applicable	0
no, not open at all (0-25%)	1
yes, about half of the time (25-75%)	2
yes, open almost or all of the time (75-100%)	3

11. (Observe) How many doors are in the kitchen?

number	

12. (Ask) Were the doors in the kitchen open during the monitoring period?

not applicable	0
no, not open at all (0-25%)	1
yes, about half of the time (25-75%)	2
yes, open almost or all of the time (75-100%	3

13. (Observe) How is the ventilation in the kitchen area (if there was a breeze outside, could you feel it in the kitchen)?

very good	1
good	2
fair	3
poor	4

14. (Ask) What was the primary type of fuel used over the monitoring period in your home for both cooking and boiling water?

(Circle only one fuel)

firewood	1
crop residues (straw or stalks)	2
saw dust	3
charcoal	4
kerosene	5
gas (LPG, biogas)	6
electricity	7
other:	8

15. (Ask) How much fuel (using the primary stove) did you use over the monitoring period for both cooking and boiling water?
16. (Ask) How much time did you spend collecting this fuel? (0 if not applicable)

cedis	
hours	

17. (Ask) Please comment on the wood you used during the monitoring period.

no wood was used	0
the wood was dry	1
the wood was wet	2
other:	3

18. (Observe) What was the secondary stove used during the monitoring period for both cooking and boiling water:

no other stove	0
three stones	1
mokyia (clay)	2
metal mokyia	3
gyapa wood (improved)	4
coal pot (for charcoal)	5
rim charcoal stove	6
gyapa charcoal (improved)	7
ahibenso (improved)	8
kerosene	9
gas stove (LPG, biogas)	10
electric stove	11
other:	12

19. (Ask) What was the secondary type of fuel used over the monitoring period in your home for both cooking and boiling water?

(Circle only one secondary fuel)

no other fuel	0
firewood	1
crop Residues (straw or stalks)	2
saw dust	3
charcoal	4
kerosene	5
gas (LPG, biogas)	6
electricity	7
others:	8

20. (Ask) How much fuel (using the secondary stove) did you use over the monitoring period for both cooking and boiling water?
21. (Ask) How much time did you spend collecting this fuel? (0 if not applicable)

cedis	
hours	

Cooking pattern questions.
22 and 23. Who cooked or boiled water during the monitoring period?

Role	Name:	1st cook (#22)	2nd cook (#23)
wife of HH head		1	1
daughter of HH head		2	2
daughter in law		3	3
mother in law		4	4
other:		5	5
no 2nd cook			0

24. Did anyone cook or boil water in the morning(s) (before 12 noon)?

no	0
yes, first morning only	1
yes, second morning only (if 48 hours)	2
yes, both mornings (if 48 hours)	3

25. Did anyone cook or boil water in the afternoon(s) (between 12 noon and 5pm)?

no	0
yes, first afternoon only	1
yes, second afternoon only (if 48 hours)	2
yes, both afternoons (if 48 hours)	3

26. Did anyone cook or boil water in the evening(s) (after 5pm)?

no	0
yes, first evening only	1
yes, second evening only (if 48 hours)	2
yes, both evenings (if 48 hours)	3

27. During the MP, how many people were cooked for (on average)?
28. During the MP, for how many people was water boiled (on average)?
29. During the MP, how long was the stove lit for cooking (on average)?
30. During the MP, how long was the stove lit for boiling water (on average)?

people	
people	
hours	
hours	

31. Was the stove put out between uses (cooking and boiling water)?

no	0
yes, only at night	1
yes, each time	2

32. During the monitoring period, was there anything unusual about your cooking pattern?

no, nothing unusual	0
yes, cooked for more people than usual	1
yes, cooked for fewer people than usual	2
yes, other:	3

Questions about other combustion in and nearby the house

33. Did you light any non-electric lamps in the kitchen?

34. How long were the lamps lit?

no	1
yes	2
hours	

35. What fuel did you use in the lamps?

not applicable	0
kerosene	1
candle wax	2
other:	3

36. Were any cigarettes smoked in the kitchen?

37. How many cigarettes were smoked?

no	1
yes	2
number	

38. Was garbage burned nearby, influencing the pollution levels inside your kitchen?
39. What was the duration of garbage burning?

no	1
yes	2
hours	

40. Did anyone burn incense in the kitchen?

41. For how long was incense burned?

no	1
yes	2
hours	

42. Did anyone burn mosquito coils in the kitchen?

43. For how long were mosquito coils burned?

no	1
yes	2
hours	

44. Was there any other combustion inside the kitchen or nearby influencing the pollution levels inside your home?

45. How long did this other combustion last?

no	1
yes	2
hours	

Questions about special conditions

46. (Ask or Observe) Did any of the following weather conditions occur during the monitoring period? (choose the most important in the 1 or 2 days)?

no rain	0
drizzle (light rain)	1
rain	2
very windy	3
harmattan	4
other:	5

47. (Ask or Observe) Were there any disturbances to the monitoring equipment?

no	1
yes	2
describe:	

End of Post- Monitoring Questions

Supervisor Check:
Name ________________________________
Date (dd/mm/yy) ____________________
Comments____
____
____

Indoor Air Pollution: Screening Questionnaire

Household ID on Master Sheet	
Region Name	
District Name	
Village/town Name	
House Description	
Person Interviewed	
Interviewer Name	
Date (dd/mm/yy)	

1. How many walls does your kitchen have? ______________________________
2. Does your kitchen have a roof? ❒ No ❒ Yes
3. Does your kitchen have enough structure to be considered enclosed and provide typical IAP levels? ❒ No ❒ Yes
4. How many people older than 5 years old live in your household? _____________
5. How many people older than 5 years old do you regularly cook or boil water for in your kitchen? ____
6. Does another family (e.g. sister/mothers family) cook inside your kitchen?
   ❒ No ❒ Yes
7. Are there any activities that emit air pollution very near or inside your kitchen and that could strongly influence the IAP readings? ❒ No ❒ Yes. If yes:
   ❒ trash burning
   ❒ busy road
   ❒ fish smoking
   ❒ restaurant or chop bar
   ❒ other: ___________________

8. Is wood your primary fuel for cooking and boiling water? ❐ No ❐ Yes
9. What is your primary stove type for cooking and boiling water?
   ❐ three stones
   ❐ mokyia (clay)
   ❐ metal mokyia
   ❐ gyapa wood (improved)
   ❐ other:____
10. Cooking pattern and availability: how many hours of cooking do you typically do on each day of the week, and mark times that the cook is unavailable for questionnaires?

Day	# hours
Monday	
Tuesday	
Wednesday	
Thursday	

Day	# hours
Friday	
Saturday	
Sunday	

CONSENT FORM

Introduction and purpose:

I (we) work with EnterpriseWorks Ghana and in collaboration with the University of California Berkeley. We are doing a study on the effects of fuel efficient stoves on indoor air quality in households of Ghana. The goal of the study is to survey more than 72 households twice over the next 4 months. These households currently use traditional wood stoves (3 stones or mokyia) and will obtain an improved wood stove during this study. The results from this study will be made public. We are asking for people in selected communities all over the Greater Accra Region to participate in this study. Your participation is completely voluntary.

Procedures:

The procedure for this study will have 3 phases:

Phase #1: We will install air quality measurement devices in your kitchen for 1 to 2 days. The devices will measure the amount of carbon monoxide and particulates in the air of your kitchen. The devices will be installed on a given day during the next month and will be removed from your kitchen 24 to 48 hours later. Upon the removal of the devices, we will ask you a series of simple questions to describe the activities in your kitchen during the monitoring period.
Phase #2: We will install an improved wood stove in your kitchen and will ask you to use it as your primary stove for at least 6 months.
Phase #3: We will return to your house to install the same devices as during Phase 1, to measure the new amounts of carbon monoxide and particulates in your kitchen air. We will return again 1 or 2 days later to collect the devices. As during Phase 1, upon the removal of the devices, we will ask you a series of simple questions to describe the activities in your kitchen during the monitoring period.

Risks:

The choice to take part in this project is completely up to you. If you choose to be part of this study, it will be very helpful in characterizing indoor air pollution and fuel efficient stoves. There is no penalty if you decide not to join the study or if you wish to stop part way through the study.
Indoor Air Pollution Monitoring: The instruments pose no personal, electrical or fire risks.
Questionnaire: The questionnaire takes time to answer (up to 25 minutes). This is the only inconvenience.

Benefits:

Benefits for you and your family include the provision of a fuel efficient wood stove. Your participation will help us plan programs to decrease indoor air pollution in homes in Ghana.

Confidentiality:

To protect your privacy, we will keep the records under a code number rather than by name. We will keep the records in locked rooms and only study staff will be allowed to look at them. Your name or other private facts will not appear when we discuss this study publicly or when we publish the results.

EnterpriseWorks Ghana Contact: Seth Mahu Agbeve, smagbeve@yahoo.com, 0244-209710
CEIHD Contact: David Pennise, david@ceihd.com

Cost/Payment:

The tests we do for this study will be done at no cost to you.

Right to Refuse or Withdraw:

If you have questions for me (us) during our household visit, ask them at any time. Also, if you want to stop the monitoring at any time, just let me (us) know. You do not have to answer any questions that you do not wish to answer.

Persons to Contact:

You may contact either of the following people for any question or concern.

Mr. Seth Mahu Agbeve
Engineer / M&E Associate
EnterpriseWorks Ghana
0244-209710
smagbeve@yahoo.com

Ms. Irene
024-321-8744

Mr. Ken
024-722-0259

You have read this form, and you understand fully all of the information that it contains. You have been given an opportunity to ask questions, and you have been given satisfactory answers. You are aware that your consent to participate is completely voluntary and may be withdrawn by you at any time. You have been given the phone number to reach Mr. Agbeve or Mr. Ken / Ms. Irene if you have additional questions.

Agreement to Participate

The above description of the research project was read to me by _______________ and anything I did not understand or had questions about was answered. I voluntarily agree to participate in this project.

Name of person giving consent:____ (print)

Signature of person giving consent: __________________________(sign or finger print)

Name of person obtaining consent: _____________________________________ (print)

Signature of person obtaining consent:___________________________________(sign)

Date:____