Published in final edited form as:
Environ Res. 2013 February ; 121: 11–16. doi:10.1016/j.envres.2012.10.004.

Seasonal concentrations and determinants of indoor particulate matter in a low-income community in Dhaka, Bangladesh

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Abstract

Indoor exposure to particulate matter (PM) increases the risk of acute lower respiratory tract infections, which are the leading cause of death in young children in Bangladesh. Few studies, however, have measured children's exposures to indoor PM over time. The World Health Organization recommends that daily indoor concentrations of PM less than 2.5 μm in diameter ($PM_{2.5}$) not exceed 25 $\mu g/m^3$. This study aimed to describe the seasonal variation and determinants of concentrations of indoor $PM_{2.5}$ in a low-income community in urban Dhaka, Bangladesh. $PM_{2.5}$ was measured in homes monthly during May 2009 to April 2010. We calculated the time-weighted average, 90th percentile $PM_{2.5}$ concentrations and the daily hours $PM_{2.5}$ exceeded 100 $\mu g/m^3$. Linear regression models were used to estimate the associations between fuel use, ventilation, indoor smoking, and season to each metric describing indoor $PM_{2.5}$ concentrations. Time-weighted average $PM_{2.5}$ concentrations were 190 $\mu g/m^3$ (95% CI 170 – 210). Sixteen percent of 258 households primarily used biomass fuels for cooking and $PM_{2.5}$ concentrations in these homes had average concentrations 75 $\mu g/m^3$ (95% CI 56 – 124) greater than other homes. $PM_{2.5}$ concentrations were also associated with burning both biomass and kerosene, indoor smoking, and ventilation, and were more than twice as high during winter than

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Competing financial interests: The authors declare that we have no competing financial interests.

during other seasons. Young children in this community are exposed to indoor $PM_{2.5}$ concentrations 7 times greater than those recommended by World Health Organization guidelines. Interventions to reduce biomass burning could result in a daily reduction of 75 $\mu g/m^3$ (40%) in time-weighted average $PM_{2.5}$ concentrations.

Keywords

particulate matter; Bangladesh; indoor air; biomass; urban health

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Introduction

Acute lower respiratory tract infections, including pneumonia, are the leading cause of death in children aged <5 years in Bangladesh (Baqui et al. 2001; Black et al. 2003). An estimated 25,000 Bangladeshi children died from acute lower respiratory infections in 2008 (Black et al. 2010). A recent meta-analysis of epidemiologic studies found that children <5 years of age with exposure to smoke from biomass fires in and around the household were 1.8 (95% confidence interval [95% CI] 1.3 – 2.2) times more likely to experience acute lower respiratory infections than children without this exposure (Dherani et al. 2008). The World Health Organization estimated that 32,000 childhood deaths from pneumonia were attributable to indoor exposures to biomass smoke in Bangladesh in 2001 (Anon. 2007).

Biomass fuels burn inefficiently and smoke from biomass combustion releases fine particles into the air which can be breathed into the lower lung (Naeher et al. 2007). Although households in low-income countries frequently burn biomass for cooking or heating (Anon. 2007), little is known about particulate matter (PM) concentrations in these homes. Until recently, most standard air quality monitors capable of measuring PM concentrations were large, expensive machines that required technical expertise to deploy (Smith 2002). Therefore, most epidemiologic studies used proxy PM exposure measurements, such as the type of cooking fuel or estimates of the amount of time the child spends near the cooking fire (Dherani et al. 2008; Ezzati and Kammen 2002). These proxy exposures were consistently associated with an increased risk of acute lower respiratory infections in children, suggesting that they are useful for discriminating between levels of exposure (Dherani et al. 2008). However, these proxy measures of exposure had major limitations (Ezzati and Kammen 2002). First, proxy exposures do not allow for comparison of exposure to PM between countries or study sites. For example, if burning wood for cooking is associated with an increased risk of acute lower respiratory infections in two studies, this provides no information about how exposures to PM may differ between those study populations. Second, these proxy measurements provide little information about how PM exposures differ between participants within the study, only whether or not the difference resulted in significant increases in risk. Third, there may be seasonal variations in fuel use or other household determinants of PM concentrations which may not be accurately captured by interviews, making it difficult to capture seasonal variations in exposure.

The few published studies describing measured indoor PM in low-income countries are limited by small sample sizes, cross-sectional design, and/or absence of detailed analyses that limit interpretations of seasonal variation and determinants of indoor PM concentrations (Ezzati and Kammen 2002; Dasgupta et al. 2006a, b; Ezzati and Kammen 2001; Bautista et al. 2009). However, information about seasonal variation and determinants of indoor PM concentrations could improve the design of interventions to decrease exposure by quantifying how PM would decrease with interventions aimed at changing fuel type or increasing ventilation (Ezzati and Kammen 2002).

For one year we measured PM concentrations each month in children's homes in a low-income community in urban Dhaka, Bangladesh monthly as part of an epidemiologic study to estimate the incidence and timing of acute lower respiratory infections in children <2 years of age. The objectives of this study were to describe seasonal patterns of indoor particulate matter concentrations and to estimate the association between these concentrations and potential sources of particulates in the home.

Materials and methods

Study population

Mirpur is a densely populated, low-income, urban community in Dhaka, Bangladesh (Haque et al. 2001). In January 2008, researchers at the International Centre for Diarrheal Diseases Research, Bangladesh (icddr,b) and the University of Virginia began enrolling a cohort of children in this community at birth to study the incidence and etiology of childhood gastrointestinal and respiratory infections and their associations with cognitive development. All pregnant women residing in the Mirpur study area between January 2008 and April 2009 were identified by community health workers employed by the study and asked to participate in the cohort. All children enrolled in this cohort between January 2008 and April 2009 were eligible to enroll in our sub-study to examine the relationship between indoor air pollution and respiratory disease. This paper presents findings on about the $PM_{2.5}$ concentrations in these children's homes.

Measurement of household characteristics and indoor $PM_{2.5}$

Every household with a child participating in the sub-study was visited in April – May 2009 and characteristics of the household were recorded using a structured questionnaire and observation form. Our study aimed to describe the determinants of indoor concentrations of particulate matter, so we attempted to measure all known sources of particulates for each household. Trained research assistants collected information from the child's mother about the number of people who lived in the house; the area of the dwelling's floor space; the number of windows and doors that opened to the outside; whether the cooking stove was inside or outside the living space; the kind of fuels burned in the home for cooking or other purposes; and whether or not any household members smoked tobacco in the house. During this survey in April – May 2009, many household respondents told us that they had specialized stoves for cooking with natural gas or electricity, but these cleaner fuel sources were sometimes unavailable due to regular power outages or limited natural gas supply. If cleaner fuels were unavailable, some households burned biomass in traditional stoves as an alternative strategy. Therefore, we conducted a survey during March 2011 to collect data on all fuel types used by the household since May 2009 to capture this heterogeneity. Households that were not available to participate in the survey at the end of the study were categorized based on their baseline fuel use information.

From May 2009 through April 2010, concentrations of particulate matter of approximately 2.5 μm in diameter ($PM_{2.5}$) were measured in the child's sleeping space for a 24 hour period once per month using PM monitors manufactured by the Berkeley Air Monitoring Group (Smith et al. 2007; Chowdhury et al. 2007; Edwards et al. 2006). The monitors were converted smoke detectors that used light scattering sensors to measure $PM_{2.5}$ approximate concentrations and these measurements were shown to correlate with gravimetric-based $PM_{2.5}$ samples (Chowdhury et al. 2007). The monitors were designed for use in highly polluted indoor environments and had a lower limit of detection of 50 $\mu g/m^3$ (Edwards et al. 2006).

Trained research assistants zeroed the monitors, placed them on the wall approximately two feet above the bed where the child enrolled in the birth cohort slept, and then retrieved the monitors from the home at least 24 hours later. The monitors logged the measured concentrations of $PM_{2.5}$ once per minute and these data were downloaded to a study computer. Twenty-four hours of measurements were retained for each day of sampling for the analysis, with one minute resolution (data collected at one minute intervals) for a total of 1440 measurements per each 24 hour period. Twenty-four hour observations with fewer than 1300 minute measurements recorded due to monitor or human error were excluded from the analysis. Readings at or below the limit of detection (50 $\mu g/m^3$) were replaced using the beta substitution method for censored data arising from limits of detection (Ganser and Hewett, 2010).

Statistical analyses

We described study households in terms of whether their cooking stove was inside or outside, the type of fuel used for cooking at baseline, tobacco smoking inside the home, and the number of doors and windows that opened to the outside. We created fuel use categories to capture heterogeneity in fuel use based on the survey at the end of the study and classified households as either using clean fuels only during the study period, which included both natural gas and electricity, using biomass fuels only, or using primarily clean, but occasionally biomass fuels. Households with missing data on fuel use from the survey at the end of the study were classified as burning biomass only if they reported at baseline that their primary fuel source was biomass. All others with missing data were classified as using primarily clean fuels with some biomass.

The $PM_{2.5}$ concentrations were summarized for each 24-hour observation period using three exposure metrics. Time-weighted average (arithmetic mean) $PM_{2.5}$ concentrations were calculated to represent daily exposures and the 90th percentile $PM_{2.5}$ concentration was used as an indicator of peak daily exposures in the home. In addition, we calculated the number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ for each 24 hour observation period (daily hours >100 $\mu g/m^3$). The threshold of 100 $\mu g/m^3$ does not represent a concentration associated with poorer health outcomes but was chosen for exploratory analyses because it represented twice the limit of detection of the monitors and four times the World Health Organization guidelines for indoor air quality (25 $\mu g/m^3$ daily mean) (Anon. 2006).

The number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ were plotted by measurement date and locally weighted scatterplot smoothing (LOWESS) curves (Cleveland and Devlin 1988) were estimated to compare seasonal variation in $PM_{2.5}$ concentrations by fuel type. We defined four seasons: winter (December – February), spring (March – May), monsoon (June – September), and post-monsoon (October – November) (Salam et al. 2003). To account for the clustered nature of observations within each household, generalized estimating equations were fitted to estimate the population-averaged associations between fuel use, stove location, the number of windows and doors, indoor tobacco smoking, and season with time-weighted average $PM_{2.5}$ concentrations, 90th percentile $PM_{2.5}$ concentrations, and daily hours >100 $\mu g/m^3$ (Liang and Zeger, 1986). We defined binary variables for each season and the season with the lowest values defined the baseline. An additional analysis objective was to estimate the subject-specific associations with covariates as well as the proportion of the variation in $PM_{2.5}$ concentrations that was explained by differences between households. To accomplish this, a random effects model, including a random intercept for each household, was fitted for each of the exposure metrics in Stata 10 using *xtmixed* with an unstructured correlation matrix. The intraclass correlation coefficients were calculated using *xtmrho* (Stata Corp, TX).

Human subject considerations

Prior to enrollment, all mothers provided either a signature or a thumb print indicating their informed consent for participation. Institutional Review Boards at the following institutions reviewed and approved the protocol: icddr,b, Dhaka, Bangladesh University of Virginia, Charlottesville, VA; US Centers for Disease Control and Prevention, Atlanta, GA; and Johns Hopkins Bloomberg School of Public Health, Baltimore, MD.

Results

Two hundred and sixty-two households were enrolled in the primary cohort since January 2008 and still enrolled when this study began in May 2009. All of these households in the birth cohort study agreed to participate in the study on indoor particulate matter. Two hundred and fifty-eight households (98%) had complete baseline information collected and were included in the analysis. Of those 258, 213 (83%) completed the survey at the end of the study on types of cooking fuels used since May 2009. Forty-two percent of households exclusively used clean fuels, such as natural gas or electricity, for cooking and 16% used primarily biomass, including wood, jute, bamboo, and paper. Fifty-two percent used a combination of both clean and biomass fuels for cooking during the study period. Households had a median of 5 residents living in a median of 9.6 meters^2 of floor space, and 28% reported that at least one household member smoked tobacco indoors (Table 1).

Fifteen (0.5%) 24-hour measurements were excluded from the analysis because fewer than 1300 minutes were recorded. Overall, 49% of all $PM_{2.5}$ measurements were at or below the limit of detection (50 $\mu g/m^3$) (Table 2). The mean time-weighted average $PM_{2.5}$ concentrations were 190 $\mu g/m^3$ (95% confidence interval [95% CI] 170–210), mean 90th percentile values were 438 $\mu g/m^3$ (387–489), and mean number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ each day (daily hours >100 $\mu g/m^3$) were 5.7 (5.5–5.9) (Table 2). All three exposure metrics were higher in winter compared to other seasons, higher in households that used only biomass fuel compared to other households, and were higher in homes with ≤1 external window or door compared to homes with ≥2 (the median number among study households) (Table 2). There were no significant differences in $PM_{2.5}$ concentrations for households that cooked inside the home compared with outside (Table 2). There were no significant differences between $PM_{2.5}$ concentrations in each season by location of cooking stove (data not shown).

For each 24-hour period, the number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ varied from 0 to 24; the lowest values occurred during the humid and rainy monsoon months (July – September) and the highest during the cooler, dry winter season (December – February) (Salam et al. 2003) (Figure 1). Households burning only biomass had more hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ compared to other homes throughout the year. The number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ during winter in homes burning only clean fuels were similar to the number in homes burning only biomass in the spring and monsoon seasons (Figure 1).

Primarily burning biomass for cooking was independently associated with a 75 $\mu g/m^3$ (95% CI 6 – 124) increase in time-weighted $PM_{2.5}$ concentrations in the marginal model. Each additional external windows and/or doors was associated with a 22 $\mu g/m^3$ decrease (95% CI −43 – −0.2) in time-weighted $PM_{2.5}$ concentrations, and winter season was associated with a 225 $\mu g/m^3$ increase (95% CI 163 – 287) (Table 3). Each additional external window or door was associated with a decrease (−56 $\mu g/m^3$, 95% CI −110 – −1) in 90th percentile $PM_{2.5}$ concentrations and winter season was associated with an increase (537 $\mu g/m^3$, 95% CI 377 – 696). All predictors except stove location were associated with the number of hours each day that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ (daily hours >100 $\mu g/m^3$), including exposure to indoor tobacco smoking. Similar to the other $PM_{2.5}$ concentration metrics, winter season was the most important predictor of the number of hours that $PM_{2.5}$ concentrations exceeded100 $\mu g/m^3$ (5.6 hours, 95% CI 5.2 – 6.0) (Table 3). Subject specific associations from the random intercept model were consistent with the population-averaged associations from the marginal model (Table 4).

The intracalss correlation coefficient was 0.02 for the time-weighted average $PM_{2.5}$ concentrations, 0.02 for the 90^{th} percentile values, and 0.16 for the number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$, representing the proportion of variation in those measurements that was attributable to differences between rather than within each household.

Discussion

Time-weighted average $PM_{2.5}$ concentrations in our study homes were approximately 7 times higher than the daily mean $PM_{2.5}$ guidelines recommended by the World Health Organization (Anon. 2006). Based on the random intercept model estimates, changing a household cookstove from biomass only to exclusive use of clean fuels would be expected to reduce the time-weighted average daily $PM_{2.5}$ concentrations by 65 $\mu g/m^3$ (95% CI 4–125). Each external door and window was associated with a significant decrease in $PM_{2.5}$, but the effect of doors and windows on $PM_{2.5}$ was less important than the effect of biomass use. World Health Organization guidelines on indoor $PM_{2.5}$ concentrations recommended interim targets for reducing daily mean PM concentrations in settings where achieving the standard of 25 $\mu g/m^3$ is difficult (Anon. 2006). Our results suggest that the first interim target of 75 $\mu g/m^3$ (Anon. 2006) may be achievable in our study community if biomass stoves are replaced by cleaner burning fuels.

Indoor tobacco smoking has been repeatedly associated with increased PM indoors in high income countries (Van Deusen et al. 2009; Monn et al. 1997), and one study in Bangladesh found that children who had a family member who smoked in the home were at increased risk for acute respiratory infection (Rahman and Rahman 1997). Smoking tobacco indoors was associated with a 0.6 hour increase (95% CI 0.1 – 1.1) in the number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ in our study. Tobacco was smoked indoors in 28% of our study households and these results suggest efforts to prevent indoor tobacco smoking may meaningfully reduce indoor exposures to $PM_{2.5}$ in this community.

Interventions to reduce indoor exposures to PM in low-income countries have focused on promoting use of cleaner burning fuels, like natural gas or electricity, or use of more efficient stoves (Smith 2002; Albalak et al. 2001; Bruce et al. 2000). Burning clean fuels was associated with lower time-weighted $PM_{2.5}$ concentrations in our study, but even homes that burned clean fuels for cooking had mean $PM_{2.5}$ concentrations approximately 6 times higher than the World Health Organization guidelines (Anon. 2006). A small study from Bangladesh showed that homes that cooked with natural gas experienced indoor PM concentrations that mirrored ambient concentrations over a 24-hour period (Dasgupta et al. 2006a). Another study from a crowded community in Bangladesh, similar to our study site, reported that the ambient air was highly polluted from numerous sources and this pollution likely influenced indoor air quality (Chowdhury et al. 2012). Penetration of ambient pollution indoors has been established in other settings (Abt et al. 2000; Sapkota et al. 2005). These findings suggest that indoor PM exposures in our urban community are partially influenced by ambient PM sources.

The most important predictor of indoor $PM_{2.5}$ concentrations in our study was season, but the explanation for this finding is unclear. There could be a number of explanations for the large increases in $PM_{2.5}$ concentrations we observed during winter. One study from rural Bangladesh showed that the ability of air to move through the house was associated with decreased concentrations of particulate matter (Begum et al. 2009). As temperatures decrease in the winter months, windows and doors may be closed more often, reducing ventilation and thus trapping $PM_{2.5}$ inside. In addition, there may have been increases in biomass burning in homes during winter that were not captured in our data collection. In our analyses, we did not repeat measurements of ventilation or fuel use in multiple seasons. However, 67% of households did not cook inside the home, the location of the cooking stove was not associated with $PM_{2.5}$ concentrations, and households that cooked outside experienced the same seasonal variation in $PM_{2.5}$ concentrations as households that cooked inside. This suggests that even if there were differences in what was burned in the stove during winter, these differences are unlikely to account for the large increases in $PM_{2.5}$ we observed.

Another plausible explanation for the increase during winter is the contribution of ambient $PM_{2.5}$ sources to indoor air in this community. Ambient PM concentrations in Dhaka show a strong seasonal pattern with peaks in the winter, similar to the winter peaks observed in this study (Begum et al. 2011). Ambient PM concentrations in Dhaka may be higher during the winter due to meteorological conditions, including temperature inversions and relatively little rainfall (Begum et al. 2011). However, there may also be seasonal differences in ambient sources of PM which contribute to these seasonal differences. Analyses of the components of ambient air pollution in Dhaka in the winter suggest that 30% of fine PM is attributable to brick kiln fires (Begum et al. 2011). More than 500 brick kilns burn continuously during the dry season, from October to May, on the northern side of Dhaka (Croitoru and Sarraf, 2012). More research is needed to better understand the possible role of ambient PM in determining indoor PM exposures in urban Bangladesh.

Measured $PM_{2.5}$ concentrations were highly variable within households over time, indicating that one 24-hour measurement at one time point is unlikely to provide a reliable estimate of exposure for epidemiologic studies. The number of hours that the $PM_{2.5}$ concentrations exceeded 100 $\mu g/m^3$ were less variable and not affected by the monitors' limit of detection, and may be a useful alternative metric for use to describe exposure-disease relationships.

Our findings are limited because we only measured fuel use at baseline and the end of the study and these may have changed over the course of the study period and may have changed by season. However, we attempted to capture variability in fuel use during the study period and defined a distinct category of households that used primarily cleaner fuels with some biomass burning during shortages of other fuels. Our results show that these homes had slightly higher concentrations of $PM_{2.5}$ than homes that used exclusively cleaner fuels, but much lower levels than homes that used exclusively biomass, indicating that our household fuel use classification system was valid. We measured the number of doors and windows that opened to the outside as a proxy measurement for ventilation in the home. However, the placement of windows or doors, and the timing of when they were open would likely change their effectiveness at reducing $PM_{2.5}$ concentrations and those data were not included in our model.

Conclusions

Indoor daily $PM_{2.5}$ concentrations in this low-income neighborhood are more than 7 times greater than those suggested by the World Health Organization guidelines for air quality (Anon. 2006). Interventions to eliminate cooking with biomass could significantly reduce exposures to $PM_{2.5}$ in these homes. Interventions to increase ventilation and prevent indoor tobacco smoking may also meaningfully reduce exposures. The most important predictor of indoor $PM_{2.5}$ concentrations was season. Large increases in $PM_{2.5}$ concentrations during winter remain unexplained. Studies to investigate additional sources of indoor $PM_{2.5}$ during winter, including ambient $PM_{2.5}$, are needed.

Acknowledgments

Acknowledgements and funding: This study was funded by the United States Centers for Disease Control and Prevention (CDC), grant number U01/CI000628-02 and the National Institutes of Health, USA (NIH), grant number 5R01 AI043596. ICDDR,B acknowledges with gratitude the commitment of CDC and NIH to its research efforts. The authors wish to thank the children and their families for their participation in this cohort. We appreciated the statistical assistance of Jaynal Abedin and Yushuf Sharker.

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Highlight

- We described the determinants of indoor particulate matter in Dhaka, Bangladesh.
- Particulate matter concentrations were 7 times higher than recommended levels.
- All homes had high levels of particulate matter, regardless of cooking fuel type.
- The strongest determinant of indoor particulate matter was season.

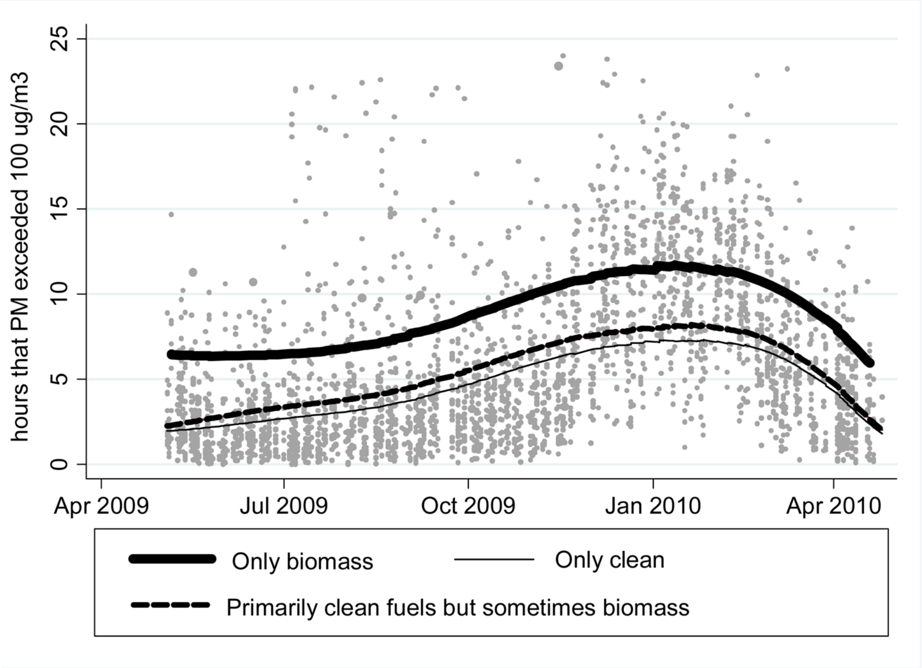

Figure 1.

Number of hours that $PM_{2.5}$ concentrations exceeded 100 μg/m^3 for all observations with locally weighted scatterplot smoothing (LOWESS) curves by the type of fuel used for cooking, May 2009 – April 2010

Table 1

Characteristics of study homes in a low-income, urban neighborhood in Mirpur, Dhaka, 2009 – 2010 (N=258)

Household characteristics	**N (%)**
Tobacco smoked inside home	73 (28)
Cooking stove located inside dwelling	85 (33)
Type of fuel primarily used for cooking	
Natural gas	164 (64)
Electricity	51 (20)
Biomass (wood, jute, bamboo, paper)	40 (16)
Kerosene	3 (1)
Regularly burns kerosene indoors for any purpose	119 (46)
Fuel use category	
Only uses clean fuels	107 (42)
Uses both clean and biomass fuels	135 (52)
Only uses biomass fuels	16 (6)
	(median, interquartile range)
Number of external doors and windows in sleeping space	2 (1 – 3)
Number of people in household	5 (4 – 6)
Floor of living space in meters^2	9.6 (7.8 – 11.3)

Table 2

Time-weighted average particulate matter ($PM_{2..5}$) concentrations, 90th percentiles, and daily hours >100 μg/m^3 by fuel type, season, location of cooking stove, and number of external doors and windows

	Percent of minute measurements at or below limit of detection	Time- weighted average in μg/m^3 (95% CI)	90th percentile in μg/m^3 (95% CI)	Daily hours >100 μg/m^3 (95% CI)
Overall	49	190 (170 – 210)	438 (387 – 489)	5.7 (5.5 – 5.9)
By fuel type used				
Biomass fuels only	37	308 (237 – 378)	708 (532 – 884)	9.0 (8.4 – 9.7)
Both clean and biomass fuels	49	193 (167 – 218)	438 (374 – 504)	5.8 (5.6 – 6.0)
Clean fuels only	52	165 (130 – 200)	390 (302 – 479)	5.0 (4.7 – 5.2)
By cooking stove location				
Inside	49	181 (160 – 203)	415 (345 – 485)	5.8 (5.5 – 6.1)
Outside	49	194 (166 – 223)	450 (382 – 518)	5.7 (5.5 – 5.9)
By season				
Winter	22	343 (295 – 392)	797 (675 – 919)	10.5 (10.2 – 10.8)
Spring	57	121 (99 – 143)	281 (201 – 360)	4.1 (3.8 – 4.3)
Monsoon	64	162 (120 – 203)	377 (278 – 475)	3.7 (3.5 – 4.0)
Post-monsoon	53	117 (98 – 136)	255 (203 – 306)	4.9 (4.6 – 5.2)
By number of external windows and doors				
2 or more	52	175 (149 – 201)	395 (335 – 454)	5.2 (5.0 – 5.4)
0 – 1	48	223 (193 – 253)	535 (440 – 630)	6.8 (6.5 – 7.2)

Table 3

Population-averaged associations between time-weighted average and 90th percentile $PM_{2.5}$ concentrations and daily hours >100 $\mu g/m^3$ and household characteristics, fuel use, and season

	Coefficient (95% CI)		
	Time-weighted average in $\mu g/m^3$	**90th percentile in $\mu g/m^3$**	**Daily hours >100 $\mu g/m^3$**
Primarily use biomass [≠]	65 (6 – 124)	124 (-23 – 272)	1.9 (1.3 – 2.5)
Ever use kerosene	40 (−4 – 85)	105 (−6 – 217)	0.7 (0.3 – 1.2)
Stove located inside home	−19 (−65 – 28)	−48 (−164 – 68)	0 (−0.5 – 0.5)
Tobacco smoked inside home	0 (−48 – 48)	−8 (−129 – 113)	0.6 (0.1 – 1.1)
Per each external window and door	−22 (−43 – −0.2)	−56 (−110 – −1)	−0.5 (−0.7 – −0.2)
Seasons [†]			
Winter	225 (163 – 287)	537 (377 – 696)	5.6 (5.2 – 6.0)
Spring	3 (−59 – 66)	24 (−138 – 184)	−0.9 (−1.3 – −0.5)
Monsoon	46 (−13 – 105)	123 (−26 – 274)	−1.2 (−1.5 – −0.8)
Intercept	140 (67 – 214)	322 (137 – 508)	5.7 (4.6 – 6.8)

[≠] Compared to households that primarily use clean fuels

[†] Post-monsoon is the baseline

Table 4

Random effects coefficients representing changes in time-weighted average and 90th percentile PM$_{2.5}$ concentrations and daily hours >100 µg/m^3 associated with household characteristics, fuel use, and season

	Coefficient (95% CI)		
	Time-weighted average in µg/m^3	**90th percentile in µg/m^3**	**Daily hours >100 µg/m^3**
Primarily use biomass ≠	65 (4 – 125)	124 (−27 – 275)	1.9 (1.3 – 2.5)
Ever use kerosene	40 (−6 – 85)	105 (−9 – 219)	0.7 (0.2 – 1.2)
Stove located inside home	−19 (−66 – 29)	−48 (−167 – 71)	0 (−0.5 – 0.5)
Tobacco smoked inside home	0 (−50 – 49)	−8 (−132 – 116)	0.6 (0.1 – 1.1)
Per each external window and door	−22 (−44 – 0)	−55 (−111 – 0)	−0.5 (−0.7 – −0.2)
Seasons †			
Winter	225 (163 – 287)	537 (377 – 696)	5.6 (5.2 – 6.0)
Spring	4 (−59 – 66)	24 (−137 – 184)	−0.9 (−1.3 – −0.5)
Monsoon	46 (−13 – 105)	124 (−26 – 274)	−1.2 (−1.5 – −0.8)
Intercept	140 (66 – 215)	323 (134 – 511)	5.1 (4.4 – 5.7)

[≠] Compared to households that primarily use clean fuels

[†] Post-monsoon is the baseline