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Improving Indoor Air in Rural Bangladesh:
Results of Controlled Experiments

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In rural Bangladesh, Indoor Air Pollution (IAP) is dangerously high for poor households dependent on biomass cooking fuels. Based on earlier World Bank research, controlled, scientifically monitored experiments were conducted in Burumdi village, Narayanganj District, to test the effects of structural arrangements and ventilation practices on IAP. Findings suggest optimal structural choices and village-level measures to reduce IAP exposure.

Most of Bangladesh's rural households collect or purchase biomass—fuelwood, cow dung, crop residues, tree leaves, and grass—to cook all or part of their meals, using traditional, fixed clay stoves. The high moisture content of biomass cooking fuels, combined with the inefficiency of traditional stoves, results in incomplete combustion, producing indoor air pollution (IAP) (Asaduzzaman, Barnes, and Khandker 2009).[1] Recent World Bank research using the latest air-monitoring technology and results of a national household survey show that, for respirable airborne particulates (PM_{10}),[2] concentrations of 300 µg per m^3 or greater are common, implying widespread exposure to a serious health hazard (Dasgupta et al. 2006).[3]

Study Rationale

To date, most IAP studies have focused on the use of modern fuels, such as kerosene and liquefied petroleum gas (LPG), and improved stove designs. But structural arrangements—from building materials and space configurations to cooking locations—and ventilation practices are also a major issue. Testing the significance of these factors in reducing IAP exposure is particularly important in rural Bangladesh, where many poor families are likely to depend on biomass cooking fuels and stoves for some time.[4]

Study Method

Architects familiar with the climatic conditions and cultural constraints faced by poor Bangladeshi households studied building materials, housing configurations, and construction techniques in various regions of the country to develop a set of structural options. At each site, local workers were hired to construct experimental houses identical to the structures used by poor families in the area, using standard local building practices.

Traditional stove use in Burumdi village.

Four sets of houses were built, corresponding to permanent walls made of thatch, mud, corrugated iron (tin), and brick. The thatch-, mud-, and tin-walled houses had mud flooring on rammed earth; while the brick-walled houses had conventional cement concrete flooring. Roofing materials were altered to produce a variety of standard combinations (Table 1). The axes of the houses were aligned in a north-south direction to capture varying wind conditions. Houses were furnished to simulate life settings.

Within these diverse sets of cooking environments, housewives cooked the standard midday meal for a family of four on traditional stoves.[5] Four common space configurations for kitchens were used: interior, attached, detached,[6] and open air. For attached and detached kitchens, construction materials for walls, floors, and roofs varied.[7] Kitchen configurations and

[1] According to the World Health Organization, acute respiratory infection from IAP kills an estimated 1 million children per year in developing countries (see WHO Global and Regional Burden of Disease Report, 2004 [www.who.int/publications/cra/en]).

[2] PM_{10} refers to particulate matter with a diameter of 10 microns.

[3] In eight Italian cities with far lower annual concentrations (45–55 µg per m^3), Galassi et al. (2000) found that reducing PM_{10} concentrations had substantial health benefits.

[4] Burumdi village, located 27 km southeast of the capital city of Dhaka, was selected as the study site. Most of Burumdi's 1,600 residents (about 290 households) are either self-employed workers in nonagricultural sectors or service providers. The nearest secondary road and manufacturing industrial unit are each located 3 km from the village; other potentially polluting manufacturing industries are more than 10 km away. No villagers own motor vehicles for private transport or motorized agricultural equipment.

[5] The midday meal consists of rice, lentils, vegetable curry, and fish.

[6] A space enclosed by walls and a roof located a short distance from the house.

[7] Variations were thatch, mud, tin, and brick (walls); cement, concrete, and mud (floors); and thatch, tin, and concrete (roofs).

Table 1. Summarized Distribution of Experiments

Wall material	*Roofing material*	*No. of experiments*
House		
Brick	Concrete	37
	Tin	63
Tin	Tin	112
	Thatch	0
Mud	Tin	117
	Thatch	0
Thatch	Tin	89
	Thatch	80
Kitchen		
Brick	Concrete	16
	Tin	34
Tin	Tin	134
	Thatch	33
Mud	Tin	46
	Thatch	34
Thatch	Tin	99
	Thatch	53

Type	*No. of experiments*
Kitchen	
Interior	59
Attached	165
Detached	225
Open air	49
Fuel	
Clean	54
Fuelwood	186
Cow dung	100
Other	158

Source: Dasgupta et al. (2009).

cooking arrangements were limited to those commonly observed in rural Bangladesh. The experiments allowed for use of a ceiling fan in the living space. Typical fuels—kerosene, LPG, fuelwood, and other forms of biomass—were used in the experiment with a small amount of kerosene used for initial ignition.[8] Other sources of indoor pollution were eliminated.[9]

Monitoring PM_{10} Concentrations

In these various cooking environments, indoor air quality was monitored from April 2005 to June 2006.[10] This period was selected to capture high- and low-dust seasonal variations. In the high-dust season (November–March), humidity is low and rainfall is rare. Conversely, in the low-dust season (April–June and October), pre- and post-monsoon rainfall is frequent.

Because brief exposure to highly concentrated particulate matter may have different health effects than sustained lower-level exposure, the controlled experiments used both real-time and air-sampler monitoring equipment. The Thermo Electric personal DataRam

Kitchen Types

Monitoring air quality of kitchen types using the Airmetrics Minivol Portable Air Sampler.

(pDR-1000) sampler was used to record airborne PM_{10} concentrations at regular 2-minute intervals over a 24-hour cycle,[11] while the Airmetrics MiniVol Portable Air Sampler measured 24-hour average PM_{10} concentrations.[12] Readings using these two types of equipment provided a detailed record of IAP concentrations for each controlled experiment. As Table 2 shows, the IAP readings were generally lower than those of other studies in rural Bangladesh. These likely resulted from the experimental design, which had varying types of living conditions.

Ambient PM_{10} concentrations were monitored 76 times over the experiment period using the MiniVol air sampler. Readings revealed wide inter- and intra-seasonal variations of PM_{10} in the outdoor environment (Table 3).

Data Analysis

Regression analysis was conducted to examine the roles of basic IAP determinants: kitchen configurations, building materials, and fuels. These factors were varied under fixed experimental conditions,

[8] For example, cooking with cow dung/rice husk/jute inside the house is uncommon and thus was excluded.

[9] Smoking, lighting of candles, burning of oil or kerosene lamps, and burning of mosquito and insect repellents were not allowed.

[10] With the exception of the monsoon period (July–September, 2005).

[11] The pDR-1000 sampler uses a light-scattering photometer (nephelometer); the operative principle is realtime measurement of light scattered by aerosols, integrated over as wide a range of angles as possible. For details, visit www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_18492.pdf.

[12] The MiniVol was programmed to draw air at 5 liters per minute through PM_{10} particle-size separators (impactors) and filters; the particles were caught on filters, which were weighed pre- and post-exposure with a microbalance. For details, visit www.airmetrics.com/products/minivol/index.html.

Table 2. Recordings of PM_{10} Concentrations

Season	Monitor location	PM_{10} (µg per m^3) concentration			
		Mean	Median	Minimum	Maximum
Airmetrics MiniVol Portable Air Sampler (24-hour average)					
High-dust	Kitchen	222	213	39	473
High-dust	Living room	161	155	45	320
Low-dust	Kitchen	129	125	30	311
Low-dust	Living room	69	64	22	184
Thermo Electric personal DataRAM (pDR-1000) (2-minute intervals)					
					95th percentile
High-dust	Kitchen	585	404	8	88,900
High-dust	Living room	468	370	1	382,400
Low-dust	Kitchen	284	146	1	95,800
Low-dust	Living room	843	132	1	194,600

Source: Dasgupta et al. (2009).

Note: Because the pDR-1000 samplers recorded shorter, more extreme exposures each time fuel was added, the resulting distributions had higher maximums, means (pulled upward by higher maximums), and standard deviations. MiniVols recorded flatter distributions for the 24-hour cycle.

Table 3. Recordings of Ambient PM_{10} Concentrations Using Airmetrics MiniVol Portable Air Sampler (24-hour average)

Season	No. of readings	Ambient PM_{10} (µg per m^3) concentration		
		Mean	Minimum	Maximum
High-dust	41	171	82	274
Low-dust	35	54	15	125

with prescribed burn times for fuels, in both high- and low-dust seasons. Regression was conducted only for houses where PM_{10} concentrations were monitored concurrently in kitchens and living rooms.

In the high-dust season, the 24-hour average PM_{10} concentration recorded in interior kitchens was 187 µg per m^3 lower than that of detached or open-air kitchens. Attached kitchens had PM_{10} concentrations 49 µg per m^3 lower than that of detached or open-air kitchens. In the high-dust season, kitchen PM_{10} concentrations were significantly higher for brick and mud than for thatch and tin. Both fuelwood and cow dung accounted for increments of 70 µg per m^3 compared to cleaner-burning fuels; other biomass fuels added an even greater increment (about 90 µg per m^3).[13] In the low-dust season, dung accounted for the greatest increment (109 µg per m^3) over cleaner fuels, followed by fuelwood (62 µg per m^3) and other biomass fuels (57 µg per m^3).

Diffusion of kitchen pollution into the living room was large during the high-dust season. All else being equal, living-room pollution increased 0.5–0.6 µg per m^3 for each increase of 1 µg per m^3 in kitchen pollution. With regard to building materials, inter-seasonal results for living-room air were mixed.

[13] Differences in performance between improved and traditional biomass stoves were not statistically significant, which may have resulted from the small sample size of improved stove experiments.

Experimental data from the pDR-1000 samplers—pollution measured at 2-minute intervals over a 24-hour cycle—provided useful information on the relationship between exposure patterns, building materials, kitchen configurations, and cooking fuels. To assess kitchen exposure patterns during the period of maximum IAP exposure for each experiment, 150 regular-interval pD-RAM observations were drawn from 5 hours covering the midday meal preparation period. For each experiment, inferences about distribution patterns were drawn from the mean, maximum, minimum, standard deviation, and median. Building materials did not significantly affect exposure patterns. Attached kitchens promoted more intense exposure, while detached configurations promoted more sustained exposure.

Findings Highlights

Seasonality is a key determinant of household-level IAP. In the high-dust season:

- Outdoor air pollution significantly affects indoor ambient pollution levels.[14]
- Interior kitchens have better air quality than detached or open-air kitchens.[15]
- Pollution from fuelwood, dung, and other biomass fuels is more severe.
- Building materials significantly affect indoor pollution; of the four materials studied, tin contributes the most to healthy air quality, followed by thatch, mud, and brick.[16]
- Use of a fan in the living room, which can be seriously affected by IAP from cooking smoke,[17] offers significant benefits.[18]

[14] Regression analysis revealed a difference of 100 µg per m^3 between high-dust (155 µg per m^3) and low-dust (55 µg per m^3) seasons (Dasgupta et al. 2004).

[15] This is not the case during the low-dust season; but, at that time, it is difficult to cook outside.

[16] In kitchens, tin or thatch walls are significantly less air-trapping than mud walls, which, in turn, are less so than brick. With regard to kitchen roofs, tin offers better air quality than thatch. In living rooms, tin walls offer better air quality than mud ones, which, in turn, are better than thatch or brick.

[17] Thus, male household members' avoidance of cooking areas does not protect them from IAP.

[18] Where households have access to electricity, use of a ceiling or table fan is common practice.

Conclusion

The above findings suggest various structural arrangements and village-level measures that could significantly mitigate IAP exposure for poor families in rural Bangladesh. First, given that outdoor pollution significantly affects indoor air quality for much of the year, simply venting cooking smoke to the outside would likely worsen indoor air quality for many village households, who typically live in clusters. Alternatively, cooking smoke could be ventilated through a stack tall enough to disperse smoke over a broad area, thereby reducing particulate concentration in village households. Over the longer term, the solution is to switch to cleaner-burning stoves and modern fuels; to increase their affordability, villagers could make negotiated bulk purchases.[19] Second, more permeable construction materials, such as tin, could be used to construct kitchens.[20] Finally, where extended family members live in household clusters, women could rotate cooking roles to reduce their exposure.

Are Bangladeshi villagers likely to adopt such collective innovations?[21] Most residents do not recognize pollution as a health issue, and changing traditional cooking patterns has often proven difficult around the world. Effective public education is required to convince village men and women that IAP poses a severe risk to themselves and their children, that the sources of IAP have been correctly identified, and that their actions could significantly improve their health. Villagers might accept centralized cooking arrangements if such activities were organized and financed effectively. Currently, the World Bank and the Government of Bangladesh are providing financial and technical assistance on a small scale via a collaborative pilot program. A follow-on impact evaluation could quantify the benefits associated with indoor air quality, IAP exposure, and health outcomes in a variety of rural household settings.

[19] Although not the focus of this work, high-quality, improved stoves with better combustion might also alleviate some of the conditions of both indoor and outdoor air pollution.

[20] A nationwide household survey conducted by the World Bank highlighted the popularity of tin as a construction material. Of the 1,550 households surveyed, 22 percent used tin to construct the walls of their living spaces, and 75 percent had tin roofs; 41 percent of kitchens had tin walls or roofs. In flood-prone areas, tin walls and roofs could be dismantled and reused. Some families noted that the heat-trapping property of tin walls and roofs kept poisonous snakes away from attached and detached kitchens.

[21] Community-based sanitation approaches have proven successful in Bangladesh and other developing countries.

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