Environ Health Prev Med (2010) 15:236–243
DOI 10.1007/s12199-009-0133-6

REGULAR ARTICLE

Indoor air pollution and the health of children in biomass- and fossil-fuel users of Bangladesh: situation in two different seasons

Md. Khalequzzaman · Michihiro Kamijima · Kiyoshi Sakai · Bilqis Amin Hoque · Tamie Nakajima

Received: 25 October 2009 / Accepted: 25 December 2009 / Published online: 21 January 2010

Abstract
Objectives Indoor air pollution levels are reported to be higher with biomass fuel, and a number of respiratory diseases in children are associated with pollution from burning such fuel. However, little is known about the situation in developing countries. The aim of the study was to compare indoor air pollution levels and prevalence of symptoms in children between biomass- and fossil-fuel-using households in different seasons in Bangladesh.
Methods We conducted a cross-sectional study among biomass- ($n = 42$) and fossil-fuel ($n = 66$) users having children <5 years in Moulvibazar and Dhaka, Bangladesh. Health-related information of one child from each family was retrieved once in winter (January 2008) and once in summer (June 2008). The measured pollutants were carbon monoxide (CO), carbon dioxide (CO_2), dust particles, volatile organic compounds (VOCs), and nitrogen dioxide.
Results Mean concentration of dust particles and geometric mean concentrations of VOCs such as benzene, toluene, and xylene, which were significantly higher in biomass- than fossil-fuel-users' kitchens ($p < 0.05$), were significantly higher in winter than in summer ($p < 0.05$). Levels of CO and CO_2, which were significantly higher in biomass than fossil-fuel users ($p < 0.05$), were significantly higher in summer than winter ($p < 0.05$). However, no significant difference was found in the occurrence of symptoms between biomass- and fossil-fuel users either in winter or in summer.
Conclusions It was suggested that the measured indoor air pollution did not directly result in symptoms among children. Other factors may be involved.

Keywords Indoor air pollution · Health · Children · Environmental · Bangladesh

Introduction

Approximately 50% of the world's population and up to 90% of rural households use biomass fuels as a domestic source of energy in the form of wood, crop residues, and animal dung [1]. Cooking and heating with such solid fuels is the major source of indoor air pollution and pollution levels that exceed the standard allowable limits in developing countries [2]. Polluted indoor air contains a range of health-damaging pollutants, such as particulate matter, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) [3–5]. These pollutants are able to cross the alveolar–capillary barrier and penetrate deep into the lungs [6]. Thus, the pollutants pose a risk for a number of respiratory diseases, such as acute respiratory tract infection (ARTI), chronic obstructive pulmonary disease (COPD), tuberculosis, and asthma, as well as for low birth weight, cataracts, and

Md. Khalequzzaman · T. Nakajima
Department of Occupational and Environmental Health, Nagoya University Graduate School of Medicine, Nagoya, Japan

M. Kamijima (✉)
Department of Occupational and Environmental Health, Nagoya City University Graduate School of Medical Sciences, 1 Kawasumi, Mizuho-cho, Mizuho-ku, Nagoya 467-8601, Japan
e-mail: kamijima@med.nagoya-cu.ac.jp

K. Sakai
Nagoya City Public Health Research Institute, Nagoya, Japan

B. A. Hoque
Environment and Population Research Center (EPRC), Dhaka, Bangladesh

blindness [7, 8]. The World Health Organization (WHO) has listed indoor air pollution from burning of biomass fuel as one of the top ten global health risks, as it is responsible for 2.7% of the global burden of disease [9]. Especially for women and children, who spend the most time indoors during fuel burning, levels of exposure to polluted air are reported to be higher [10]. Every year, 1.5–2 million deaths worldwide are attributed to indoor air pollution [7, 11], 1 million of which take the lives of children <5 years old due to ARTI but also of women due to COPD and lung cancer [12]. ARTI accounts for 19% of the total deaths in children <5 years old, making it the second most common cause of death in that age group [13].

Bangladesh is located in the northeastern part of south Asia. From March to June, the country experiences a hot summer season with high humidity and from November to the end of February, a cool, dry winter. For their domestic source of energy, 92% of Bangladesh's people depend on biomass fuel [14]. Indoor air pollution is responsible for an estimated 3.6% of the overall disease burden in the country [15]. About 25% of deaths among children <5 years old in Bangladesh is associated with ARTI [16]. Switching from biomass to fossil fuel is thus encouraged in Bangladesh, as pollution levels are believed to be higher with biomass fuel. Little is known about the situation in developing countries.

In our previous study, we found the level of indoor air pollutants was higher in fossil fuel than in biomass fuel, but the prevalence of some respiratory symptoms was significantly higher in biomass-fuel users' children [17]. Disagreement of our findings with most other studies encouraged us to conduct further study to clarify the seasonal difference as a possible confounding factor in pollution level, as well as the prevalence of symptoms. Some studies have suggested that the level of indoor air pollutants, especially VOCs, were the highest in winter and the lowest in summer [18–20]. Thus, we planned to conduct a cross-sectional study in Bangladesh among the biomass- and fossil-fuel users in two different seasons, winter and summer. The purpose of the study was to compare the indoor air pollution levels and prevalence of symptoms in children between biomass- and fossil-fuel-using households in different seasons in Bangladesh. By comparisons between seasons, we aimed to clarify whether a seasonal difference may play a role in the levels of indoor air pollution and the prevalence of respiratory symptoms in children in a developing country.

Methods

Study population

A cross-sectional study was conducted among biomass- and fossil-fuel users of urban Dhaka and urban Moulvibazar in Bangladesh: once in winter (January) and once in summer (June) 2008. There was socioeconomic and cultural proximity between the inhabitants of both areas. We found that both the biomass- and fossil-fuel users coexist in those areas. As there was natural gas supply in those areas and the gas users pay a fixed amount of money for the whole month, the number of biomass-fuel users was less compared with gas users. The areas were densely populated, and houses were very close to each other and in a cluster, separated by narrow roads. We asked if there was any child <5 years old in the household and if they agreed to participate in the study. If the answers were positive, we included them. This procedure was repeated in every house in the selected clusters until the targeted number of households (approximately 40 for each fuel type) was recruited. As a result, 42 biomass- and 66 fossil-fuel-using families with children <5 years of age (range 0–5 years) were selected. Most biomass-fuel users used wood as a cooking fuel, whereas fossil-fuel users employed only gas. Sociodemographic data of the respondents using questionnaires and observation checklists were collected from mothers of the children. Air pollution data were collected once in winter and once in summer. For gathering the health-related information of the children, one child from each household was taken into consideration. To apply the same selection rule throughout recruitment, we considered the oldest child when the number of eligible children was more than one. Symptom-related information of the children for the previous 1 month was collected from mothers using the questionnaire during interview. This study was conducted with all participants' informed consent and was approved by the ethical committee of Nagoya University Graduate School of Medicine.

Monitoring indoor air quality

Temperature, humidity, levels of CO, CO_2, and dust particles were measured in the kitchen during interviews with the respondents. CO and CO_2 concentrations were measured with detector tubes (type 106SC for CO and type 126SF for CO_2, Komyo Rikagaku Kogyo, Kawasaki, Japan) for 4 and 2 min, respectively. Concentrations of dust particles were measured with a digital dust monitor (model LD-3, Sibata Scientific Technology, Tokyo, Japan), and the mean of five 1-min measurements was used for statistical analysis. As the air quality of the kitchen was measured during interviewing and the cooking time was different from household to household, some mothers were cooking and others were not at the time of our visit. Formaldehyde (HCHO) and nitrogen dioxide (NO_2) were collected using a diffusion sampler packed with silica gel containing triethanolamine (passive gas tube for HCHO and NO_2; Sibata Scientific Technology). A diffusion sampler packed with activated charcoal (passive gas tube for organic solvents; Sibata Scientific Technology) was used for collecting 14 VOCs. The samplers were placed for approximately 24 h in the kitchen at a height of 80–90 cm, which is the average breathing height of children <5 years old. The households we studied were in clusters, and we assumed that the outdoor air pollutant concentrations of one household from one cluster were representative of other households of that cluster. Thus, we decided to measure the outdoor concentrations of one household from each cluster.

Analytical methods

Samplers used in Bangladesh were transported to Japan by air and analyzed by the same researchers. HCHO and NO_2 were extracted with distilled water and analyzed using spectrophotometry by the 4-amino-3-hydrazino-5-mercapto-1,2,4-triazole method and the sulfanilamide method, respectively [21]. VOCs were analyzed by the method reported by Sakai et al. [22]. Briefly, the adsorbent in the diffusive sampler was transferred into 7-ml vials, and 2-ml carbon disulfide (CS_2 to assess the working environment, Wako Pure Chemical Industries, Japan) was added. The vials were then shaken, left for 2 h, and centrifuged for 10 min at 3,000 rpm. One milliliter of a supernatant added with 5 µl of an internal standard solution (200 µg/ml, toluene-d8, Aldrich, USA) was then analyzed by a gas chromatograph with a mass spectrometer (GC–MS). The GC–MS (5980 Series II/5971A, Hewlett Packard, USA) was equipped with a 60 m × 0.25 mm i.d. capillary column coated with a 1.5-µm film of NB-1 (GL Sciences, Japan). The GC oven temperature was first maintained at 45°C for 5 min then programmed to 300°C at 10°C/min and maintained at 300°C for 7 min. For some samples, the analysis was performed under a total-ion-monitoring mode to examine all major peaks after selected-ion-monitoring mode targeting 14 VOCs.

Statistical methods

Pollutant concentrations, temperature, and humidity between biomass and fossil fuels were statistically compared by Student's t test after appropriate transformation of variables, if necessary. Frequencies of findings were compared using Fisher's exact test. When comparing between biomass and fossil fuels based on measurement during cooking or noncooking time, a two-way analysis of variance (ANOVA) was performed to calculate significance. Mann–Whitney U test was performed for calculating the significance of monthly income. A two-tailed p value <0.05 was considered to indicate a statistically significant difference. The mean concentrations of 14 VOCs, HCHO, and NO_2, which were approximately log-normally distributed, were calculated as geometric mean. When the concentrations were below the detection limit, they were set at half of the detection limit while calculating the geometric means. By taking the biomass-fuel-users' children as a control group, we clarified how much the fossil-fuel-users' children were at risk of suffering from symptoms. In this regard, multivariate regression analysis was conducted to estimate the crude and adjusted odd ratios (ORs) and their 95% confidence intervals (95% CIs) for children's symptoms with/without adjustment for potential confounders, including education, monthly income, number of family members per room, frequency of cooking, main wall material of house, main floor material of house, and location of kitchen. Calculations were performed with Statistical Package for the Social Sciences (SPSS) for Windows, version 16.0 software (SPSS Inc., Chicago, IL, USA).

Results

Table 1 describes the sociodemographic conditions of respondents. Educational background was significantly higher in fossil-fuel users than in biomass-fuel users ($p < 0.01$). The monthly income for fossil-fuel users was significantly higher than the biomass-fuel users ($p < 0.01$). There was no significant difference in the number of family members, but as the number of rooms was significantly higher in fossil-fuel users ($p < 0.01$), the number of family members per room was significantly higher in biomass-fuel users than fossil-fuel users ($p < 0.01$). Considering kitchen location, there was a significant difference between the biomass- and fossil-fuel users ($p < 0.01$). For biomass-fuel users, 69% of the houses had a separate kitchen and in contrast, 89% of the fossil-fuel users did not have a kitchen separate from the house. In fossil-fuel users, a significantly higher percentage of houses (62%) cooked three times per day compared with biomass-fuel users, where 62% of houses cooked twice a day ($p < 0.01$). Thus, there was a significant difference in the mean cooking hours between fossil- (3.3 h/day) and biomass-(2.8 h/day)-fuel users ($p < 0.01$).

The house and kitchen characteristics of the respondents are shown in Table 2. There was a significant difference in the type of main roof, wall, and floor materials between biomass- and fossil-fuel-user houses and kitchens ($p < 0.01$). For roofs and walls, biomass-fuel users' houses and kitchens were mainly of tin, whereas those fossil-fuel users were made of concrete and brick. A large number of biomass-fuel users' houses and kitchen floors were made of mud, whereas fossil-fuel users employed concrete.

Temperature, humidity, CO, CO_2, and dust particles are shown in Table 3. Considering the time of measurement,

Table 1 Sociodemographic conditions of respondents

Factor	Biomass ($n = 42$)	Fossil ($n = 66$)	p Value
Age (years, mean ± SD)	28.0 ± 7.7	27.7 ± 5.6	0.79
Education n (%)			<0.01
No education	36 (85)	13 (20)	
Primary	4 (10)	13 (20)	
Secondary	2 (5)	40 (60)	
Monthly Income			
USD, median (min/max)	58.0 (11.6/ 101.4)	87.0 (29.0/ 724.6)	<0.01
Number of family members (mean ± SD)	6.6 ± 2.4	6.9 ± 3.9	0.61
Number of rooms n (%)			<0.01
One room	19 (45)	8 (12)	
Two or more rooms	23 (55)	58 (88)	
Number of family members per room (mean ± SD)	4.0 ± 1.9	2.6 ± 1.8	<0.01
Separate kitchen n (%)			<0.01
Yes	29 (29)	7 (11)	
No	13 (31)	59 (89)	
Frequency of cooking n (%)			<0.01
Once	5 (17)	2 (3)	
Twice	26 (62)	23 (35)	
Three times	11 (26)	41 (62)	
Cooking hours/day, mean ± SD	2.8 ± 1.1	3.3 ± 0.9	<0.01
Fuel cost			0.45
USD/month, mean ± SD	6.3 ± 3.0	5.9 ± 0.3	
Sleeping in cooking room n (%)			0.75
Yes	5 (12)	6 (9)	
No	37 (88)	60 (91)	
Number of children <5 years old per family (mean ± SD)	1.2 ± 0.4	1.1 ± 0.2	<0.05
Age of observed children (years, mean ± SD)	2.7 ± 1.3	2.9 ± 1.4	0.51
Sex of observed children n (%)			0.98
Male	33 (79)	52 (79)	
Female	9 (21)	14 (21)	

SD standard deviation, *Max* maximum, *min* minimum

Table 2 Characteristics of houses and kitchens

Factor	Biomass ($n = 42$)	Fossil ($n = 66$)	p Value
House			
Main roof material n (%)			<0.01
Concrete	0 (0)	28 (42)	
Corrugated tin	42 (100)	38 (58)	
Main wall material n (%)			<0.01
Brick	22 (52)	62 (95)	
Tin	13 (31)	3 (5)	
Wood/bamboo	7 (17)	0 (0)	
Floor material n (%)			<0.01
Concrete	23 (55)	64 (97)	
Mud	19 (45)	2 (3)	
Kitchen			
Main roof material n (%)			<0.01
Concrete	0 (0)	25 (38)	
Tin	19 (45)	40 (61)	
No roof	23 (55)	1 (1)	
Main wall material n (%)			<0.01
Brick	16 (38)	62 (94)	
Tin	18 (43)	3 (5)	
Bamboo	7 (17)	1 (1)	
No wall	1 (2)	0 (0)	
Floor material n (%)			<0.01
Concrete	12 (29)	63 (96)	
Mud	30 (71)	3 (4)	

the level of CO in a fossil-fuel-using kitchen in winter, and the humidity and CO levels in a biomass-fuel-using kitchen in summer were significantly higher during cooking than at other times ($p < 0.05$). Levels of humidity, CO, dust particles, in winter and humidity, CO, CO_2, and dust particles in summer were significantly higher in the biomass-fuel-using kitchen than the fossil-fuel-using kitchen, both during cooking and at other times ($p < 0.05$). Levels of CO and CO_2 in biomass-fuel-users' kitchen measured during cooking were significantly lower in winter than summer ($p < 0.05$). There was a significant difference in the level of dust particles in biomass-fuel kitchens measured during noncooking times and fossil kitchens during cooking ($p < 0.05$). They were both higher in winter.

Airborne concentrations of VOCs and NO_2 are displayed in Table 4. In winter, the geometric mean indoor concentrations of hexane, benzene, toluene, xylene, and tetrachloroethylene were significantly higher in biomass-fuel-using than in fossil-fuel-using kitchens ($p < 0.05$). But the level of formaldehyde was significantly higher with fossil fuel than biomass fuel ($p < 0.05$). In summer, levels of benzene, toluene, and xylene were significantly higher in biomass- than fossil-fuel-using kitchens ($p < 0.05$). The outdoor concentrations of hexane, benzene, toluene, and NO_2 were also significantly higher in biomass- than fossil-fuel users both in winter and summer ($p < 0.05$). In addition, the levels of xylene, tetrachloroethylene, and methyl ethyl ketone were significantly higher in biomass- than fossil-fuel users outdoors during winter ($p < 0.05$). Geometric mean outdoor concentrations of benzene, xylene, tetrachloroethylene, and methyl ethyl ketone in biomass-fuel users, and NO_2 in fossil-fuel users outdoors were significantly higher in winter than summer ($p < 0.05$).

Table 3 Indoor air quality in kitchens

Indicators	During cooking[a] ($n = 51$)		During noncooking[a] ($n = 57$)	
	Biomass ($n = 18$)	Fossil ($n = 33$)	Biomass ($n = 24$)	Fossil ($n = 33$)
Winter				
Temperature (°C)	27.4 ± 2.4†	27.7 ± 2.5†	27.6 ± 2.8†	28.0 ± 2.9
Humidity (%)	52.0 ± 8.4$^{\#,\dagger}$	57.9 ± 7.3†	50.5 ± 8.7$^{\#,\dagger}$	58.3 ± 6.0
CO (ppm)	6.3 ± 9.8$^{\#,\dagger}$	2.3 ± 3.6*	2.8 ± 4.0$^{\#}$	0.6 ± 0.9
CO_2 (ppm)	619 ± 196†	582 ± 158	652 ± 235	617 ± 186
Dust particles (mg/m^3)	0.821 ± 1.011$^{\#}$	0.141 ± 0.119†	0.454 ± 0.306$^{\#,\dagger}$	0.097 ± 0.080
Summer				
Temperature (°C)	31.0 ± 1.6	31.6 ± 2.1	33.5 ± 7.6	33.1 ± 8.1
Humidity (%)	81.1 ± 7.2*$^{,\#}$	73.6 ± 7.4	75.1 ± 6.8	75.7 ± 4.9
CO (ppm)	19.6 ± 15.1*$^{,\#}$	2.0 ± 3.7	3.6 ± 7.6$^{\#}$	0.6 ± 1.9
CO_2 (ppm)	858 ± 278$^{\#}$	674 ± 259	797 ± 296$^{\#}$	597 ± 182
Dust particles (mg/m^3)	0.633 ± 0.727$^{\#}$	0.064 ± 0.099	0.208 ± 0.253$^{\#}$	0.041 ± 0.049

Mean ± standard deviation, *$p < 0.05$ compared with noncooking time, $^{\#}p < 0.05$ compared with fossil, $^{\dagger}p < 0.05$ compared with summer

[a] Households were divided according to whether mothers were cooking or not during the environmental measurement

Table 4 Airborne concentrations (μg/m^3) of volatile organic compounds (VOCs) and nitrogen dioxide (NO_2) in kitchens and outdoors

Class	Compounds	Concentration (μg/m^3)[a]				
		DL	Kitchen		Outdoors	
			Biomass ($n = 42$)	Fossil ($n = 66$)	Biomass ($n = 9$)	Fossil ($n = 10$)
Alkanes	Hexane	3.2				
	Winter		7.1 (2.7)*	<DL$^{\#}$	13.4 (3.7)*	<DL$^{\#}$
	Summer		5.4 (2.2)	7.3 (2.7)	5.8 (2.9)*	20.4 (1.9)
Aromatics	Benzene	7.6				
	Winter		54.2 (2.5)*$^{,\#}$	13.7 (2.1)$^{\#}$	60.8 (2.2)*$^{,\#}$	7.4 (2.0)
	Summer		31.4 (2.7)*	7.8 (2.3)	23.1 (2.3)*	5.6 (2.2)
	Toluene	1.6				
	Winter		34.2 (5.1)*	2.7 (6.3)$^{\#}$	35.1 (8.7)*	1.1 (3.0)
	Summer		26.8 (2.8)*	7.3 (2.8)	15.3 (2.2)*	3.0 (4.2)
	Xylene	3.3				
	Winter		18.5 (2.9)*$^{,\#}$	3.8 (3.2)$^{\#}$	17.8 (3.9)*$^{,\#}$	2.0 (1.9)
	Summer		9.3 (3.0)*	4.6 (2.4)	5.2 (1.9)	<DL
Hydrocarbons	Tetrachloroethylene	1.4				
	Winter		2.9 (2.3)*$^{,\#}$	<DL	4.3 (3.0)*$^{,\#}$	<DL
	Summer		<DL*	<DL	<DL	<DL
Ketones	Methyl ethyl ketone	8.1				
	Winter		<DL*	<DL	8.6 (2.2)*$^{,\#}$	<DL
	Summer		<DL*	<DL	<DL	<DL
Aldehydes	Formaldehyde					
	Winter		9.9 (4.1)*$^{,\#}$	17.2 (3.2)	5.5 (2.6)	3.7 (4.0)
	Summer		19.1 (2.7)	14.4 (3.8)	9.6 (2.6)	1.8 (5.2)
NO_2	Winter		60.1 (2.0)	56.2 (2.3)	68.0 (2.0)*	18.5 (1.6)$^{\#}$
	Summer		45.2 (1.9)	46.7 (3.3)	38.2 (2.1)*	7.4 (2.2)

Levels of trichloroethylene, chloroform, 1,1,1-trichloroethane, 1,2-dichloroethane, carbon tetrachloride, *p*-dichlorobenzene, butyl acetate, and butyl alcohol are not shown, as they were found to be below the detection limit in all measured cases

DL detection limit

* $p < 0.05$ compared with fossil

$^{\#}$ $p < 0.05$ compared with summer

[a] Geometric mean (geometric standard deviation). Concentrations below DL were set at half of the DL for calculating geometric mean

Table 5 Prevalence of symptoms and signs among biomass- and fossil-fuel-users' children

Symptoms in last 1 month	Biomass[a] *n* (%)	Fossil[a] *n* (%)	Crude OR			Adjusted OR[b]			Other significant factors
			OR	95% CI	*p* Value	OR	95% CI	*p* Value	
Winter									
Redness of eye	24 (57)	19 (29)	0.3	0.1–0.7	<0.01	2.4	0.5–12.3	0.29	
Eye itchiness	11 (26)	18 (27)	1.1	0.4–2.5	0.90	1.7	0.2–14.0	0.60	Main wall material of house
Skin itchiness	17 (41)	21 (32)	0.7	0.3–1.5	0.36	0.3	0.1–1.4	0.12	Education, frequency of cooking
Runny nose	39 (93)	45 (68)	0.2	0.04–0.6	<0.01	1.3	0.1–11.9	0.82	
Cough	36 (86)	52 (79)	0.6	0.2–1.8	0.37	0.9	0.1–6.4	0.89	
Shortness of breath	8 (19)	10 (15)	0.8	0.3–2.1	0.60	1.6	0.2–11.3	0.63	Main wall material of house
Throat pain	5 (12)	7 (11)	0.9	0.3–3.0	0.83	0.6	0.5–7.3	0.72	
Diarrhea	16 (38)	26 (39)	1.1	0.5–2.3	0.89	0.7	0.1–3.3	0.61	Education
Summer									
Redness of eye	12 (29)	8 (12)	0.3	0.1–0.9	<0.05	0.9	0.1–7.9	0.92	Number of family members per room
Eye itchiness	7 (17)	4 (6)	0.3	0.1–1.2	0.09	0.9	0.1–11.0	0.60	Number of family members per room
Skin itchiness	8 (19)	7 (11)	0.5	0.2–1.5	0.22	0.3	0.03–2.2	0.23	
Runny nose	27 (64)	40 (61)	0.9	0.4–1.9	0.70	0.9	0.2–5.4	0.99	Location of kitchen
Cough	30 (71)	39 (59)	0.6	0.3–1.3	0.20	0.4	0.1–2.3	0.30	Main wall material of house, location of kitchen
Shortness of breath	10 (24)	17 (26)	1.1	0.5–2.7	0.82	3.6	0.6–20.4	0.15	Main wall material of house
Throat pain	0 (0)	0 (0)	NC	NC	NC	NC	NC	NC	
Diarrhea	10 (24)	7 (11)	0.4	0.1–1.1	0.07	0.5	0.1–2.8	0.46	

OR odds ratio, *95% CI* 95% confidence interval, *NC* not calculated due to small number

[a] Number of children observed at biomass- and fossil-fuel users was 42 and 66, respectively

[b] Adjusted for education, monthly income, number of family members per room, frequency of cooking, main wall material of house, main floor material of house, location of kitchen

Hexane levels in fossil-fuel users outdoors were significantly higher in summer than in winter ($p < 0.05$).

In Table 5, the prevalence of symptoms and signs of children <5 years in both winter and summer is shown. Crude ORs show that there was no significant difference in the occurrence of symptoms between children of biomass- and fossil-fuel users in both winter and summer. After adjustment with the potential confounders, the result remained the same. However, in winter, we found a significant association of the main wall material of houses with eye itchiness and shortness of breath, education with skin itchiness and diarrhea, and frequency of cooking with skin itchiness. In summer, results show association between the number of family members per room with eye redness and eye itchiness, location of kitchen with runny nose and cough, and main wall material with cough and shortness of breath.

Discussion

We measured the pollutant concentrations of CO, CO_2, and dust particles during the interviews. Airborne concentrations of these pollutants were significantly higher in biomass-fuel-users' than fossil-fuel-users' kitchens at different measured times, which is consistent with the findings of other studies [23–26]. Considering the seasonal variation, we found a significant difference in the levels of dust particles and CO between winter and summer. The mean concentrations of dust particles in winter and CO in summer were significantly higher, even much higher than the standard allowable limits (0.1 mg/m^3 for dust particles, and 7.6 ppm for CO) mentioned by the United Nations Development Program/Department of Economic and Social Affairs/World Energy Council (UNDP/DESA/WEC) World Energy Statement [2]. The possible reason behind the higher concentration of dust particles may be the dry, less humid weather in winter. In the wet summer, because of the significantly higher humidity, biomass-fuel users very often use less dried wood for cooking. Incomplete wood combustion might explain the high CO concentration in biomass-fuel use in summer.

Except for formaldehyde in winter, 24-h airborne concentrations of major VOCs, such as benzene, toluene, and xylene, were significantly higher in biomass- than in fossil-fuel-users' kitchens both in winter and summer. However, toluene and xylene levels were much lower than the guideline value of 260 μg/m^3 for toluene and 870 μg/m^3 for xylene set for Japan [27]. The levels of benzene and xylene were higher in winter than in summer. Some other studies also found the same seasonal difference [18–20]. Ventilation might be a key factor in our study regarding the higher concentrations in winter. The natural ventilation was poorer in winter because dwellers kept doors and windows closed. Outdoors, there was a similar trend in the levels of VOCs. For some pollutants in biomass-fuel use, concentrations outdoors were even higher than in the kitchen. Thus, indoor air in those households could be contaminated by outdoor air pollutants. In contrast with our study, we obtained significantly higher VOC concentrations for fossil-fuel users than biomass-fuel users in our previous study [17], presumably due to socioeconomic differences with biomass-fuel users in the studies. Biomass-fuel users in our previous study were poorer than those in this study. Kitchens of biomass-fuel users in this investigation were made with a mixture of tin, brick, and bamboo; almost all kitchens in our previously studied biomass-fuel users were of bamboo. There were many broken parts in those kitchen walls, which facilitated natural ventilation. Moreover, research revealed that concentrations of pollutants in the houses dramatically decrease within an hour of cooking, when ventilation is common [28].

Many studies have shown a positive association between the higher concentrations of indoor air pollutants from biomass-fuel users and the occurrence of respiratory diseases, especially in children <5 years of age. WHO/UNDP stated that indoor air pollution doubles the risk of pneumonia in children <5 years [2]. A significant association of cooking smoke from biomass-fuel combustion with the prevalence of asthma (OR = 2.20; 95% CI = 1.2–4.2) and other respiratory diseases in young children was observed by Mishra [29]. A study conducted on children aged 4–6 years in Guatemala showed the higher prevalence of asthmatic symptoms in biomass-fuel-using households, with ORs >2.0 [30]. In their prospective cohort study, Etiler et al. [31] found a significant association between symptoms of ARTI in infants and the use of biomass fuel (RR = 1.8, 95% CI = 1.3–2.5). Awasthi et al. [32] reported a significant positive association of respiratory symptoms with the choice of biomass fuel (OR = 2.7, 95% CI = 1.4–5.3). Other studies revealed the association of exposure to indoor VOCs with respiratory diseases and symptoms [33, 34]. Some other studies also demonstrated a positive relationship between air pollution from biomass combustion and child health [23, 24, 35, 36]. In this study, although in both winter and summer there were differences in pollution levels with different fuel types, we noted no such differences in the occurrence of respiratory symptoms either in winter or summer. We could not establish an association between the choice of fuel type and the occurrence of respiratory symptoms in children <5 years. This is consistent with our previous study finding, which indicated no association between symptom occurrence and fuel type [17]. The results of the study reported here is also consistent with results of Wafuala et al. [37].

After adjustment with possible confounders, we found a significant association of the main wall material of houses with eye itchiness, cough, and shortness of breath. Whereas the main wall material for fossil-fuel users was brick, tin and bamboo were the choice of biomass-fuel users. Fungus and mold growth tended to be higher with building materials in biomass-fuel-users' houses [38]. Moreover, consistent associations between molds and respiratory symptoms, with ORs ranging from 1.2 to 2.3, were reported by other researchers [39, 40]. Thus, exploration of the possible role of fungus and molds should be incorporated in future studies.

Conclusions

The levels of some indoor air pollutants were found to be higher in biomass- than fossil-fuel-users' homes both in winter and summer. With some pollutants, indoor air was more polluted in winter than in summer. There was no difference in the prevalence of some symptoms among children of biomass- and fossil-fuel users between winter and summer. There was also no association between measured indoor air pollution and prevalence of symptoms among children <5 years in Bangladesh. Other factors may be involved.

Acknowledgments This study was partially supported by a Grant-in-aid for Scientific Research (B 19406020) from the Japan Society for the Promotion of Science. The authors are grateful to the EPRC staffs for their generous assistance in collecting as well as ensuring the quality of data.

References

1. World Resources Institute, UNEP, UNDP, World Bank. 1998–99 world resources: a guide to the global environment. Oxford: Oxford University Press; 1998.
2. WHO/UNDP Joint statement. Indoor air pollution-the killer in the kitchen. Geneva: WHO/UNDP; 2004.
3. Zhang J, Smith KR. Emissions of carbonyl compounds from various cookstoves in China. Environ Sci Technol. 1999; 33:2311–20.
4. Smith KR, Samet JM, Romieu I, Bruce N. Indoor air pollution in developing countries and acute respiratory infections in children. Thorax. 2000;55:518–32.
5. Jan AJS. Risk assessment of acute health and comfort effects of indoor air pollution. Ann N Y Acad Sci. 1992;641:56–62.

6. Tesfaigzi Y, Singh SP, Foster JE, et al. Health effects of subchronic exposure to low levels of wood smoke in the rats. Toxicol Sci. 2002;65:115–25.
7. Bruce N, Perez-padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. Bull WHO. 2000;78:1080–92.
8. Boadi KO, Kuitunen M. Factors affecting the choice of cooking fuel, cooking place and respiratory health in the Accra metropolitan area, Ghana. J Biosoc Sci. 2006;38:403–12.
9. Anees W, Moore VC, Burge PS. FEV1 decline in occupational asthma. Thorax. 2006;61:751–5.
10. Albalak R, Frisancho AR, Keeler GJ. Domestic biomass fuel combustion and chronic bronchitis in two Bolivian villages. Thorax. 1999;54:1004–8.
11. Hong C. Global burden of disease from indoor air pollution, Geneva, Switzerland: World Health Organization; 1995.
12. Ezzati M, Kammen DM. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. Environ Health Perspect. 2002;110:1057–68.
13. World Health Report 2005: Make every mother and child count. Geneva, Switzerland: World Health Organization; 2005, p. 10–191.
14. National Institute of Population Research and Training (NIPORT), Mitra and Associates, and ORC Macro 2005. Bangladesh Demographic and Health Survey 2004. Dhaka, Bangladesh and Calverton, Maryland (USA): National Institute of Population Research and Training, Mitra and Associates, and ORC Macro.
15. World Health Organization. Indoor air pollution: national burden of disease estimates. Geneva: World Health Organization; 2007.
16. Baqui AH, Black RE, Arifeen SE, Hill K, Mitra SN, Sabir A. Causes of childhood deaths in Bangladesh: results of a nationwide verbal autopsy study. Bull World Health Organ. 1998;76:161–71.
17. Khalequzzaman M, Kamijima M, Sakai K, Chowdhury NA, Hamajima N, Nakajima T. Indoor air pollution and its impact on children under five years old in Bangladesh. Indoor Air. 2007;17:297–304.
18. Cheng L, Fu L, Angle RP, Sandhu S. Seasonal variation of volatile organic compounds in Edmonton, Alberta. Atmos Environ. 1997;31:239–46.
19. Perez-Pastor RM, Garcia-Alonso S, Cabezas AJQ. Distribution of volatile organic compounds in Madrid (Spain). Environ Sci Pollut Res. 1999;6:141–6.
20. Kumie A, Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, et al. Magnitude of indoor NO_2 from biomass fuels in rural settings of Ethiopia. Indoor Air. 2009;19:14–21.
21. The Pharmaceutical Society of Japan. Standard methods of analysis for hygienic chemists—with commentary. Tokyo: Kanehara-Shuppan; 1990. pp. 1387–8, 1451–2 (in Japanese).
22. Sakai K, Kamijima M, Shibata E, Ohno H, Nakajima T. Indoor air pollution by 2-ethyl-1-hexanol in non-domestic buildings in Nagoya, Japan. J Environ Monit. 2006;8:1122–8.
23. Padhi BK, Padhy PK. Domestic fuels, indoor air pollution, and children's health—the case of rural India. Ann N Y Acad Sci. 2008;1140:209–17.
24. Kumar R, Nagar JK, Raj N, Kumar P, Kushwah AS, Meena M, et al. Impact of domestic air pollution from cooking fuel on respiratory allergies in children in India. Asian Pac J Allergy Immunol. 2008;26:213–22.
25. Siddiqui AR, Lee K, Bennett D, Yang X, Brown KH, Bhutta ZA, et al. Indoor carbon monoxide and PM2.5 concentrations by cooking fuels in Pakistan. Indoor Air. 2009;19:75–82.
26. Bailis R, Ezzati M, Kammen DM. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Science. 2005;308:98–103.
27. Ministry of Health, Labour and Welfare of Japan. Committee on sick house syndrome: indoor air pollution progress report no. 4: summary on the decisions at 8th and 9th meetings; 2004. http://www.nihs.go.jp/mhlw/ocs/sickhouse/rep-eng4.pdf.
28. Dasgupta S, Huq M, Khaliquzzaman M, Pandey K, Wheeler D. Indoor air quality for poor families: new evidence from Bangladesh. Indoor Air. 2006;16:426–44.
29. Mishra V. Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe. Int J Epidemiol. 2003;32:847–53.
30. Schei MA, Hessen JO, Smith KR, Bruce N, Mccracken J, Lopez V. Childhood asthma and indoor woodsmoke from cooking in Guatemala. J Expo Anal Environ Epidemiol. 2004;14:110–7.
31. Etiler N, Velipasaoglu S, Aktein M. Incidence of acute respiratory infections and the relationship with some factors in infancy in Antalya, Turkey. Pediatr Int. 2002;44:64–9.
32. Awasthi S, Glick HA, Fletcher RH. Effect of cooking fuels on respiratory diseases in preschool children in Lucknow. India Am Trop Med Hyg. 1996;55:48–51.
33. Rumchev K, Spickett J, Bulsara M, Philips M, Stick S. Association of domestic exposure to volatile organic compounds with asthma in young children. Thorax. 2004;59:746–51.
34. Saijo Y, Kishi R, Katakura Y, Urashima Y, Hatakeyama A, Kobayashi S, et al. Symptoms in relation to chemicals and dampness in newly built dwellings. Int Arch Occup Environ Health. 2004;77:461–70.
35. Pandey MR, Neupane RP, Gautam A, Shrestha LB. Domestic smoke pollution and acute respiratory infections in a rural community of the hill region of Nepal. Environ Int. 1989;15:337–40.
36. Kilabuko JH, Matsuki H, Nakai S. Air quality and acute respiratory illness in biomass fuel using homes in Bagamoyo, Tanzania. Int J Environ Res Public Health. 2007;4:39–44.
37. Wafula EM, Onyango FE, Thairu H, et al. Indoor air pollution in a Kenyan village. East Afr Med J. 1990;67:24–32.
38. Husman T. Health effects of indoor-air microorganisms. Scand J Work Environ Health. 1996;22:5–13.
39. Brunekreef B, Dockery DW, Speizer FE, Ware JH, Spengler J, Ferris BG. Home dampness and respiratory morbidity in children. Am Rev Respir Dis. 1989;140:1353–67.
40. Dales R, Miller D. Residential fungal contamination and health: microbial cohabitants as covariates. Environ Health Perspect. 1999;107(Suppl 3):481–3.