PUBLIC HEALTH RESEARCH

Does Exposure To Household and Ambient Air Pollution Pose a Risk To Cardiovascular Health? - A Cross-Sectional Study in Nepal

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ABSTRACT

Accepted 15 September 2013

Introduction Over half the world's population is exposed daily to very high levels of household air pollutants arising from burning biomass fuels; however the effects of these pollutants on cardiovascular health have not been fully established. This study aimed to compare the relationship between household indoor and outdoor air pollution with cardiovascular health in biomass and non-biomass exposed group.

Objective To compare the relationship between household indoor and outdoor air pollution with cardiovascular health in biomass and non-biomass exposed group.

Methods This cross-sectional study compared parameters of cardiovascular health in populations exposed to household indoor pollutants from biomass burning and non-biomass respectively among adults in Nepal. Data using an interviewer administered questionnaire including chest pain, blood pressure measurements and real-time measurements of household and ambient airborne particulate ($PM_{2.5}$) concentrations were collected.

Results Rural dwellers cooking with biomass fuels reported significantly more chest pain on exertion compared with non-biomass fuel users. 24-hour direct $PM_{2.5}$ and CO measurements were not associated with changes in blood pressure as was the case for other measures of airborne particulate exposure except outdoor $PM_{2.5}$ with men in non-biomass using households. Ambient temperature and seasonality was negatively associated with increase in blood pressure. The prevalence of both systolic (21% vs. 6%, p<0.001) and diastolic (32% vs. 7%, p<0.001) hypertension was higher amongst non-biomass fuel users compared with biomass users.

Conclusions There was no association between 24-hour real-time airborne pollutants data from biomass smoke and cardiovascular health effects but significantly more chest pain on exertion was found in those exposed to smoke from biomass fuel burning. Urban dwellers in Nepal were found to have higher blood pressure compared to rural dwellers, which was associated with their higher BMI levels and seasonality.

Keywords Indoor air pollution - Biomass smoke - Cardiovascular risk - Systolic blood pressure - Diastolic blood pressure - Hypertension.

INTRODUCTION

Acute exposure to outdoor air pollution is a recognised cause of cardiovascular events both in terms of mortality[1] and hospital admissions[2]. Long term exposure to ambient particulates also contributes to the development and potentially the progression of cardio-pulmonary disease as witnessed by higher mortality in those exposed to airborne particles[3]. The mechanism for these associations may involve interstitialisation of respirable particles in the lung leading to release of inflammatory cytokines and enhancement of thrombogenesis[4]. This proposed mechanism is supported by both epidemiological[5] and in vitro[6] studies. In addition, atheroma is an inflammatory process and exposure to airborne particles from vehicle exhausts have been associated with worsening the indices of atheroma activity[7].

Around 3 billion people worldwide are exposed to biomass smoke[8] with peak levels of $PM_{2.5}$ exposure during cooking reaching 15-20,000 µg/m^3 [9] and mean 24-hour levels ranging between 400 and 1500 µg/m^3 [10, 11]. While exposure to household indoor biomass smoke is associated with chronic obstructive pulmonary disease (COPD), cataract, lung cancer and, in children acute lower respiratory tract infection, there is little information on its role in cardiovascular diseases[12]. Such airborne particulates exposures could in theory are associated with cardiovascular morbidity. The RESPIRE intervention study from Guatemala reported a reduction of 3.7mm Hg in systolic blood pressure following the installation of vented stoves[13], but another study from Nicaragua investigating the effect of improved cook stoves, reported a significant decrease in systolic blood pressure only in women of over 40 years of age[14]. Data from a number of cross-sectional studies suggest that exposure to smoke from biomass combustion is a risk factor for elevated blood pressure and therefore cardiovascular events among adults[15-18].

Nepal is a developing country where over 90% of the people live and farm in rural villages. Almost all rural residents use biomass as their main energy source for cooking, usually in poorly ventilated kitchens and are therefore exposed to very high concentrations of biomass smoke[9]. Exposure to biomass smoke in Nepal is reported to be associated with a range of adverse health outcomes such as chronic bronchitis, tuberculosis, cataract and acute respiratory infections[19]. However to date there are no published population studies that have investigated the cardiovascular health effects of airborne exposure from biomass smoke and non-biomass fuels (liquefied petroleum gas, LPG) in Nepal. In Nepal, the majority of the urban population use LPG (non-biomass) as primary cooking fuel with occasional use of kerosene and are exposed to higher road traffic generated ambient air pollution.

In this study we assessed the relationship between exposure to household smoke (from biomass and non-biomass fuels) and traffic-generated outdoor air pollution with cardiovascular health outcomes (cardiovascular symptoms and blood pressure) in both men and women of Nepal.

MATERIALS AND METHODS

This cross-sectional study was carried out between April 2006 and February 2007. Biomass-exposed population (98.9% used wood) was sampled from two village development committees (VDCs) in the Kathmandu Valley. Four wards (out of nine) in each VDC were randomly selected and all individuals in the selected wards aged ≥16 years were eligible to be included if they met the inclusion criteria (willing to have their blood pressure and lung function measured and also agreeing to have 24-hour continuous airborne exposure monitoring in their homes). The non-exposed population (98.4% used LPG) meeting the above inclusion criteria were selected from six wards (from a total of 35) in the Kathmandu municipality: three selected randomly on the periphery of the ring road and the other three selected from 1-2 km inside the ring road. The non-exposed sample lived around 10-12 km to the south-west of the biomass-exposed sampling sites. All locations were between 1300 m to 1600 m above sea level. The majority of the houses sampled using biomass fuels were constructed from a mud-based material with a thatched or tiled roof whereas the houses occupied by the LPG users (non-biomass exposed) were made of brick and cement. The non-biomass smoke exposed population lived in close proximity to main roads, while the biomass smoke-exposed lived in rural areas with almost no busy vehicle traffic or industrial activities. However, individuals from the biomass using area regularly travelled to the non-biomass using areas near the ring road to sell their agricultural products in the early mornings (when road traffic is minimal). The study protocol was approved by the Nepal Health Research Council. Written consent was obtained from all study participants.

The study was primarily designed to investigate the association between biomass and lung disease[20], with the secondary aim to compare the relationship between household indoor and outdoor air pollution with cardiovascular health in biomass and non-biomass exposed groups.

Questionnaire

Subjects were invited to complete an interviewer administered questionnaire, which sought information on demographic details, respiratory symptoms, smoking habits, environmental tobacco smoke (ETS) exposure, socio-economic status (SES: income, education status, job types, house types and history of cooking stove) and history of fuel use. It also included the Rose chest pain questionnaire[21] for cardiac symptoms. The questionnaires were translated into Nepalese and back translated into English by an independent translator. Standing height and weight was measured according to WHO criteria[22].

Blood pressure

Blood pressure was measured by an automatic sphygmomanometer (Prestige Medical HM-20, Northridge, CA, USA) according to the British Hypertension Society[23] and European Society of Hypertension guidelines[24]. Measurements were taken in the left arm in the sitting position, with three consecutive readings taken at five minute intervals. The first reading was taken after at least 10 minutes rest. The average systolic blood pressure and diastolic blood pressure were calculated from the second and the third of the three blood pressure measurements. The presence of hypertension was based on average systolic and diastolic readings, a systolic blood pressure (SBP) equal to or greater than 140 mm Hg was classified as systolic hypertension and a diastolic blood pressure (DBP) greater or equal to 90 mmHg was classified as diastolic hypertension. Those individuals on medication for hypertension but with normal systolic and diastolic blood pressures were also included in the hypertension category in this study.

Airborne particle exposure and temperature and relative humidity measurement

Household indoor $PM_{2.5}$ levels were measured over a 24-h continuous period in most dwellings (n=490) and outdoor (veranda) $PM_{2.5}$ levels in randomly selected households (n=104) using a photometric device (SidePak AM510 and DustTrak Model 8520, TSI Inc, Shoreview, MN, USA). Household indoor $PM_{2.5}$ levels were measured at a fixed height of 1.5 m and 0.5-1.0 m from the centre of cooking stoves. Mean 24-hour $PM_{2.5}$ (μg/m^3) was used as a measure of exposure. Results from 442 houses out of 490 households (Biomass burning homes=206 and non-biomass burning homes=236) had $PM_{2.5}$ sampling data for over 20 hours and are reported here. Outdoor $PM_{2.5}$ was measured in 118 homes (biomass burning=46 and non-biomass burning=72). 24-hour indoor carbon monoxide (CO) levels were measured in 126 homes (biomass burning=40 and non-biomass burning=86) using HOBO CO loggers (MicroDAQ, Contoocook, NH, USA). Results for $PM_{2.5}$ levels and CO are expressed as geometric mean and geometric standard deviation unless indicated. The direct reading photometric instruments were calibrated using data from co-located gravimetric samplers[9].

The ESCORT iLog Data logger (Buchanan, VA, USA) was used to measure indoor temperature and relative humidity in 413 homes (biomass burning=241 and non-biomass burning = 172). It was programmed to measure data at one minute intervals that provided the highest, lowest and average readings over the time period of measurement.

Statistical Analysis

Statistical analyses were performed using Stata (version 12, College Station, TX, USA). Baseline demographic characteristics were compared between biomass exposed and non-biomass exposed samples for both men and women separately by regression for survey data taking into account the household clustering. As there was significant differences between biomass exposed and non-exposed groups in terms of height and socio-economic status, we analysed the data from the two groups separately. Regression models (linear for continuous and logistic for categorical outcome variables) were constructed to evaluate the effect of possible different risk factors (exposure to $PM_{2.5}$ and CO, temperature, relative humidity, ventilation in the kitchen, seasonality) on SBP, DBP, heart rate (HR), hypertension and chest pain symptoms for those exposed to biomass smoke and non-biomass smoke separately (analyses with combined data are provided in supplementary tables S4 and S5) as there were significant differences between the two groups on a number of factors (Table 1). All known and potential risk factors were routinely adjusted for to obtain regression coefficient (β), with robust variance estimates to allow for household clustering effect. The $PM_{2.5}$ concentrations were transformed to natural logarithmic scale to account for the high concentration skewed data in biomass burning homes.

RESULTS

A total of 1648 participants were enrolled, of whom 96.7% (n=1593; 740 men and 853 women) had blood pressure measurement (3.3% either did not meet the inclusion criteria or refused to allow blood pressure measurement) and were used in analysis. Of these, 50.2% (n=800) were exposed to biomass smoke and the remaining 49.8% (n=793) used non-biomass (primarily LPG) fuel for domestic purposes (Table1). Of the 1593 used in the analyses, 107 (6.72%) has used kerosene as cooking fuel and 693 (43.50%) used kerosene occasionally as energy source for lighting. Biomass smoke-exposed men and women were significantly shorter, weighed less, were more likely to be illiterate and farming was their main occupation compared to the non-biomass using counterparts.

The biomass-exposed groups had much lower annual incomes compared to the non-biomass group (median Nepalese Rupees 4500 vs. 15000, p<0.001) and had a higher proportion of current smokers, especially among women (Table 1).

Table 1 Demographic data of 1593 Nepalese adults aged ≥16 years according to type of fuel used and gender

	Men			Women		
	Biomass	Non-biomass	p-value	Biomass	Non-biomass	p-value
n	364	376		436	417	
Age, years (SD)	35.5 (17.1)	35.2 (15.1)	0.871	35.5 (16.4)	34.4 (15.1)	<0.001
Height, cm (SD)	162.2 (7.3)	166.1 (6.8)	<0.001	149.8 (5.8)	153.0 (6.2)	<0.001
Weight, kg (SD)	52.6 (8.2)	61.9 (10.2)	<0.001	46.4 (7.1)	56.0 (10.2)	<0.001
Body mass index, kg/m^2 (SD)	20.2 (2.6)	22.4 (3.5)		20.7 (2.8)	23.9 (4.0)	
BMI<18.5 kg/m^2, n (%)	106 (27.8)	58 (15.3)		111 (24.0)	38 (9.0)	
BMI=18.5–24.99 n (%)	258 (67.5)	233 (61.3)	<0.001	314 (67.8)	228 (53.9)	<0.001
BMI≥25 kg/m^2, n (%)	18 (4.7)	89 (23.4)		38 (8.2)	157 (37.1)	
Literate, n (%)	301 (82.7)	366 (97.3)		199 (45.6)	335 (80.3)	
Undergraduate or higher	16 (4.4)	170 (45.2)		3 (0.7)	94 (22.5)	
12 yrs of formal education	48 (13.2)	83 (22.1)	<0.001	21 (4.8)	93 (22.3)	<0.001
10 years of formal education	74 (20.3)	53 (14.1)		37 (8.5)	55 (13.2)	
<10 years of formal education	163 (44.8)	60 (16.0)		138 (31.7)	93 (22.3)	
Smoking status, n (%)						
Non-smoker	201 (55.2)	244 (64.9)	<0.001	285 (65.4)	379 (90.9)	<0.001
Ex-smoker	29 (7.8)	56 (14.9)	0.142	48 (11.0)	23 (5.5)	<0.001
Current smoker	134(3.8)	76 (20.2)	<0.001	103 (23.6)	15 (3.6)	<0.001
ETS, n (%)	275 (75.6)	192 (51.0)	<0.001	333 (76.4)	164 (39.3)	<0.001
Farmer, n (%)	342 (94.0)	59 (15.7)	<0.001	421 (97.0)	81 (19.4)	<0.001
≥10 yrs of current fuel use, n (%)	304 (83.5)	171 (45.5)	<0.001	374 (85.8)	186 (44.6)	<0.001
Monthly household income in Nepalese Rupees (SD)	6196 (8671)	21832 (19226)	<0.001	6340 (8470)	23128 (22957)	<0.001

P values were derived from regression analysis of survey data taking into account the clustering of household

Exposures

The geometric mean (± geometric standard deviation) 24-hour indoor $PM_{2.5}$ concentrations in biomass using homes was significantly greater than in non-biomass using homes (455±1.5 vs. 102±1.4 µg/m^3, $p<0.001$) (Supplement Table S1). Indoor $PM_{2.5}$ concentration in kitchens with ventilation (presence of windows and/or eaves space and/or mechanical ventilation) where biomass fuel was burnt was significantly higher compared to non-biomass fuel burning kitchens either with ventilation (biomass: 448±1.5 vs. non-biomass with ventilation: 120 ±1.4 µg/m^3, $p<0.001$) or without ventilation (biomass: 459±1.5 vs. non-biomass without ventilation: 99±1.4 µg/m^3, $p<0.001$). The geometric mean (±geometric standard deviation) for outdoor air pollution did not differ significantly between biomass and non-biomass using homes (129±1.5 vs. 115±1.5, p=0.992). The outdoor air pollution in both the rural and urban areas was measured in the veranda for both practicability and safe use of sampling instrumentation. The concurrent measurement of $PM_{2.5}$ on the veranda and outdoors (100m from 6 houses) in biomass exposed rural location showed relatively high veranda concentrations but substantially lower (15µg/m^3) concentrations outdoors. The geometric mean (± geometric standard deviation) CO concentrations in kitchens were significantly higher where biomass fuel was used compared with houses using non-biomass fuel (13.4±1.4 vs 2.0 ±1.4, $p<0.001$). The exposure concentrations for both $PM_{2.5}$ and CO were much higher during cooking periods particularly in those houses where biomass was used as cooking fuel (Supplementary Figures S1). The geometric mean (± geometric standard deviation) of temperature (^{0}C) and relative humidity for the non-biomass group (18±1.21 and 63.7±1.2) was lower compared to that of biomass users (25.7±1.1 and 70.7±1.2).

Supplement Table S1 4-hr exposure ($PM_{2.5}$ and CO) data in houses using wood and LPG as cooking fuel

Pollutant	Fuel Type	n	AM (95% CI)	Median (95% CI)	GM (95% CI)	IQR
24-hr $PM_{2.5}$	Wood	206	689.7 (558.2-821.2)	472.0 (432.2-517.9)	455.1 (402.9-514.1)	562.2
24-hr CO	Wood	35	16.9 (12.7-21.0)	13.6 (8.2-21.2)	12.9 (9.8-17.0)	16.9
24-hr $PM_{2.5}$	LPG	230	149.3 (110.2-188.3)	94.7 (83.1-111.2)	102.6 (93.3-112.8)	91.6
24-hr CO	LPG	79	2.6 (2.1-3.1)	2.1 (1.7-2.6)	2.0 (1.7-2.4)	1.9

AM=Arithmetic mean; GM=Geometric mean; IQR=Inter-quartile range; CI= Confidence interval; $PM_{2.5}$=Particulate matter with aerodynamic diameter of less than 2.5µm; CO=Carbon monoxide; LPG=Liquefied petroleum gas; Unit of $PM_{2.5}$ and CO values are µg/m^3 and parts per million respectively.

Cardiovascular symptoms

Men and women using non-biomass fuel reported significantly less chest pain or discomfort when not doing anything strenuous compared with men (20.7% and 26.6% respectively, p=0.05) and women (29.3% and 36.7% respectively, p=0.014) who lived in houses where biomass fuel was used. These significant differences were also seen for the presence of chest pain on walking at an ordinary pace on level ground for both men and women but only for women for when walking uphill or hurrying. Women from both biomass and non-biomass using houses reported significantly more chest pain compared to men (Supplement Table S2). Women ever exposed to kerosene smoke from cooking reported more ever chest pain compared to men (35.4% vs. 29.1%, p=0.463).

Supplement Table S2 Chest pain for all ages among rural and urban dwellers

		Non-biomass fuel (%)	Biomass fuel (%)	p-value[a]
Male	Number	376	364	
	1	78(20.7)	97 (26.6)	0.050
	2	74 (19.7)	74 (20.3)	0.810
	3	8 (2.1)	23 (6.3)	0.004
Female	Number	417	436	
	1	122 (29.3)	160 (36.7)	0.014
	2	107 (25.7)	143 (32.8)	0.018
	3	19 (4.6)	37 (8.5)	0.020
Total	Number	793	800	
	1	200 (25.2)	257 (32.1)	0.001
	2	181 (22.8)	217 (27.1)	0.041
	3	27 (3.4)	60 (7.5)	<0.001

[a] P-values from Chi-square tests for categorical variables
1=Ever chest pain; 2=Chest pain while walking uphill or hurrying;
3=Chest pain while walking on level ground at ordinary pace

Table 2 Odds ratios for chest pain using robust variance estimates in biomass users

	Ever chest pain		Chest pain – walking uphill/hurrying		Chest pain – walking on level ground at ordinary pace	
	Odds ratio (95% CI)*	p-value	Odds ratio (95% CI)*	p-value	Odds ratio (95% CI)*	p-value
			Women Data Only			
Indoor $PM_{2.5}$ #	0.90 (0.71 – 1.13)	0.361	0.97 (0.68 – 1.39)	0.871	0.85 (0.66 – 1.09)	0.195
O. $PM_{2.5}$#	-	-	-	-	-	-
CO (in ppm)#	1.19 (0.66 – 2.16)	0.559	0.50 (0.21 – 1.17)	0.108	0.93 (0.51 – 1.68)	0.808
Temp (^{0}C)#	0.23 (0.61 – 4.66)	0.338	2.79 (0.03 – 285.1)	0.664	0.20 (0.01 – 4.71)	0.317
Rel. humidity#	0.50 (0.17 – 1.48)	0.209	0.47 (0.07 – 3.26)	0.444	0.83 (0.26 – 2.71)	0.762
Ventilation	1.09 (0.72 – 1.67)	0.683	1.20 (0.61 – 2.36)	0.605	0.92 (0.60 – 1.40)	0.690
Seasonality	0.50 (0.20 – 1.24)	0.135	-	-	0.51 (0.17 – 1.57)	0.239
			Men Data Only			
Indoor $PM_{2.5}$#	0.85 (0.64 – 1.14)	0.274	1.17 (0.71 – 1.91)	0.529	1.00 (0.74 – 1.34)	0.988
O. $PM_{2.5}$#	-	-	-	-	-	-
CO (in ppm)#	0.72 (0.23 – 2.29)	0.583	0.91 (0.24 – 3.51)	0.892	0.83 (0.28 – 2.48)	0.737
Temp (^{0}C)#	0.23 (0.01 – 4.91)	0.347	138.0 (0.39 – 48899.6)	0.100	13.18 (0.19 – 905.70)	0.232
Rel. humidity#	0.33 (0.08 – 1.46)	0.144	3.27 (0.43 – 25.10)	0.255	0.70 (0.13 – 3.68)	0.673
Ventilation	1.40 (0.84 – 2.35)	0.202	0.98 (0.40 – 2.41)	0.959	1.18 (0.66 – 2.11)	0.567
Seasonality	0.38 (0.07 – 2.16)	0.278	1.47 (0.14 – 15.14)	0.748	0.80 (0.17 – 3.84)	0.778
			Combined Data For Men And Women			
Indoor $PM_{2.5}$#	0.89 (0.74 – 1.07)	0.213	1.02 (0.77 – 1.34)	0.913	0.90 (0.74 – 1.10)	0.291
O. $PM_{2.5}$#	0.85 (0.26 – 2.79)	0.789	-	-	0.76 (0.21 – 2.72)	0.671

CO (in ppm)#	1.10 (0.65 – 1.88)	0.714	0.69 (0.35 – 1.35)	0.277	0.93 (0.55 – 1.58)	0.798
Temp (^{0}C)#	0.23 (0.02 – 2.56)	0.232	5.94 (0.17 – 206.4)	0.325	0.85 (0.05 – 14.77)	0.913
Rel. humidity	0.43 (0.17 – 1.11)	0.080	0.99 (0.25 – 3.96)	0.992	0.80 (0.28 – 2.30)	0.684
Ventilation	1.22 (0.86 – 1.73)	0.265	1.10 (0.65 – 1.86)	0.721	1.02 (0.71 – 1.48)	0.913
Seasonality	0.45 (0.19 – 1.04)	0.061	0.29 (0.03 – 2.38)	0.248	0.55 (0.20 – 1.53)	0.253

#= log transformed; Ventilation (1=not adequately ventilated; 0=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer); Indoor & Outdoor PM in mg/m^3 ; O. $PM_{2.5}$=Outdoor PM2.5

* Adjusted for age, height, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke ['Yes' = regularly exposed to other people tobacco smoke where 'regularly' = on most days or nights] and farmer as main occupation

Table 3 Odds ratios for chest pain using robust variance estimates in non-biomass users

	Ever chest pain		Chest pain – walking uphill/hurrying		Chest pain – walking on level ground at ordinary pace	
	Odds ratio (95% CI)*	p-value	Odds ratio (95% CI)*	p-value	Odds ratio (95% CI)*	p-value
			Women Data Only			
Indoor $PM_{2.5}$#	1.13 (0.83 – 1.52)	0.440	1.11 (0.81 – 1.52)	0.510	0.68 (0.39 – 1.18)	0.169
O. $PM_{2.5}$#	2.34 (0.66 – 8.29)	0.187	2.64 (0.61 – 11.52)	0.195	-	-
CO (in ppm)#	0.88 (0.50 – 1.55)	0.660	0.85 (0.45 – 1.60)	0.615	0.93 (0.25 – 3.40)	0.912
Temp (^{0}C)#	0.11 (0.03 – 0.48)	0.004	0.05 (0.01 – 0.23)	<0.001	1.15 (0.10 – 13.11)	0.913
Rel. humidity#	0.53 (0.11 – 2.71)	0.450	0.48 (0.09 – 2.59)	0.394	0.65 (0.01 – 4701)	0.842
Ventilation	0.35 (0.14 – 0.89)	0.028	0.40 (0.16 – 1.02)	0.054	0.61 (0.19 – 1.99)	0.417
Seasonality	-	-	-	-	-	-
			Men Data Only			
Indoor $PM_{2.5}$#	1.24 (0.83 – 1.84)	0.291	1.22 (0.83 – 1.80)	0.300	3.85 (2.01 – 7.38)	<0.001
O. $PM_{2.5}$#	-	-	-	-	-	-
CO (in ppm)#	1.39 (0.63 – 3.03)	0.413	1.21 (0.61 – 2.44)	0.585	-	-
Temp (^{0}C)#	0.58 (0.11 – 3.06)	0.524	0.34 (0.06 – 1.90)	0.220	0.03 (0.001 – 0.97)	0.048
Rel. humidity#	0.34 (0.06 – 1.95)	0.227	0.27 (0.05 – 1.53)	0.139	0.78 (0.02 – 35.85)	0.896
Ventilation	1.73 (0.73 – 4.07)	0.213	1.31 (0.52 – 3.33)	0.568	1.35 (0.24 – 7.53)	0.734
Seasonality	-	-	0.98 (0.89 – 1.08)	0.678	-	-
			Combined Data For Men And Women			
Indoor $PM_{2.5}$#	1.16 (0.92 – 1.45)	0.219	1.16 (0.91 – 1.47)	0.239	1.02 (0.64 – 1.61)	0.941
O. $PM_{2.5}$#	2.35 (0.88 – 6.30)	0.090	2.47 (0.85 – 7.13)	0.096	-	-
CO (in ppm)#	1.12 (0.75 – 1.69)	0.570	1.05 (0.68 – 1.62)	0.824	0.96 (0.35 – 2.66)	0.944
Temp (^{0}C)#	0.23 (0.08 – 0.67)	0.007	0.12 (0.04 – 0.37)	<0.001	0.52 (0.06 – 4.74)	0.565
Rel. humidity#	0.40 (0.13 – 1.26)	0.119	0.35 (0.11 – 1.17)	0.089	0.36 (0.02 – 8.28)	0.522
Ventilation	0.74 (0.39 – 1.40)	0.354	0.70 (0.34 – 1.41)	0.313	0.82 (0.25 – 2.76)	0.753
Seasonality	0.33 (0.17 – 0.62)	0.001	-	-	-	-

#= log transformed; Ventilation (1=not adequately ventilated; 0=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer) ; Indoor & Outdoor PM in mg/m^3; O. $PM_{2.5}$=Outdoor $PM_{2.5}$

* Adjusted for age, height, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke ['Yes' = regularly exposed to other people tobacco smoke where 'regularly' = on most days or nights] and farmer as main occupation

Univariate analysis showed ever chest pain was significantly associated with use of biomass as cooking fuel, increase in $PM_{2.5}$ concentration in the kitchen, age, female, illiteracy, current and ex-smoker separately, ever having smoked, the number of years smoked and pack years whereas higher income, increasing height, and autumn/winter season had a protective effect. The same pattern of associations were seen for the questions relating to exertional chest pain and chest pain when walking at ordinary pace on the level ground as for ever chest pain (data not presented). No significant association was observed between indoor and outdoor $PM_{2.5}$, CO, ventilation, relative humidity and chest pain after adjusting for age, height, education, income, BMI, smoking history, ETS, farmer as main occupation in both biomass fuel and non-biomass user (Table 2 & 3). However, the risk of ever having chest pain and chest pain while climbing uphill or hurrying was lower with increase in temperature for women only and also when the data for women and men were combined (Table 3). The risk of reporting chest pain while walking on level ground at ordinary pace was also lower during autumn/winter compared to spring/summer for combined men and women data (Table 3). We also noticed significant positive association between chest pain and winter periods, indoor and outdoor particulate matter and negative association with increase in temperature when the data was combined for biomass and non-biomass (Supplementary table S4).

Supplementary Table S4 Odds ratio for chest pain using robust variance estimates in biomass and non-biomass user

Table 4 Biomass and non-biomass user	Ever chest pain		Chest pain – walking uphill/hurrying		Chest pain – walking on level ground at ordinary pace	
	Odds ratio (95% CI)*	p- value	Odds ratio (95% CI)*	p- value	Odds ratio (95% CI)*	p- value
WOMEN DATA ONLY						
Indoor $PM_{2.5}$#	1.02 (0.87 – 1.20)	0.772	0.99 (0.83 – 1.17)	0.867	0.99 (0.87 – 1.13)	0.882
Outdoor $PM_{2.5}$#	2.12 (0.96 – 4.67)	0.062	2.42 (1.04 – 5.66)	0.041	1.67 (0.97 – 2.89)	0.065
CO (in ppm)#	1.04 (0.76 – 1.45)	0.783	0.93 (0.66 – 1.30)	0.662	0.90 (0.68 – 1.18)	0.443
Temp (^{0}C)#	0.25 (0.08 – 0.79)	0.019	0.14 (0.04 – 0.47)	0.001	0.21 (0.08 – 0.52)	0.001
Rel. humidity#	0.61 (0.25 – 1.49)	0.278	0.79 (0.31 – 2.02)	0.617	0.63 (0.29 – 1.37)	0.248
Ventilation	0.88 (0.62 – 1.26)	0.495	0.78 (0.54 – 1.11)	0.171	0.88 (0.65 – 1.19)	0.418
Seasonality	0.68 (0.41 – 1.12)	0.131	0.72 (0.42 – 1.24)	0.235	0.94 (0.60 – 1.46)	0.768
MEN DATA ONLY						
Indoor $PM_{2.5}$#	0.95 (0.77 – 1.18)	0.650	0.98 (0.79 – 1.21)	0.835	0.93 (0.71 – 1.22)	0.600
Outdoor $PM_{2.5}$#	0.81 (0.27 – 2.44)	0.711	0.62 (0.21 – 1.83)	0.388	0.74 (0.13 – 4.27)	0.740
CO (in ppm)#	0.94 (0.51 – 1.72)	0.831	0.86 (0.50 – 1.48)	0.593	1.20 (0.70 – 2.07)	0.508
Temp (^{0}C)#	0.55 (0.15 – 2.10)	0.388	0.39 (0.10 – 1.57)	0.184	1.98 (0.33 – 11.97)	0.455
Rel. humidity#	0.34 (0.11 – 1.04)	0.059	0.50 (0.15 – 1.63)	0.250	0.54 (0.10 – 3.03)	0.484
Ventilation	1.38 (0.91 – 2.10)	0.127	1.04 (0.66 – 1.64)	0.865	1.09 (0.60 – 1.98)	0.768
Seasonality	0.77 (0.37 – 1.60)	0.489	1.44 (0.72 – 2.90)	0.301	0.56 (0.23 – 1.35)	0.196
COMBINED DATA FOR MEN AND WOMEN						
Indoor $PM_{2.5}$#	1.00 (0.88 – 1.14)	0.953	0.99 (0.87 – 1.13)	0.882	1.41 (1.03 – 1.92)	0.034
Outdoor $PM_{2.5}$#	1.62 (0.97 – 2.70)	0.066	1.67 (0.98 – 2.89)	0.065	-	-
CO (in ppm)#	1.00 (0.77 – 1.31)	0.985	0.90 (0.68 – 1.18)	0.443	1.11 (0.68 – 1.81)	0.679
Temp (^{0}C)#	0.34 (0.14 – 0.83)	0.018	0.21 (0.08 – 0.52)	0.001	1.29 (0.28 – 5.90)	0.739
Rel. humidity#	0.47 (0.23 – 0.95)	0.036	0.63 (0.29 – 1.37)	0.248	0.82 (0.24 – 2.77)	0.753
Ventilation	1.08 (0.81 – 1.44)	0.609	0.88 (0.65 – 1.19)	0.418	1.05 (0.66 – 1.67)	0.846
Seasonality	0.70 (0.46 – 1.08)	0.107	0.94 (0.60 – 1.46)	0.768	0.69 (0.37 – 1.30)	0.254

#= log transformed; Ventilation (1=not adequately ventilated; 0=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer) ; Indoor & Outdoor PM in mg/m^3; Rel. Humidity= Relative humidity

* Adjusted for age, height, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke [‘Yes’ = regularly exposed to other people tobacco smoke where ‘regularly’ = on most days or nights] and farmer as main occupation

Blood pressure

The mean blood pressure of men using non-biomass fuel (SBP±SD: 128±18 mmHg and DBP±SD: 85±12 mmHg) was greater than those using biomass fuel (SBP±SD: 115±16 mmHg and DBP±SD: 74±14 mmHg), similar to the women from non-biomass (SBP±SD: 123±18 mmHg and DBP±SD: 82±10 mmHg) and biomass (SBP±SD: 112±15 mmHg and DBP±SD: 74±10 mmHg) (Supplementary Table S3)**.** The prevalence of systolic and diastolic hypertension was significantly higher in non-biomass fuel users both in men (23.14% vs. 6.75%, $p<0.001$) and women (17.75% vs. 5.96 %, $p<0.001$) compared to biomass fuel users. There was a positive trend for SBP, DBP and HR with increase in age group and BMI (Supplement Table S3). Those men (130 vs. 115, $p<0.001$) and women (116 vs. 112, $p=0.044$) who used kerosene as cooking fuel had significantly higher systolic blood pressure compared to biomass fuel users. Similar was the case for diastolic blood pressure (data not shown).

Supplement Table S3 Mean blood pressure and heart rate in biomass and non-biomass using homes

	Systolic blood pressure (Mean ± SD, n)			Diastolic blood pressure (Mean ± SD, n)			Heart rate (Mean ± SD, n)		
	Biomass	Non-Biomass	p-value	Biomass	Non-Biomass	p-value	Biomass	Non-Biomass	p-value
Combined (Male and Female)									
Smoking status									
Non-smoker	110.9 ± 11.8, 486	124.4 ± 17.4, 623	<0.001	72.6 ± 9.2, 486	82.8 ± 10.8, 623	<0.001	75.1 ± 11.9, 485	79.8 ± 11.4, 623	<0.001
Ex-smoker	123.2 ± 23.1, 77	135.6 ± 21.4, 79	<0.001	79.5 ± 14.9, 77	88.2 ± 11.7, 79	<0.001	74.0 ± 10.9, 77	76.3 ± 10.1, 79	0.099
Current smoker	114.7 ± 18.3, 237	132.0 ± 18.4, 91	<0.001	75.0 ± 11.8, 237	88.1 ± 12.4, 91	<0.001	73.0 ± 11.2, 237	77.1 ± 10.4, 91	0.001
BMI (Kg/m²)									
<18.5	105.7 ± 14.3, 198	115.6 ± 11.1, 96	<0.001	67.5 ± 10.3, 198	76.4 ± 9.1, 96	<0.001	74.5 ± 12.7, 198	81.4 ± 13.1, 96	<0.001
18.5 - 25.5	115.3 ± 15.6, 547	126.3 ± 18.4, 454	<0.001	75.8 ± 10.2, 547	83.7 ± 11.2, 454	<0.001	74.0 ± 11.2, 546	78.8 ± 10.6, 454	<0.001
≥ 25.5	119.6 ± 13.3, 55	130.7 ± 18.8, 243	<0.001	80.0 ± 9.4, 55	87.3 ± 10.6, 243	<0.001	77.7 ± 11.4, 55	79.0 ± 11.2, 243	0.221
Age group (in yrs)									
16 - 25	109.8 ± 11.3, 285	117.8 ± 10.7, 281	<0.001	71.1 ± 8.7, 285	78.4 ± 8.5, 281	<0.001	75.9 ± 12.8, 285	81.6 ± 11.6, 281	<0.001
26 – 35	111.3 ± 10.9, 186	122.2 ± 13.3, 191	<0.001	74.3 ± 9.1, 186	83.3 ± 9.5, 191	<0.001	74.0 ± 11.1, 185	78.2 ± 11.5, 191	0.002
36 – 45	112.8 ± 13.9, 125	129.4 ± 16.8, 124	<0.001	75.9 ± 10.4, 125	88.1 ± 11.2, 124	<0.001	73.3 ± 11.0, 125	77.9 ± 9.5, 124	<0.001
46 – 55	113.7 ± 12.5, 72	137.0 ± 21.4, 106	<0.001	75.3 ± 10.5, 72	90.0 ± 11.6, 106	<0.001	72.6 ± 11.3, 72	77.2 ± 10.4, 106	0.003
> 55	123.3 ± 25.8, 132	145.0 ± 23.5, 91	<0.001	77.3 ± 15.6, 132	89.5 ± 13.3, 91	<0.001	73.8 ± 10.1, 132	77.7 ± 11.5, 91	0.004
Female group									
Smoking status									
Non-smoker	109.8 ± 12.2, 285	123.3 ± 17.8, 379	<0.001	73.1 ± 8.6, 285	81.9 ± 10.1, 379	<0.001	78.7 ± 11.6, 284	82.1 ± 10.6, 379	<0.001
Ex-smoker	123.9 ± 19.9, 48	138.1 ± 22.6, 23	0.004	80.3 ± 11.2, 48	84.5 ± 10.1, 23	0.063	74.1 ± 9.8, 48	77.7 ± 9.5, 23	0.074
Current smoker	111.8 ± 18.4, 103	129.3 ± 21.4, 15	0.001	73.8 ± 11.7, 103	84.9 ± 13.8, 15	0.001	76.4 ± 9.6, 103	77.3 ± 12.6, 15	0.367
BMI (Kg/m²)									
<18.5	103.7 ± 13.8, 97	114.1 ± 11.8, 38	<0.001	68.4 ± 8.8, 97	76.6 ± 10.1, 38	<0.001	80.2 ± 11.0, 97	86.4 ± 12.3, 38	0.002
18.5 - 25.5	113.6 ± 15.2, 302	123.1 ± 18.4, 224	<0.001	75.1 ± 9.5, 302	81.1 ± 9.7, 224	<0.001	76.6 ± 11.0, 301	81.5 ± 10.1, 224	<0.001
≥ 25.5	118.5 ± 14.0, 37	128.7 ± 18.8, 155	0.001	80.0 ± 9.6, 37	85.2 ± 10.2, 155	0.002	79.6 ± 10.7, 37	80.7 ± 10.8, 155	0.291
Age group (in yrs)									
16 - 25	108.0 ± 10.5, 153	116.0 ± 10.3, 156	<0.001	71.5 ± 8.0, 153	78.4 ± 8.2, 156	<0.001	81.3 ± 12.0, 153	84.7 ± 10.0, 156	0.003
25 – 35	109.4 ± 10.6, 99	118.1 ± 13.5, 95	<0.001	73.9 ± 8.2, 99	79.9 ± 9.4, 95	<0.001	76.6 ± 9.8, 98	81.0 ± 11.2, 95	0.002
35 – 45	111.2 ± 12.5, 77	130.1 ± 18.5, 64	<0.001	74.4 ± 9.0, 77	87.6 ± 11.8, 64	<0.001	75.0 ± 11.1, 77	80.3 ± 9.2, 64	0.001
45 – 55	113.1 ± 12.0, 38	135.2 ± 20.9, 56	<0.001	75.7 ± 8.5, 38	86.6 ± 9.4, 56	<0.001	73.3 ± 9.8, 38	76.9 ± 10.4, 56	0.045
≥ 55	123.6 ± 25.9, 69	144.5 ± 21.9, 46	<0.001	78.5 ± 15.1, 69	86.9 ± 11.9, 46	0.001	76.4 ± 9.0, 69	80.2 ± 11.1, 46	0.021
Male group									
Smoking status									
Non-smoker	112.4 ± 11.2, 201	126.0 ± 16.7, 244	<0.001	72.0 ± 10.0, 201	84.1 ± 11.6, 244	<0.001	70.0 ± 10.3, 201	76.3 ± 11.8, 244	<0.001
Ex-smoker	122.2 ± 28.0, 29	134.5 ± 21.0, 56	0.012	78.2 ± 19.7, 29	89.8 ± 12.1, 56	<0.001	74.3 ± 12.8, 29	75.8 ± 10.4, 56	0.284
Current smoker	116.9 ± 17.9, 134	132.5 ± 17.8, 76	<0.001	76.0 ± 11.8, 134	88.7 ± 12.1, 76	<0.001	70.5 ± 11.7, 134	77.1 ± 9.9, 76	<0.001
BMI (Kg/m²)									
<18.5	107.6 ± 14.6, 101	116.6 ± 10.6, 58	<0.001	66.6 ± 11.5, 101	76.4 ± 8.5, 58	<0.001	69.0 ± 11.7, 101	78.1 ± 12.7, 58	<0.001
18.5 - 25.5	117.3 ± 15.9, 245	129.5 ± 17.9, 230	<0.001	76.5 ± 10.9, 245	86.3 ± 12.0, 230	<0.001	70.9 ± 10.7, 245	76.1 ± 10.7, 230	<0.001
≥ 25.5	121.8 ± 11.7, 18	134.2 ± 18.4, 88	<0.001	79.9 ± 9.2, 18	91.1 ± 10.3, 88	<0.001	73.8 ± 12.1, 18	76.0 ± 11.3, 88	0.228
Age group (in yrs)									
16 - 25	111.8 ± 11.8, 132	120.1 ± 10.8, 125	0.003	70.5 ± 9.5, 132	78.3 ± 8.7, 125	<0.001	69.7 ± 10.8, 132	77.6 ± 12.2, 125	<0.001
25 – 35	113.3 ± 11.0, 87	126.3 ± 11.9, 96	<0.001	74.8 ± 10.1, 87	86.7 ± 9.4, 96	<0.001	71.1 ± 11.7, 87	75.4 ± 11.2, 96	0.006
35 – 45	115.5 ± 15.8, 48	128.6 ± 14.8, 60	<0.001	78.3 ± 12.1, 48	88.7 ± 10.6, 60	<0.001	70.5 ± 10.3, 48	75.3 ± 9.1, 60	0.005
45 – 55	114.4 ± 13.2, 34	139.0 ± 21.9, 50	<0.001	74.7 ± 12.5, 34	93.9 ± 12.6, 50	<0.001	71.8 ± 12.8, 34	77.5 ± 10.5, 50	0.015
≥ 55	122.9 ± 25.7, 63	145.6 ± 25.3, 45	<0.001	76.1 ± 16.2, 63	92.2 ± 14.3, 45	<0.001	71.0 ± 10.4, 63	75.2 ± 11.4, 45	0.025

Table 4 Regression coefficients (blood pressure) and Odds ratios (hypertension) using robust variance estimates in biomass users

	SBP		DBP		Heart rate		Systolic hypertension		Diastolic hypertension	
	Regression coefficient β (95% CI)*	p- value	Regression coefficient β (95% CI)*	p- value	Regression coefficient β (95% CI)*	p- value	Odds ratio (95% CI)*	p- value	Odds ratio (95% CI)*	p-value
WOMEN'S DATA ONLY										
Indoor $PM_{2.5}$#	0.861 (-0.713, 2.436)	0.282	0.666 (-0.327, 1.659)	0.188	-0.459 (-1.564, 0.647)	0.414	0.96 (0.56, 1.65)	0.894	0.75 (0.45, 1.26)	0.279
Outdoor $PM_{2.5}$#	0.826 (-5.572, 7.224)	0.790	2.001 (-3.725, 7.727)	0.473	1.201 (-5.513, 7.915)	0.712	-	-	-	-
CO (in ppm)#	-0.265 (-6.799, 6.270)	0.935	-1.241 (-4.329, 1.846)	0.419	-0.992 (-4.654, 2.669)	0.585	1.31 (0.335, 5.15)	0.696	-	-
Temp (°C)#	14.260 (-6.095, 34.615)	0.169	6.806 (-4.219, 17.831)	0.225	5.788 (-10.245, 21.821)	0.478	5865.37 (1.11, 3.11e+07)	0.047	5.77 (0.003, 10255.01)	0.646
Rel. humidity#	-0.891 (-10.305, 8.523)	0.852	1.529 (-3.976, 7.033)	0.585	-8.264 (-13.819, -2.709)	0.004	0.14 (0.01, 2.95)	0.208	0.84 (0.06, 12.28)	0.901
Ventilation	2.467 (-0.518, 5.451)	0.105	2.300 (0.371, 4.227)	0.020	1.325 (-0.777, 3.428)	0.215	2.11 (0.81, 5.51)	0.126	1.60 (0.60, 4.25)	0.346
Seasonality	7.949 (-2.277, 18.174)	0.127	3.980 (-0.099, 8.058)	0.056	2.853 (-4.128, 9.834)	0.421	2.77 (0.19, 40.09)	0.454	3.10 (0.64, 14.91)	0.159
MEN'S DATA ONLY										
Indoor $PM_{2.5}$#	-0.615 (-2.809, 1.579)	0.581	-0.744 (-2.111, 0.623)	0.285	0.888 (-0.836, 2.612)	0.311	0.85 (0.41, 1.79)	0.678	0.77 (0.46, 1.31)	0.338
Outdoor $PM_{2.5}$#	4.657 (-2.269, 11.582)	0.172	0.300 (-2.694, 3.294)	0.834	4.354 (1.452, 7.256)	0.006	-	-	-	-
CO (in ppm)#	0.215 (-6.290, 6.719)	0.947	-1.514 (-5.292, 2.265)	0.421	-2.664 (-7.802, 2.473)	0.299	2.22 (0.24, 20.89)	0.487	0.49 (0.09, 2.71)	0.409
Temp (°C)#	-11.558 (-32.538, 9.422)	0.279	-8.377 (-23.168, 6.415)	0.266	-3.016 (-22.092, 16.059)	0.756	0.49 (0.0001, 2699.73)	0.870	0.15 (0.0006, 41.83)	0.511
Rel. humidity#	9.954 (0.235, 19.674)	0.045	7.044 (0.223, 13.864)	0.043	-4.229 (-11.714, 3.256)	0.267	4.13 (0.12, 140.05)	0.430	4.73 (0.42, 53.20)	0.208
Ventilation	1.362 (-2.150, 4.874)	0.446	0.775 (-1.713, 3.264)	0.540	1.828 (-0.602, 4.258)	0.140	3.60 (1.348, 9.59)	0.011	2.74 (1.26, 5.99)	0.011
Seasonality	15.888 (1.895, 29.880)	0.026	8.752 (1.340, 16.164)	0.021	3.932 (-0.780, 8.645)	0.102	12.57 (1.857, 85.03)	0.009	8.50 (1.70, 42.58)	0.009
COMBINED DATA FOR MEN AND WOMEN										
Indoor $PM_{2.5}$#	0.183 (-1.334, 1.700)	0.812	0.043 (-0.874, 0.959)	0.927	0.029 (-1.047, 1.105)	0.958	0.89 (0.53, 1.47)	0.640	0.75 (0.52, 1.07)	0.112
Outdoor $PM_{2.5}$#	1.306 (-2.347, 4.960)	0.473	0.439 (-2.302, 3.179)	0.747	0.827 (-1.867, 3.522)	0.537	-	-	0.68 (0.29, 1.60)	0.378
CO (in ppm)#	-0.307 (-5.297, 4.683)	0.901	-1.678 (-4.120, 0.764)	0.171	-1.857 (-5.115, 1.402)	0.255	1.39 (0.49, 3.92)	0.535	0.71 (0.25, 2.01)	0.520
Temp (°C)#	1.031 (-16.489, 18.551)	0.908	-0.358 (-10.081, 9.364)	0.942	2.494 (-11.405, 16.393)	0.724	40.59 (0.02, 76006.58)	0.335	0.79 (0.01, 56.67)	0.913
Rel. humidity#	3.610 (-4.544, 11.763)	0.384	3.660 (-1.158, 8.478)	0.136	-6.194 (-11.208, -1.181)	0.016	0.64 (0.05, 8.90)	0.737	1.98 (0.31, 12.49)	0.469
Ventilation	1.789 (-0.757, 4.335)	0.168	1.513 (-0.152, 3.179)	0.075	1.687 (-0.043, 3.417)	0.056	2.57 (1.27, 5.20)	0.009	2.03 (1.12, 3.72)	0.021
Seasonality	11.112 (0.484, 21.740)	0.041	6.041 (1.213, 10.869)	0.014	3.528 (-1.333, 8.389)	0.154	6.17 (1.17, 32.41)	0.032	4.70 (1.37, 16.19)	0.014

#= log transformed; SBP=Systolic blood pressure, DBP=Diastolic blood pressure, CI=confidence interval; PM transformed to natural log scale; Ventilation (0=not adequately ventilated; 1=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer), Indoor & Outdoor $PM_{2.5}$ in mg/m^3.

* Adjusted for age, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke ['Yes' = regularly exposed to other people tobacco smoke where 'regularly' = on most days or nights] and farmer as main occupation;

Table 5 Regression coefficients (blood pressure) and Odds ratios (hypertension) using robust variance estimates in non-biomass users

	SBP		DBP		Heart rate		Systolic hypertension		Diastolic hypertension	
	Regression coefficient β(95% CI)*	p- value	Regression coefficient β (95% CI)*	p- value	Regression coefficient β (95% CI)*	p- value	Odds ratio (95% CI)*	p- value	Odds ratio (95% CI)*	p- value
WOMEN'S DATA ONLY										
Indoor $PM_{2.5}$#	-0.737 (-2.767, 1.294)	0.475	-0.810 (-2.375, 0.755)	0.309	-1.099 (-2.632, 0.433)	0.159	0.92 (0.59, 1.42)	0.695	0.87 (0.58, 1.30)	0.485
Outdoor $PM_{2.5}$#	1.456 (-4.540, 7.451)	0.627	0.744 (-2.024, 3.512)	0.591	1.802 (-2.454, 6.058)	0.398	0.88 (0.35, 2.25)	0.790	1.18 (0.53, 2.62)	0.686
CO (in ppm)#	-0.902 (-5.159, 3.354)	0.674	-1.768 (-4.406, 0.870)	0.186	0.613 (-1.932, 3.159)	0.633	0.77 (0.33, 1.80)	0.550	1.16 (0.43, 3.16)	0.769
Temp (^{0}C)#	-7.315 (-18.028, 3.397)	0.179	-6.107 (-12.886, 0.672)	0.077	-0.224 (-8.203, 7.755)	0.956	0.52 (0.08, 3.27)	0.481	0.39 (0.07, 2.22)	0.288
Rel. humidity#	8.842 (-0.440, 18.124)	0.062	4.870 (-0.765, 10.506)	0.090	-1.871 (-8.499, 4.757)	0.578	10.73 (1.50, 76.81)	0.018	3.93 (0.81, 19.04)	0.089
Ventilation	-3.536 (-8.199, 1.128)	0.137	-2.290 (-5.929, 1.349)	0.216	-3.110 (-6.002, -0.218)	0.035	0.21 (0.05, 0.82)	0.025	0.72 (0.23, 2.21)	0.563
Seasonality	16.612 (9.549, 23.675)	<0.001	8.077 (4.101, 12.053)	<0.001	-0.732 (-5.470, 4.006)	0.761	-	-	-	-
MEN'S DATA ONLY										
Indoor $PM_{2.5}$#	3.085 (1.116, 5.053)	0.002	0.002 (-1.651, 1.656)	0.998	-1.454 (-3.488, 0.579)	0.160	1.73 (1.09, 2.74)	0.021	1.36 (0.91, 1.04)	0.134
Outdoor $PM_{2.5}$#	17.109 (6.704, 27.514)	0.003	7.485 (0.027, 14.942)	0.049	-3.732 (-11.227, 3.762)	0.311	-	-	3.53 (0.42, 29.33)	0.243
CO (in ppm)#	0.796 (-3.362, 4.955)	0.704	0.010 (-2.249, 2.270)	0.993	1.596 (-1.429, 4.621)	0.297	1.65 (0.95, 2.87)	0.073	1.39 (0.76, 2.51)	0.283
Temp (^{0}C)#	-16.307 (-25.711, -6.902)	0.001	-10.347 (-17.541, -3.153)	0.005	-2.977 (-11.496, 5.543)	0.491	0.28 (0.05, 1.62)	0.157	0.09 (0.02, 0.51)	0.006
Rel. humidity#	0.235 (-8.542, 9.011)	0.958	3.973 (-2.472, 10.417)	0.225	-1.509 (-9.060, 6.042)	0.694	1.02 (0.19, 5.56)	0.984	2.69 (0.68, 10.61)	0.157
Ventilation	-1.303 (-8.032, 5.426)	0.703	-2.787 (-6.041, 0.468)	0.093	-3.102 (-6.347, 0.143)	0.061	1.45 (0.56, 3.72)	0.441	0.69 (0.32, 1.49)	0.347
Seasonality	12.124 (7.337, 16.912)	<0.001	6.900 (3.141, 10.656)	<0.001	-1.418 (6.605, 3.769)	0.590	-	-	-	-
COMBINED DATA FOR MEN AND WOMEN										
Indoor $PM_{2.5}$#	0.892 (-0.689, 2.472)	0.268	-0.576 (-1.922, 0.770)	0.400	-1.259 (-2.354, -0.163)	0.025	1.18 (0.89, 1.57)	0.239	1.01 (0.75, 1.34)	0.985
Outdoor $PM_{2.5}$#	4.770 (-0.698, 10.237)	0.086	1.567 (-1.089, 4.224)	0.243	0.433 (-3.259, 4.125)	0.816	1.10 (0.51, 2.41)	0.803	1.10 (0.53, 2.27)	0.804
CO (in ppm)#	0.096 (-3.252, 3.443)	0.955	-0.664 (-2.606, 1.279)	0.499	1.198 (-0.979, 3.374)	0.277	1.22 (0.82, 1.82)	0.327	1.22 (0.71, 2.11)	0.477
Temp (^{0}C)#	-11.992 (-19.192, -4.792)	0.001	-8.120 (-13.465, -2.775)	0.003	-1.680 (-7.712, 4.351)	0.583	0.41 (0.12, 1.37)	0.146	0.19 (0.05, 0.69)	0.012
Rel. humidity#	5.884 (-1.094, 12.863)	0.098	5.408 (0.903, 9.913)	0.019	-2.347 (-7.719, 3.026)	0.390	3.54 (0.99, 12.64)	0.052	3.92 (1.43, 10.76)	0.008
Ventilation	-2.578 (-7.195, 2.039)	0.273	-2.212 (-5.077, 0.654)	0.130	-2.939 (-5.291, -0.588)	0.014	0.69 (0.32, 1.47)	0.332	0.77 (0.38, 1.57)	0.472
Seasonality	16.630 (13.035, 20.226)	<0.001	9.053 (6.532, 11.573)	<0.001	-0.455 (-3.474, 2.564)	0.766	-	-	-	-

#= log transformed; SBP=Systolic blood pressure, DBP=Diastolic blood pressure, CI=confidence interval; PM transformed to natural log scale; Ventilation (0=not adequately ventilated; 1=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer), Indoor & Outdoor $PM_{2.5}$ in mg/m^3.

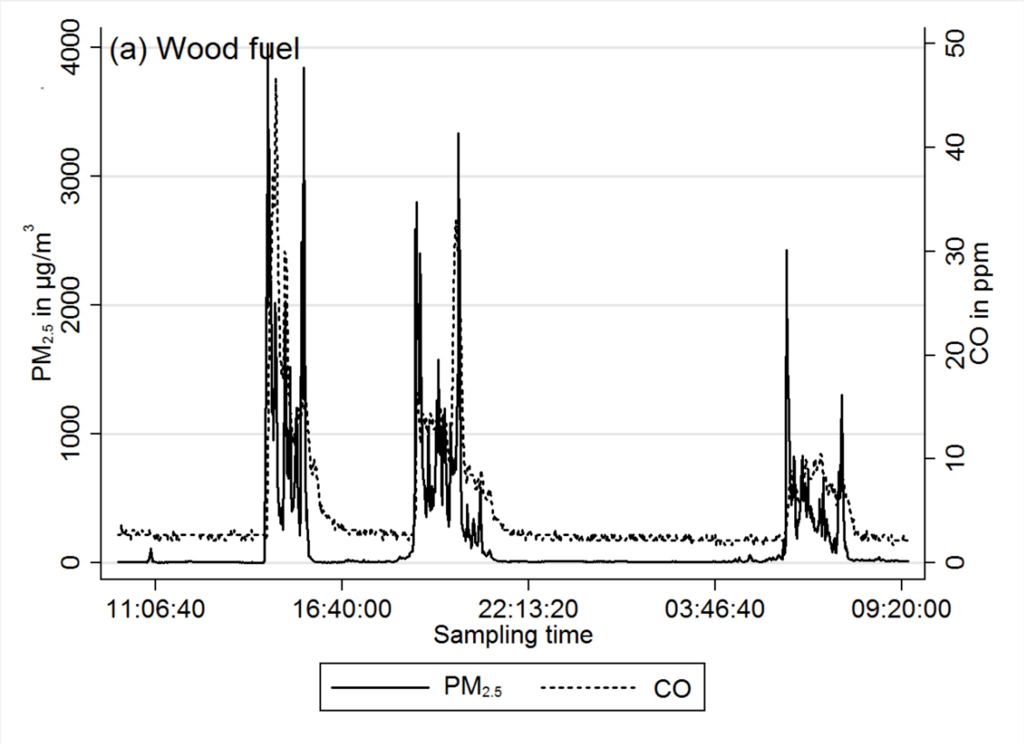
* Adjusted for age, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke ['Yes' = regularly exposed to other people tobacco smoke where 'regularly' = on most days or nights] and farmer as main occupation;

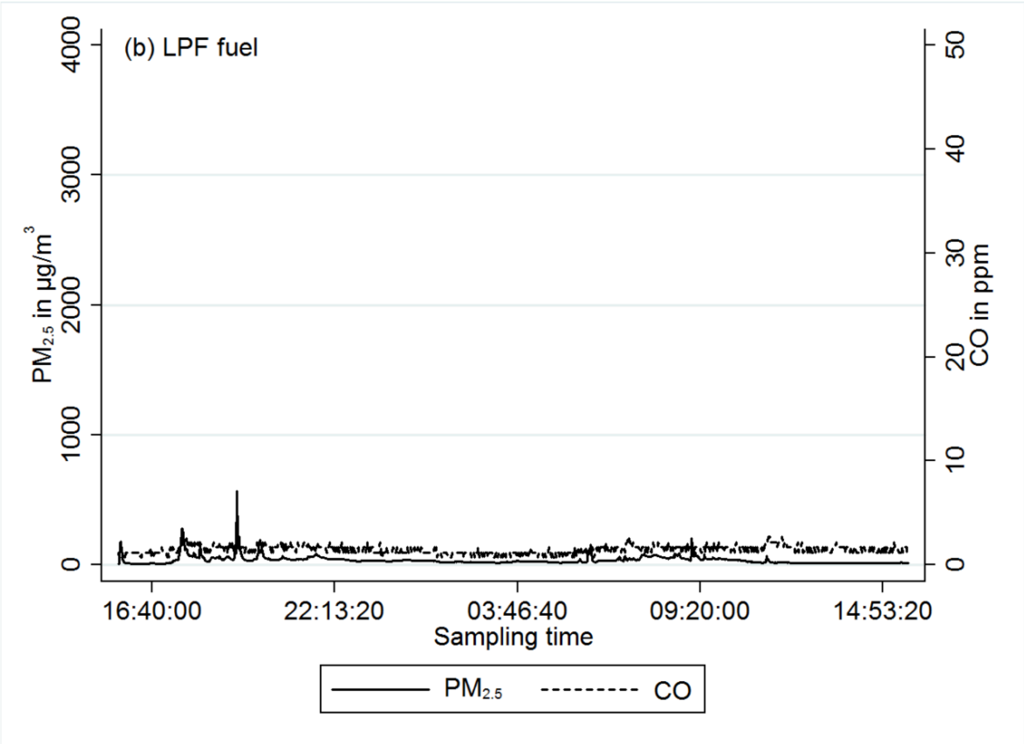
Supplementary Table S5 Regression coefficients (Blood pressure) and odds ratio (hypertension) using robust variance estimates in biomass and non-biomass user

Biomass and non-biomass user	SBP Regression coefficient β (95% CI)*	SBP p- value	DBP Regression coefficient β (95% CI)*	DBP p- value	Heart rate Regression coefficient β (95% CI)*	Heart rate p- value	Systolic hypertension Odds ratio (95% CI)*	Systolic hypertension p- value	Diastolic hypertension Odds ratio (95% CI)*	Diastolic hypertension p- value
WOMEN DATA ONLY										
Indoor $PM_{2.5}$#	-1.103 (-2.310, 0.105)	0.073	-0.660 (-1.460, 0.140)	0.106	-1.033 (-1.849, -0.216)	0.013	0.76 (0.54, 1.08)	0.125	0.68 (0.51, 0.91)	0.009
O. $PM_{2.5}$#	0.0404 (-4.404, 5.211)	0.867	0.534 (-1.867, 2.935)	0.658	1.427 (-1.954, 4.809)	0.402	0.97 (0.44, 2.15)	0.946	1.01 (0.54, 1.88)	0.976
CO (in ppm)#	-2.964 (-6.313, 0.386)	0.082	-2.751 (-4.371, -1.131)	0.001	-0.740 (-2.611, 1.132)	0.435	0.91 (0.49, 1.70)	0.774	0.69 (0.34, 1.37)	0.283
Temp (⁰C)#	-9.464 (-17.984, -0.944)	0.030	-7.140 (-12.314, -1.966)	0.007	-1.239 (-7.551, 5.072)	0.700	0.364 (0.07, 2.02)	0.248	0.20 (0.04, 0.95)	0.043
R. humidity#	2.267 (-4.407, 8.941)	0.505	2.465 (-1.518, 6.448)	0.224	-5.442 (-9.829, -1.056)	0.015	1.27 (0.26, 6.34)	0.768	1.92 (0.51, 7.24)	0.335
Ventilation	0.200 (-2.339, 2.739)	0.877	0.582 (-1.101, 2.265)	0.497	0.164 (-1.554, 1.882)	0.851	0.72 (0.35, 1.46)	0.360	0.81 (0.42, 1.55)	0.520
Seasonality	8.419 (3.770, 13.067)	<0.001	4.529 (1.986, 7.071)	0.001	2.442 (-0.617, 5.502)	0.117	4.10 (1.66, 10.11)	0.002	4.07 (1.79, 9.23)	0.001
MEN DATA ONLY										
Indoor $PM_{2.5}$#	-1.144 (-2.437, 0.148)	0.082	-1.795 (-2.694, -0.895)	<0.001	-1.118 (-2.221, -0.015)	0.047	0.92 (0.69, 1.22)	0.574	0.74 (0.58, 0.95)	0.016
O. $PM_{2.5}$#	9.118 (0.732, 17.505)	0.034	2.357 (-2.358, 7.072)	0.317	0.673 (-3.721, 5.067)	0.758	1.26 (0.21, 7.48)	0.797	1.11 (0.25, 4.82)	0.893
CO (in ppm)#	-1.548 (-4.458, 1.362)	0.294	-2.204 (-3.766, -0.642)	0.006	-0.533 (-2.768, 1.702)	0.637	1.38 (0.80, 2.37)	0.248	0.77 (0.50, 1.19)	0.235
Temp (⁰C)#	-19.198 (-26.929, -11.467)	<0.001	-14.206 (-19.778, -8.635)	<0.001	-6.497 (-13.206, 0.211)	0.058	0.11 (0.02, 0.53)	0.006	0.04 (0.01, 0.16)	<0.001
R. humidity#	5.623 (-1.058, 12.303)	0.099	5.499 (0.757, 10.242)	0.023	-2.635 (-7.901, 2.631)	0.326	1.80 (0.39, 8.37)	0.451	3.82 (1.14, 12.84)	0.030
Ventilation	-0.805 (-3.805, 2.195)	0.598	-1.349 (-3.370, 0.672)	0.190	-0.524 (-2.485, 1.436)	0.599	1.54 (0.82, 2.89)	0.177	1.00 (0.59, 1.70)	0.998
Seasonality	12.059 (7.602, (16.516)	<0.001	8.609 (5.803, 11.416)	<0.001	5.088 (2.007, 8.169)	0.001	7.86 (2.94, 21.01)	<0.001	7.15 (3.50. 14.59)	<0.001
COMBINED DATA FOR MEN AND WOMEN										
Indoor $PM_{2.5}$#	-1.199 (-2.186, -0.213)	<0.001	-1.189 (-1.867, -0.511)	0.001	-1.122 (-1.813, -0.432)	0.001	0.80 (0.63, 1.01)	0.060	0.69 (0.57, 0.84)	<0.001
O. $PM_{2.5}$#	1.786 (-1.990, 5.562)	0.350	0.045 (-1.992, 2.082)	0.965	0.369 (-1.896, 2.634)	0.747	1.22 (0.67, 2.21)	0.510	0.79 (0.47, 1.33)	0.375
CO (in ppm)#	-2.309 (-4.782, 0.164)	0.067	-2.474 (-3.757, -1.192)	<0.001	-0.811 (-2.490, 0.868)	0.341	1.29 (0.86, 1.93)	0.220	1.05 (0.67, 1.65)	0.822
Temp (⁰C)#	-13.829 (-19.821, -7.838)	<0.001	-10.090 (-14.121, -6.059)	<0.001	-4.410 (-9.256, 0.435)	0.074	0.22 (0.07, 0.71)	0.012	0.10 (0.03, 0.30)	<0.001
R. humidity#	4.145 (-1.276, 9.565)	0.134	3.978 (0.663, 7.293)	0.019	-4.513 (-8.209, -0.816)	0.017	1.65 (0.51, 5.28)	0.402	2.87 (1.21, 6.84)	0.017
Ventilation	-0.328 (-2.562, 1.907)	0.774	-0.275 (-1.714, 1.165)	0.708	-0.178 (-1.581, 1.226)	0.804	1.07 (0.65, 1.75)	0.801	0.94 (0.61, 1.43)	0.764
Seasonality	10.079 (6.479, 13.680)	<0.001	6.292 (4.224, 8.360)	<0.001	4,212 (1.976, 6.447)	<0.001	6.01 (2.89, 12.47)	<0.001	5.38 (3.09, 9.37)	<0.001

#= log transformed; SBP=Systolic blood pressure, DBP=Diastolic blood pressure, CI=confidence interval, O. $PM_{2.5}$=Outdoor $PM_{2.5}$; PM transformed to natural log scale; Ventilation (0=not adequately ventilated; 1=adequately ventilated); Seasonality (1=autumn/Winter, 0=Spring/summer), Indoor & Outdoor $PM_{2.5}$ in mg/m^3.

* Adjusted for age, education, BMI, income, smoking history [Ex- & current smoker = at least 20 packs of cigarettes or 12 oz (360 grams) of tobacco in a lifetime, or at least one cigarette per day or one cigar a week for one year; lifelong non-smoker] and environmental tobacco smoke [‘Yes’ = regularly exposed to other people tobacco smoke where ‘regularly’ = on most days or nights] and farmer as main occupation;





Supplement Figure S1 Typical temporal profiles of $PM_{2.5}$ and CO concentration (Nepalese data). (a) Rural: Wood burnt in a 3-stone stove. Afternoon snacks prepared during 1400-1445, evening meal prepared during 1900-2000 and morning lung prepared during 0700-0830 hours and (b) Urban: LPG fuel burnt in gas stove. Afternoon snacks prepared during 1515-1530, evening meal prepared during 1800-1900, morning breakfast prepared during 0445-0600 and morning lunch prepared during 0700-0800.

Univariate analysis showed that SBP and DBP was positively associated with outdoor particulate matter, temperature, BMI, age, income, smoking cigarettes among male in both urban and rural areas whereas among women increased with BMI, those having higher education, age and smoking status. Multivariate analysis demonstrated that SBP and DBP was not significantly associated with real time particulate matter measurement among women (Table 4 & 5) but the relationship between SBP among men increased significantly with both real time indoor and outdoor particulate matter measurement and only outdoor particulate matter for DBP (Table 5). Blood pressure measurements were significantly higher among men and women during winter periods, increased when the humidity was higher and decreased with increase in temperature (Table 5). Similar results were obtained from systolic and diastolic hypertension with the prevalence increasing significantly during winter periods, higher humidity and with inadequate ventilation (lack of proper cross ventilation). Outdoor $PM_{2.5}$ was significantly (OR=3.82, p=0.025) associated with heart rate (HR) (β=4.354, p=0.006) in men. The HR was negatively associated with relative humidity and inadequate ventilation (Table 4 & 5).

DISCUSSION

This cross-sectional study of adults in Nepal was designed to investigate the markers of cardiovascular health for rural and urban populations exposed to indoor pollutants from biomass and non-biomass (liquefied petroleum gas (LPG)) respectively. We also investigated the association between indoor biomass smoke and traffic generated outdoor air pollution with markers of cardiovascular health.

Majority of indoor air pollutants in the rural comes from burning biomass whereas in the urban is due to very high ambient outdoor air pollution generated from poorly maintained road vehicles and local congested traffic. The higher outdoor air pollution (measured on the veranda rather than true ambient concentration) in rural homes suggests that the outdoor pollution measurements (in the veranda) in the rural areas may partly arise from indoor biomass burning. The higher $PM_{2.5}$ concentration in urban kitchens with adequate ventilation might be due to the influx of highly polluted ambient air pollution from traffic.

Biomass exposed men and women reported significantly more chest pain, particularly exertional chest pain when compared with the non-biomass users on univariate analysis but these associations largely disappeared after adjustment except for higher temperature which appeared to be protective. This association might be due to chance but, if real, needs to be explored further in future studies. Chest pain in women was significantly greater than male both in biomass and non-biomass exposed groups. Non-biomass dwellers were more likely to have systolic and diastolic hypertension which was strongly related to BMI, outdoor air pollution, seasonality, temperature and previous smoking history. However, in biomass fuel users, although mean blood pressure was lower than the non-biomass user, there was a relationship between blood pressure and different exposure metrics of higher indoor particulate exposures (e.g. cooking and ventilation) but the relationship was statistically not significant.

The largely negative findings for reported chest pain after adjustment for potential confounding factors need to be interpreted with some caution although we found positive associations between indoor particulate matter and men regarding severe chest pain symptoms in non-biomass fuel users. We did not use any objective measures of coronary artery disease such as resting or exercise ECG, and relying on a reported chest pain questionnaire as a marker of cardiac impairment has its limitations. Differing education achievement levels (urban and rural) may have influenced the interpretation of the symptom questions which may have resulted in biased responses in either direction in the biomass smoke exposed population. Equally, the chest pain questionnaire used might have low sensitivity, generating a positive response to questions on pain of muscular or cardiovascular origin particularly for the biomass exposed group who regularly conduct physical manual farming tasks. Although we measured a number of factors related to SES, residual confounding due to imperfect measure of SES could also be a possibility.

As biomass exposed groups were more likely to smoke cigarettes than non-biomass exposed group and both current and ex-smokers reported significantly more chest pain than life-long non-smokers, smoking is likely to be a critical factor. In this study the self reported smoking history was not validated with an objective measure such as salivary cotinine.

The lack of consistent positive association between blood pressure/cardiovascular outcomes and indoor $PM_{2.5}$ contrasts with the findings from studies of outdoor pollutant exposure[2, 25] and indoor air pollution[13-15, 17 18] suggesting that other factors such as nutrition, exercise and seasonal variation are more important than biomass for study population. Previous studies on household air pollution that have shown positive associations between exposure to biomass smoke and blood pressure are either intervention studies[13 14] or studies which estimate exposure using personal sampling[15 17 18], while employing a better experimental design, are inconsistent. The stove intervention study from Guatemala[13] and Nicaragua[14] reported a significant reduction in smoke levels which only produced a small reduction in blood pressure (3 to 4mmHg). The reduction in exposures (in this intervention stove study) was much greater than the spread in rural exposures in our study, which may explain why no detectable effect was found in this study.

Surrogate indicators of biomass smoke exposure such as poor ventilation and lack of windows are suggestive of higher indoor exposures, but qualitative assessment of these measures are insufficient to estimate biomass exposures adequately. Our study measured indoor particulate concentrations (static samples) within 0.5 m distance of cooking stove and at a height of 1 m from the ground over a single 24 hour period which is representative of current practices but do not allow estimation of lifetime cumulative personal exposures which may be a better indicator of chronic health effects such as cardiovascular symptoms. One previous study showed day to day and seasonal variability of exposure within a house using biomass[26]. Hence repeated measurements of personal exposure over longer periods and over different seasons are recommended to understand better the dose-response relationship between biomass smoke and cardiovascular effects.

Our findings suggest positive association between winter/autumn and inverse association between temperature with both SBP and DBP in both men and women which is in line with previous epidemiological findings[27].

Hypertension was more common in the non-biomass group compared to the biomass group and was strongly influenced by BMI, ambient air pollution and seasonality. This conclusion remained unchanged when the data were re-analysed removing underweight individuals (BMI<18.5 kg/m^2) and adjusting for other potential confounders. Our data also suggest that systolic hypertension was associated with traffic generated air pollution in the non-biomass exposed men which is in line with findings reported in other studies on ambient air pollution and cardiovascular health effects[28,29] but the relationship was not significant in women. One possible reason for this may be that most urban women in Nepal stay at home and very few regularly travel to work resulting in reduced daily exposure to traffic air pollutants. The association of outdoor air pollution to systolic hypertension but not to household air pollution generated from biomass could be explained by exposure to different pollutant types both in terms of nature (particle size characteristics) and chemical composition. The ambient air pollution in the non-biomass group were predominantly from vehicle diesel exhausts which is associated with increase in blood pressure due to its oxidative potential and also inflammation[30].

CONCLUSIONS

These results show no consistent evidence of a cardiovascular effect from biomass smoke exposure either in terms of cardiac symptoms or blood pressure. Urban dwellers exposed to traffic related air pollution and with high BMI are at greater risk of having higher blood pressure and systolic hypertension compared to biomass exposed rural dwellers. Low temperature and autumn/winter season were also positively associated with increase in both SBP and DBP.

ACKNOWLEDGEMENTS

We are extremely grateful to research staff for their help in sampling and local co-ordinators for their help in co-ordinating with the house members. We would like to thank all the participants for taking part in this study. OK was awarded a PhD studentship by University of Aberdeen for this work.

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