Cooking Fuel Smoke and Respiratory Symptoms among Women in Low-Income Areas in Maputo

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The association between exposure to air pollution from cooking fuels and health aspects was studied in Maputo, Mozambique. Almost 1200 randomly selected women residing in the suburbs of Maputo were interviewed and 218 were monitored for air pollution. The fuels most commonly used were wood, charcoal, electricity, and liquified petroleum gas (LPG). Wood users were exposed to significantly higher levels of particulate pollution during cooking time (1200 $\mu g/m^3$) than charcoal users (540 $\mu g/m^3$) and users of modern fuels (LPG and electricity) (200–380 $\mu g/m^3$). Wood users were found to have significantly more cough symptoms than other groups. This association remained significant when controlling for a large number of environmental variables. There was no difference in cough symptoms between charcoal users and users of modern fuels. Other respiratory symptoms such as dyspnea, wheezing, and inhalation and exhalation difficulties were not associated with wood use. Reducing wood use would likely improve acute respiratory health effects in wood users and possibly improve the ambient air pollution conditions in Maputo. To reduce the health impact of wood smoke exposure, it appears that the least costly and quickest method would be to encourage charcoal use to a greater extent, although high carbon monoxide levels would have to be addressed. Turning to modern fuels is beyond the means of most these households in the short term and could not be shown to be more effective. *Key words*: air pollution, charcoal, cooking energy, cooking fuels, developing countries, PEF, respiratory health, urban environment, women's situation, wood fuel. *Environ Health Perspect* 104:980–985 (1996)

Air pollution from smoky cooking fuels has been identified as a serious health hazard in developing countries over at least three decades (*1*), and especially for women and children (*2,3*). Smith (*4*) compiled an authoritative book on the issues of indoor air pollution and health in which he lamented the lack of studies that monitored pollution and health effects simultaneously, especially in rural areas of developing countries. Some early studies focused on health effects and used indirect measures of exposure (*5,6*), while others performed detailed monitoring of pollution but without simultaneous assessment of health effects (*7,8*).

Much of the evidence on the effects of air pollution on health is acquired from extrapolation, either in the case of the pollution estimate or in the case of the population exposed. Most research has been performed in North America or Europe. Dockery and Pope (*9*) associated increased morbidity and mortality to increases of particulate pollution at ambient levels, which are certainly much lower than what is generally encountered in many developing countries. Lambert and Samet (*10*) noted the limited epidemiologic evidence of health effects of wood smoke, while Chen et al. (*11*) reviewed Chinese literature on health effects of cooking fuel smoke, mentioning health outcomes such as chronic bronchitis, emphysema, expectorative cough, and dyspnea.

Health effects from biomass fuel use is sometimes offered as an argument to increase the speed of electrification of households in developing countries. In addition to being convenient as a cooking fuel, electricity produces no pollution at the site of end use. However, electrification is expensive, both to the government and to the households if there are no great subsidies. Hence, the arguments for electrification need to be examined.

Many health effects are attributed to particulate air pollution. Lung cancer in tobacco smokers is the least controversial, but it is an effect of exposure to substantially higher concentrations of particulates than normally encountered in everyday life. Even ambient concentrations of particulates have been shown to cause respiratory symptoms such as chronic bronchitis, acute respiratory infections, and acute changes in lung function (*12*), and especially increased symptoms in asthmatic persons (*13*). Effects of carbon monoxide, another major pollutant from wood-based cooking fuels, are also well documented (*14*), ranging from hypoxia and headache on exertion to unconsciousness and death on prolonged exposure to high concentrations. Though carbon monoxide exposure was also measured in the present study, this paper focuses on the effects of particulate pollution.

In a previous study in Lusaka (*15*), no significant differences in health symptoms could be found between users of wood, charcoal, and electricity in spite of significant differences in exposure at cooking time. The present study attempts to verify if this is generally the case in south-central Africa using essentially the same methods.

The aim of the present study was to determine the levels of pollution to which women in Maputo, Mozambique were exposed and to try to link this pollution to the actual health status experienced by these women. The null hypothesis was that air pollution from smoky cooking fuels does not cause adverse health effects. This should be possible to determine using a sample survey to measure air pollution and questionnaire to determine health status.

Methods

A sample survey was carried out in 1992 in 10 of the 17 suburbs of Maputo. These suburbs are characterized by unplanned construction of separate houses, most made from mud or cement blocks but some made from reeds and flattened oil drums. In some of the suburbs there were multistory houses closer to the urban fringe. The population of all the suburbs of Maputo was 470,000 in 1990 (the most recent census) and that of the surveyed suburbs was 270,000. There were 41,000 households in the surveyed suburbs out of which 1188 were surveyed (2.9%). Selection of the suburbs to be surveyed was made arbitrarily rather than randomly (convenience sample). Households were randomly selected from computer lists supplied by the Statistical Department in eight of the suburbs and by random sequential selection in the remaining two. The probability of the sample was 5%. The final completion rate was 58%. Most of the nonresponse was due to nobody being at home at the time of the interview (38% of nonresponse), followed by interviewers not finding the house (23%) or discovering that the

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family had moved (11%). Only in 4% of the failed attempts was the lack of success due to refusal to take part in the survey.

The person who was interviewed and monitored was the person who generally did the cooking and was over 14 years of age; this was always a woman. The first household on the list or in the sequential order was selected as the one to be monitored that day. Monitoring started when the stove was ignited or turned on to cook the main midday meal and ended when cooking was completed. Average cooking and monitoring time was 1.5 hr. Only one meal per household was monitored.

Air pollution was monitored with the help of person-carried equipment. For particulates, a Gil-Air SC pump (Gilian Instrument Corporation, W. Caldwell, NJ) was used. The air flow was adjusted to 1.9 l/min with a high-precision rotameter in the morning before going into the field and checked immediately on return. The pump was attached to a belt around the subject's waist, and the air inlet was attached to her collar as close to the breathing zone as possible. An SKC cyclone (SKC Inc., Eighty Four, PA) was used to remove particles of sizes larger than 7.1 µm so that mostly respirable particles were collected. Hence, the concentration figures should be roughly comparable to PM_{10} (particulate matter less than 10 µm diameter) (*9*). The size selection also served to screen off some of the larger particles of noncombustion origin and reduce the influence of, for example, road dust. The pumps were fitted with 8 µm Millipore SCWP filters (Millipore Corporation, Bedford, MA). Filters were conditioned in an air-conditioned room overnight to adjust for variable humidity and then weighed on a 5-digit electronic balance. Humidity in the laboratory was monitored with a Fischer hygrograph (VEB Feingerätbau, Drebach/Erzg., Germany). Carbon monoxide exposure was monitored with Dräger diffusion tubes (Dräger AG, Lübeck, Germany). Fuel users were grouped during monitoring by the fuel actually used for cooking rather than by the principal fuel, if these were different.

The respondents were weighed on bathroom scales, their standing height was measured with a tape measure against a vertical surface, and their peak expiratory flow (PEF) rate was determined with a Wright Mini-Peak Flow Meter (Airmed, Clement Clarke International, London, UK). The respondents were allowed to make a few training efforts, rest for a while and, finally, make three blows at maximum effort. The highest of the three was recorded as the value for the respondent. PEF rates were measured before and after cooking in monitored respondents and independent of cooking in other respondents.

Data on a large number of health, infrastructure, social, and energy use variables was gathered by means of a questionnaire. Most questions were formal and closed, giving little room for variable answers. The questionnaire was developed in English, based on a questionnaire previously used in Lusaka, Zambia (*16*) and translated into Portuguese. The questionnaire was printed in Portuguese and, when necessary, translated into local language by the enumerators at the time of the interview, which was always carried out orally. The rate of missing answers was generally 1–2%. There was no examination by a physician at the time of the interview. Persons stating they had a cough and were worried about breathing problems were provided a free checkup at the Central Hospital, with bus fare also payed for by the project. For ethical reasons, persons in obvious need of medical attention or soliciting such attention were also included in this offer.

The survey was undertaken by 24 enumerators in teams of two. There were no all-male teams. Most of the field workers were from the suburbs of Maputo, and the majority were women. The requirements were that the enumerators could read and write in Portuguese and speak at least the major local language (Shangani). The enumerators were trained in using the equipment and performing interviews for 2 weeks before field work started. Great care was taken while discussing the health questions so that correct interpretations were used by all field workers when posing them. One team was assigned to follow up the achievements of the other groups. In no case was there any indication of false reporting.

Respondents were asked to rank the fuels used in order of use frequency. The principal fuel was defined as the fuel used most often to cook the main meal. This refers to the current general situation. The duration of fuel use was also requested, as well as the fuel used principally previously. Principal fuel was used as a criterion variable when grouping the respondents in the analysis of health and socioeconomic variables. For the pollution data, the actual fuel used while cooking was used as the criterion variable.

In most of the analyses, the number of fuel user groups investigated was restricted for reasons of brevity and clarity. Wood and charcoal users were kept as separate groups representing traditional and transitional fuels, respectively, while electricity and liquid petroleum gas (LPG) users were collapsed into one group representing modern fuels. Other fuel user groups were excluded from these analyses. This reduced the total sample by 90 (from 1188 to 1098).

An estimate of the lifetime exposure from cooking fuels was made. It was computed as the product of the exposure with the fuel, the number of years it had been used, the duration of daily cooking, and a use intensity factor. This was done for both principal and secondary fuels. The use intensity factor for the principal fuel was taken as the ratio between the fuel actually used on the day of the survey and the stated principal fuel. The use intensity of the secondary fuel was 1-(use intensity for principal fuel). In addition, the exposure from the previous principal fuel was estimated by assuming that the time it had been used was from the time when the woman started helping her mother to cook to the time when she started using her current fuel. No use intensity factor was used for the previous fuel because no information on previous secondary fuels was available. The average daily cooking time in the sample (2 hr 50 min) was used as an estimate for all groups and all years. The total exposure was the sum of the exposure using principal, secondary, and previous fuels.

Data Analysis

Health questions were posed with a recall period of 3 weeks and coded in the following way. The answer "no" or "never," indicating that the respondent had not had the symptom in question, was coded 0 (zero). The answer "yes, sometimes" indicated that the respondent had perceived the symptom or condition one to four times and was coded 1 (one). The answer "yes, often" was defined has having the symptom more than four times and was coded as 2.

Health indices were then computed by adding the codes for the answers for certain groups of related health questions. This resulted in two continuous variables. The first was a cough symptom index, which included several aspects of cough. The second index combined other respiratory symptoms and was called the non-cough respiratory symptom index. In the computation of indices, missing values were included as zeroes. The division of respiratory symptoms on two indices was supported by logistic factor analysis and bears some resemblance of the division into upper (cough symptoms) and lower (non-cough symptoms) used by Pope and Dockery (*13*). The health indices were treated as ratio scales.

Data was entered onto the computer immediately after the completed questionnaires were received. This sometimes made it possible to check inconsistencies and update information from the respondent in the field. Data analysis was carried out using the SPSS statistical package (SPSS Inc., Chicago, IL). Generally, *t*-tests were used for comparisons between two groups. Analysis of the health indices and PEF rate was made using correlation and stepwise multivariate regression. Correlation was used to select independent variables for regression for use in the regression models. The significance level $\alpha = 0.01$ was used as selection criterion for correlation, while $\alpha = 0.05$ was used in the regression. Smoking, (active and passive), alcohol and medicine use, principal fuel use, and exposure years were always included in the regressions. Regression analysis was carried out separately for the three dependent variables (cough index, non-cough index, and PEF rate) but simultaneously for all independent variables.

Results

The pattern of principal fuel use in the suburbs of Maputo is shown in Table 1. Most of the respondents used more than one fuel from time to time. Wood and charcoal were most often used as principal fuels. Almost all (97% of the sample) used wood or charcoal at least occasionally. Electricity was used for cooking by less than 5% of the respondents, although 30% of the respondents were connected to the electric grid. Coal was used only in one suburb situated close to the thermal power plant. LPG was said to have been used more extensively earlier, but lack of gas and cylinders had reduced its availability. Kerosene was used mainly in wick stoves.

Wood, coal, and kerosene users were exposed to high levels of particulates (Table 2). Charcoal users were intermediate, while electricity and LPG users were exposed to lower levels of particulate pollution. The difference in particle concentration was statistically significant between wood users and users of charcoal, electricity, and LPG, respectively ($p<0.0005$, *t*-test). There was a slightly significant difference between charcoal users and users of LPG ($p = 0.018$, *t*-test). Differences between other groups were not statistically significant.

Wood and charcoal users were exposed to almost the same levels of carbon monoxide (42 and 37 ppm, respectively). This was significantly more than users of modern fuels (0–5 ppm; $p<0.0005$, *t*-tests) and higher than the World Health Organization (WHO) recommended values for the general public (*11*). Carbon monoxide exposure will not be further discussed in this paper.

Wood users reported more cough symptoms than the users of other fuels, but there was less difference with respect to non-cough respiratory symptoms (Table 3). Prevalence of socioeconomic, infrastructure, and background health variables that correlated significantly with the health indices or the PEF rate are also shown in Table 3.

Table 1. Principal fuel use, duration, and use intensity in Maputo suburbs

Principal fuel	Percent of sample ($n = 1188$)	Years of fuel use	Intensity of principal fuel use[a]
Wood	48.0	23	0.85
Charcoal	34.0	17	0.92
Electricity	5.6	6	0.91
LPG	4.9	16	0.59
Kerosene	4.9	6	0.76
Coal	2.2	4	0.73
Sawdust	0.5	6	0.67

[a]The ratio between the fuel used on the day of the survey and the stated principal fuel use for each fuel user group.

Table 2. Concentration of particulates encountered while cooking with the indicated fuel

Fuel	Mean ± SE (μg/m³)[a]	Number
Wood	1200 ± 131	114
Charcoal	540 ± 80	78
Electricity	380 ± 94	8
LPG	200 ± 110	3
Kerosene	760 ± 270	10
Coal	940 ± 250	4

Size of particulates was <7.1 μm.
[a]Standard error of the mean = standard deviation $\sqrt{n}$.

Table 3. Frequency of cough and respiratory index variables and background variables[a]

Variables	Wood users ($n = 570$)	Charcoal users ($n = 404$)	Modern fuel users ($n = 124$)
Cough index variables			
Cough	51	38	40
Dry cough	29	19	17
Cough with sputum	35	22	26
Cough in the morning	31	20	20
Cough while lying down	44	31	32
Cough for more than a month[b]	10	5	4
Hoarseness	22	23	20
Respiratory index variables			
Breathing problems	22	17	22
Chest pains	21	19	16
Wheezing breath	17	16	13
Breathless on exertion	34	35	34
Difficulties inhaling	16	14	15
Difficulties exhaling	15	12	15
Breathing problems caused worry	21	15	19
Breathing problems caused panic	16	13	15
Breathing problems disturb sleep	15	12	10
Breathing problems have increased	10	8	8
Social and infrastructure variables			
Family has enough to eat	23	28	35
Literacy	42	58	67
Piped water in house	18	24	56
Connected to the electric grid	21	28	89
Uses pit latrine	83	73	33
Uses flush toilet	1	6	28
Mold problems in house	36	35	29
Uses bottle lamp	34	25	4
Cooking place well ventilated	73	81	77
Cooking outdoors	60	53	8
Finds fuel expensive	90	91	92
Background health variables			
Felt abnormally tired	66	61	45
Sleeping problems	61	57	68
Stomach pains	56	52	48
Felt ill	52	44	47
Loss of appetite	47	42	35
Abnormal night sweat	52	50	46
Muscle cramps	52	48	37
Dry mouth	17	14	19
Active smoking	5	3	4
Passive smoking	36	31	31
Used medicines	44	36	37
Used alcohol	38	34	26
Eyes water while cooking	56	43	31

[a]Percent of principal fuel user group; missing values are 0–4% of sample.
[b]Recall period for this question was 1 year.

The averages for the health indices, PEF rate, and lifetime exposure are presented in Table 4, together with means of continuous background variables. Wood users had a significantly higher cough index than charcoal users and users of modern fuels ($p<0.0005$, $t = 4.33$; $p = 0.006$, $t = 2.78$, respectively). There was no difference between charcoal users and modern fuel users. There were no significant differences between the fuel user groups with respect to the non-cough respiratory symptom index, although wood users exhibited the highest values. Wood users also had significantly lower PEF rates compared to charcoal users ($p = 0.004$, $t = -2.88$) and lower than users of modern fuels, although this difference was not statistically significant ($p = 0.067$, $t = -1.84$). All groups exhibited lower than expected PEF rates when calculated according to an equation based only on age and height (*17*). The empirical data for this equation was, however, based on investigations in industrialized nations.

The majority of principal wood and charcoal users had used these fuels all their active cooking life. About half of the users of other fuels had used charcoal as a principal fuel previously, and about a third had used wood. The exposure years presented in Table 4 indicate the importance of cooking fuel exposure during the active cooking life of the women. For wood users, the current principal fuel completely dominates the lifetime exposure to cooking fuel pollution. Among charcoal users, about half of the pollution was from the current principal fuel and most of the rest from previously used fuels. In modern fuel users, less than a quarter of the estimated lifetime exposure was achieved while cooking with the current principal fuel, and almost all of the rest was achieved from a previously used fuel. Differences between the principal fuel user groups with respect to total lifetime exposure were all highly significant ($p<0.0005$, t-tests).

In the presentation of the health index means in Table 4, smokers were included. The influence of smoking is shown in Table 5, in which the averages of the indices for the smokers and nonsmokers are presented although not distributed between the fuel user groups due to the limited number of active smokers (Table 3). Smokers had a significantly higher cough index than nonsmokers, but there was no difference between smokers and nonsmokers with respect to non-cough symptoms. The difference in PEF rate was suggestive but not significant.

The background variables presented in Tables 3 and 4 are significant in one of the multivariate regression models. They show that wood users most often experienced the worst situation and modern fuel users the best. Charcoal users were generally intermediate between the two. In addition to the background variables shown in Tables 3 and 4, a large number of variables (data not shown) that were analyzed turned out to be insignificant for the health outcomes studied. Among these were variables that showed that wood users had the largest households in the smallest houses and the greatest number of children. Wood was more often used in the homes of the wood users' parents, compared to the situation in the homes of parents of other fuel users. Structural aspects of the cooking place, such as number of walls, roof, and cooking indoors or outdoors, generally were not significantly correlated with the symptom indices. Cooking with windows open was correlated to both respiratory health symptoms and cough indices but was omitted from the analysis due to the limited number of observations.

The results of the multivariate regression analysis for the cough symptom index are presented in Table 6. The coefficient of determination (R^2) was modest. This indi-

Table 4. Averages of health indices, PEF rate, and continuous background variables by principal fuel user group[a]

	Wood users (n = 570)	Charcoal users (n = 404)	Modern fuel users (n = 124)
Health indicator variables			
Cough index	2.42 ± 0.104	1.77 ± 0.108	1.75 ± 0.198
Non-cough respiratory index	2.15 ± 0.144	1.94 ± 0.156	1.95 ± 0.295
PEF rate (l/min)[b]	365 ± 3.4	382 ± 4.0	379 ± 7.4
Exposure years[c]			
Current principal fuel	2800 ± 82	1020 ± 43	240 ± 30
Current secondary fuel	118 ± 8	267 ± 16	108 ± 19
Previous principal fuel	329 ± 35	697 ± 66	1040 ± 134
Total exposure years[d]	3240 ± 80	1970 ± 63	1390 ± 129
Continuous background variables			
Age, years	36.8 ± 0.6	32.7 ± 0.6	34.0 ± 1.4
Age when started cooking, years	10.7 ± 0.1	10.9 ± 0.1	10.8 ± 0.2
Time gone to school, years	2.0 ± 0.1	3.1 ± 0.1	4.0 ± 0.3
Time lived in house, years	13.6 ± 0.5	12.1 ± 0.5	14.4 ± 0.4
Time spent cooking, hours/day	2.8 ± 0.05	2.9 ± 0.05	2.8 ± 0.09
Standing height, cm	157.6 ± 0.3	157.9 ± 0.4	158.6 ± 0.8
Weight, kg	57.5 ± 0.5	59.0 ± 0.6	61.2 ± 1.4

Missing values are 0–5% of sample except for exposure years.
[a]Values are mean ± standard error.
[b]PEF measurements before or independent of cooking time exposure.
[c]Exposure years = exposure (μg/m^3) × years of exposure × duration of daily exposure × use intensity factor.
[d]The sums do not add up because there were fewer observations for previous exposure, thus for total exposure years (wood = 459, charcoal = 349, modern = 111).

Table 5. Averages of health indices and PEF rate among smokers and nonsmokers[a]

Fuel	Nonsmokers[a] (n = 1051)	Smokers[a] (n = 47)	p^b
Cough index	2.066 ± 0.072	3.000 ± 0.376	0.008
Non-cough respiratory index	2.058 ± 0.102	1.894 ± 0.475	0.908
PEF rate l/min	372 ± 2.5	356 ± 12.3	0.181

[a]Values given as mean ± SE.
[b]Probability based on variance estimate in t-tests.

Table 6. Variables found to be significantly associated with the cough symptom index in multiple regression

Variable	Coefficient	t-value	Significance t	Dim.
Felt ill	0.93	5.616	<0.00005	Y/N
Time spent cooking	-0.35	-4.449	<0.00005	H/D
Wood is principal fuel	0.56	3.542	0.0004	Y/N
Abnormal night sweat	0.47	3.035	0.0025	Y/N
Kitchen well ventilated	-0.58	-3.305	0.0025	Y/N
Pit latrine used	0.50	2.847	0.0045	Y/N
Dry mouth	0.57	2.737	0.0063	Y/N
Muscle cramps	0.41	2.541	0.0113	Y/N
Stomach pains	0.39	2.432	0.0152	Y/N
Finds fuel expensive	0.89	2.156	0.0314	Y/N
Constant	1.20	2.865	0.0043	Index

Multiple $R = 0.4802$; $R^2 = 0.2306$. For regression and residual, respectively, degrees of freedom = 10 and 753, sum of squares = 987 and 3295, and mean square = 98.7 and 4.38. $F = 22.56$, significance of $F<0.00005$.

cates that the cough symptoms are only explained to a small degree by the environmental variables tested here. The model shows that cough symptoms were significantly increased in persons who use wood for cooking; however, the most important variable for increasing the cough index was whether the respondent had been feeling ill during the preceding 3 weeks. Several other health-related conditions were also significant. Wood users had slightly higher prevalences in most of these variables. The most important variable for reducing the index was the time usually spent cooking; it is somewhat surprising that the longer the time spent cooking, the less cough. Having a well-ventilated kitchen was associated with less cough symptoms while using a pit latrine and finding fuel expensive (most did; see Table 4) was associated with more. Neither the use of modern fuels nor the lifetime exposure years was associated with the cough index. By forcing charcoal into the model, it was shown that charcoal use was associated with fewer cough symptoms. Neither active nor passive smoking or alcohol use were associated with increased cough symptoms.

Results of multivariate analysis for the non-cough respiratory symptom index are presented in Table 7. The degree of explanation was lower than for the cough index. The only significant variable that was related to cooking conditions was the age of the woman when she started to help her mother cook; starting at a higher age was clearly associated with less respiratory problems. There was little difference between the fuel user groups in this respect (Table 4), indicating that a higher age for starting kitchen duties is associated with reduced non-cough respiratory problems later in life. All other variables significantly associated with the respiratory symptom index were related to health aspects. Historical exposure was not a significant variable in determining the non-cough respiratory symptoms. Fuel use, infrastructure, and use of tobacco and alcohol were not significant.

The PEF rate was also analyzed using multivariate regression. Results are shown in Table 8; the paramount variable determining the PEF rate was the height of the respondent, as expected. A number of socioeconomic, health related, and infrastructure variables were also important. The influence of literacy is taken as a socioeconomic indicator rather than an effect of reading (instructions printed on the PEF tubes were in English). The significance of age was relatively low. Historical exposure to cooking fuel pollution (exposure years) was not significantly associated with the PEF rate. In a separate regression (not shown) with only age, height, weight, and the three fuel user groups included in the model, wood actually turned out to reduce the PEF rate, although at a low level of significance ($p = 0.0383$). A similar regression was performed with the present principal and secondary exposure years and the previous exposure years. In this case, the previous exposure years were significantly associated with an increased PEF rate, although again at a low significance level ($p = 0.0422$).

Discussion

The observation that modern fuel users were exposed to such high particle concentrations may seem surprising, because electricity and LPG essentially do not emit any such pollution. This suggests that there is a relatively high background level of ambient particulate pollution in Maputo. In a previous study (*18*), this was shown to be the case, with a month average during July of 140 µg RSP/m^3 (less than 10 µm) and a TSP average of 230 µg/m^3. The pollution was suspected to originate mainly from domestic cooking fuels since there was very limited traffic and industrial activity at the time. These values were obtained by different methods (nephelometry and large volume sampling) and were calculated as ambient averages of every hour of the day during the whole month. Thus, they may not be entirely comparable to the situation during midday cooking time. However, cooking fuel pollution is probably still a major contributor to particulate pollution in the suburbs.

Among wood and charcoal users, the degree of use of the principal fuel was high. These fuels were also used for a long time, which suggests that the principal fuel is a relevant grouping from the viewpoint of exposure for these fuels. This was also confirmed through the analysis of lifetime exposure. Among modern fuels, electricity had generally been used for a shorter period but with a high degree of use, and LPG had been used for a long time with a lower degree of use.

Wood users exhibited more cough symptoms than the other groups, but there was no difference between users of modern fuel and charcoal. The greater prevalence of symptoms in wood users could either imply that the adverse health outcome with respect to cough was actually due to pollution exposure or that the background conditions among those who used wood were conducive to ill health. Controlling for background variables in regression analysis showed, however, that principal wood use was actually significantly associated with increased cough symptoms in its own right. This is contrary to findings in Lusaka where the same methods were used (*15,16*) but there were no differences in symptoms between users of wood, charcoal, and electricity, in spite of significantly different exposures to particulates.

Table 7. Variables found significantly associated with the non-cough respiratory symptom index in multiple regression

Variable	Coefficient	*t*-value	Significance *t*	Dim.
Age when started to cook	-0.29	-4.834	<0.00005	Years
Dry mouth	1.12	3.565	0.0004	Y/N
Sleeping problems	0.79	3.238	0.0013	Y/N
Loss of appetite	0.75	3.044	0.0024	Y/N
Felt ill	0.57	2.375	0.0178	Y/N
Abnormal night sweat	0.57	2.351	0.0190	Y/N
Constant	3.63	5.463	<0.00005	Index

Multiple $R = 0.3416$; $R^2 = 0.1167$. For regression and residual, respectively, degrees of freedom = 6 and 729, sum of squares = 948 and 7181, and mean square = 158.2 and 9.85. $F = 16.05$, significance of $F < 0.00005$.

Table 8. Variables found significantly associated with the PEF rate in multiple regression

Variable	Coefficient	*t*-value	Significance *t*	Dim.
Standing height	2.1	5.772	<0.00005	cm
Literacy	21.6	3.839	0.0001	Y/N
Used medicines	-19.8	-3.565	0.0004	Y/N
Felt ill	-14.6	-2.653	0.0081	Y/N
Age	-0.6	-2.587	0.0099	Years
Weight	0.5	2.494	0.0129	kg
Felt abnormally tired	12.3	2.182	0.0294	Y/N
Kitchen well ventilated	13.1	2.092	0.0368	Y/N
Time stayed in house	-0.5	-1.840	0.0661	Years
Constant	32.6	0.602	0.5475	Index

Multiple $R = 0.3808$; $R^2 = 0.1450$. For regression and residual, respectively, degrees of freedom = 9 and 776, sum of squares = 693,873 and 4,090,265, and mean square = 77,097 and 5270. $F = 14.63$, significance of $F < 0.00005$.

Fuel use variables were not significantly associated with the non-cough respiratory symptoms. This is similar to findings by Viegi et al. (*19*), although the spectrum of fuels was different. The only significant fuel use-related variable was the time generally spent cooking each day, and it is not entirely clear how the effect of this should be interpreted. It was expected that wood users who cook for a longer time each day would be exposed to more particulate pollution and exhibit more cough symptoms; however, the model suggests otherwise—the longer a woman cooks, the less symptoms are exhibited. One possible reason could be that those who cook longer do so simply because they have more food to cook, and better nutrition would offset some of the effects of air pollution. Malnutrition has been shown to have effects on the respiratory health (*20*).

The weak associations between PEF rate and wood use or exposure years, which only occurred in the absence of other background variables, suggest that substandard general conditions of wood users caused this association to a greater extent than the influence of cooking fuel pollution exposure.

The lifetime exposure calculations show that the contribution from cooking with the secondary fuel was limited. Exposure from previously used fuels was the dominating exposure source for modern fuel users; in charcoal users, it was on the level with the current fuel, and for wood users it was negligible. This suggests that fuel pollution should affect mainly chronic conditions in modern fuel users. The long duration of current principal fuel use among wood and charcoal users suggests that, in these groups, the current principal fuel exposure would determine both acute and chronic effects and that wood users would be more strongly affected. Because the analysis of the health outcome shows no difference between charcoal users and modern fuel users, either in cough (acute) or non-cough (less acute) symptoms, but worse health status among wood users, it could be suggested that the cooking fuel exposure among charcoal users is actually irrelevant compared to influence from ambient pollution, as it is assumed to be for current fuel use among modern fuel users. However, the ambient influence could be considerable for all groups, and this is further aggravated by the suspicion that ambient influence originates from wood use to a great extent. An indication that the respiratory condition in the women was impaired is that the PEF rates for all groups were lower than expected for women in the industrialized world when calculated from age and height only.

Conclusions

This study shows that using wood for fuel is associated with more cough problems but that other respiratory symptoms and PEF rate could not be associated with fuel use directly. In the analysis, there were controls for a large number of environmental variables, which reinforces the confidence in the conclusion. Although carbon monoxide exposure was measured, it was not included in the present analysis because the symptoms associated are different.

The null hypothesis of no effects of particulate pollution from cooking fuels can reasonably be rejected as long as the health effects are restricted to cough. Wood use was found to be associated with more such symptoms.

For other respiratory symptoms such as dyspnea, wheezing, inhalation and exhalation problems, and worry about breathing problems, there was no reason to reject the null hypothesis. These types of symptoms appear to be determined by other factors, of which the age of a girl when she starts helping her mother to cook and other health conditions are prominent. It may be worthwhile to further investigate the reasons that non-cough respiratory symptoms are not largely related to use of smoky cooking fuels.

The results of this study show that biomass fuels should not be aggregated. Both wood and charcoal are biomass fuels, but charcoal is not associated with as high levels of particulate pollution as wood or is it conducive to the same health effects that wood is.

The results suggest that wood use in urban areas should be restricted due to its effect on the acute respiratory health of its users. This may also have an effect on chronic respiratory conditions of users of other fuels because most of the ambient pollution was believed to originate from wood used for cooking.

To overcome the health effects associated with wood use, the simplest solution may be to encourage charcoal use to a greater degree, although of course other environmental and health aspects of charcoal use would have to be further assessed, especially with respect to carbon monoxide emissions. The same effect would probably be achieved from a substitution of modern fuels, but this is a much costlier intervention. Improvements in infrastructure and social aspects such as provision of water, sanitation, and education would probably have as great an effect on the health status of these women as fuel modernization and would also have beneficial side effects.

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