Pergamon

Energy 26 (2001) 949–962

ENERGY

www.elsevier.com/locate/energy

Exposure from cooking with biofuels: pollution monitoring and analysis for rural Tamil Nadu, India

Jyoti Parikh [a], Kalpana Balakrishnan [b], Vijay Laxmi [a,*], Haimanti Biswas [a]

[a] *Indira Gandhi Institute of Development Research, Gen. Vaidya Marg, Santosh Nagar, Goregoan (E), Mumbai 400065, India*

[b] *Sri Ramchandra Medical College and Research Institute, Chennai, India*

Received 12 July 2000

Abstract

In this paper, statistical analysis to examine the links between pollution and the types of kitchen and fuels is carried out for rural houses by first monitoring the indoor air quality (IAQ) followed by regression analysis of 418 households in Tamil Nadu, India. Exposures to the chief cook (females, who are mainly involved in the cooking during monitoring) are measured with personal monitors. The result shows that the values of respirable particles (PM10) ranged from 500–2000 $\mu g/m^3$ during a two-hour cooking period from burning biofuels. The range depends on the type of kitchen and fuel use. Stationary monitors, placed two metres away from the stove, also recorded similar concentrations. Thus, the individuals who stay inside the houses using biofuels also face high concentrations even if they are not cooking. They could be senior citizens, children or adult males. Thus, there are two major findings from this analysis. Improved house designs that pay attention to kitchen location and put up partitions should also be considered in the intervention portfolio. Secondly, the exposure is not limited to the cooks alone. The rest of the family in the vicinity is also exposed through a "passive cooking effect". © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

In rural India, 90% of the primary energy use is biomass, of which wood accounts for 56%, crop residues for 16%, and dung-cakes for 21% [1]. Combustion of these bio-fuels in poorly ventilated kitchens using inefficient stoves leads to the release of very high concentrations of suspended particulate matter and noxious gases [2–4]. Exposure to these pollutants has also been

* Corresponding author. Fax: +91-22-840-2752 and +91-22-840-2026.
E-mail address: vijay@igidr.ac.in (V. Laxmi).

0360-5442/01/$ - see front matter
PII: S0360-5442(01)00043-3

shown in several recent studies to be associated with several health effects especially among women who cook with these biofuels and the young children.

A number of air pollutants — NO_x, SO_2, CO, particulates and ozone — have been identified to be associated with adverse health effects particularly in urban centres of developed countries. However, Smith [5] concentrates on particulates as “the most important single class of air pollutants”. Unprocessed biomass fuels produce 10–100 times more respirable particulate matter than the modern fuels because of their low thermal, combustion and heat transfer efficiencies. Almost in all cases the trend of pollution concentrations is as follows [6–8]:

Dung>Crop residue>Wood>Charcoal>Kerosene>LPG>Electricity

Raiyani [6] discusses the indoor concentration of Total Suspended Particles (TSP) during cooking hours across the houses belonging to a low socio-economic group in eastern Ahmedabad, India. He concludes that houses using wood, cattle dung and coal emit large amounts of TSP. Particulate matter inside houses using LPG and kerosene are due to the outside environment rather than indoor sources. Ramakrishna [9] tried to establish quantitative estimates of several environmental and cultural characteristics like stove type, kitchen location, and fuel on the TSP exposures. Though the variable location of kitchen was found to be a statistically significant variable, the difference between exposure level using traditional and improved stoves did not prove to be significant. But these results need to be taken with some amount of caution, as the sample size was small. In addition to the factors mentioned above there are several others, which have been identified in the literature to explain the large and significant difference in concentration of Respirable Particulate Matter (*RPM*) between living area and kitchen while cooking activity is going on — ventilation, chimney type, kitchen volume, outdoor concentrations and so on [2,4].

Since a large number of variables are involved in the studies of air pollution, it is very difficult to prove that air pollution has a clear demonstrable effect on human health over normal concentrations. However, there is consistent evidence that indoor air pollution due to the burning of biofuels increases the risk of chronic obstructive pulmonary disease, acute respiratory infections among children, cataract, adverse pregnancy outcomes, pulmonary tuberculosis, asthma and cancer [10–14]. Moreover, most of these studies were observational with small sample sizes (rarely exceeding 200). In the present study we try to address the following questions:

— What is the level of pollution exposure to chief cooks due to biofuels?
— What are the levels of pollution concentration in different microenvironments?
— How serious is the “passive cooking” effect on the non-cooks?
— Do kitchen location, fuel types and stove types make any significant difference to exposure and concentration levels?

2. Data and variables

This article is based on a comprehensive survey conducted in the rural areas of Tamil Nadu (TN) covering 5028 households from 30 villages and 4 districts.

2.1. Survey design

Based on the incidence of Acute Respiratory Infections (ARI) reported by the National Family Health Survey (NFHS) 1992–93, a total of 5000 households were proposed to be covered in Tamil Nadu. In order to have a random selection with a good spread and proper representation of the population, we used multistage sampling with stratification based on a priori information. At the first stage four representative districts were chosen based on population, namely Chengelpattu, Coimbatore, Tirunelveli and Trichy. The districts were further stratified by village population sizes. The villages were divided into 3 strata on the basis of population. In stratum 1, villages with a population of less than 1000 (1 K) were included; stratum 2 had villages with a population of 1000–3000 (1 K–3 K), and in stratum 3, villages with a population of between 3000–5000 (3 K–5 K) were included. Villages with a population above 5000 were excluded from the sample. The number of households from each district was in proportion to household distribution in the selected four districts of Tamil Nadu (Population Proportion Sampling (PPS)). See Table 1.

Again, the selection of villages from each village stratum was by using the PPS method, i.e. in proportion to the number of households each village has. Within a village, the selection of household was done by systematic random sampling (details are given in Appendix A1). The survey of 5028 households (HH) was a comprehensive one having the following features:

- Face-to-face interview by survey,
- symptoms and health assessment,
- physical examination and diagnostic approach by medical experts and
- pollution monitoring and exposure.

Detailed description of the above can be found in Parikh et al. [15]. For this particular exercise, we will focus on the fourth aspect listed above. A smaller sub-sample of 8% of the households was selected randomly from the larger sample of 5028 households for Indoor Air Quality (IAQ) monitoring.

Table 1
Number of households across four districts of Tamil Nadu[a]

Districts selected	Number of households (HH)				Actual sampled HH
	<1000	1000–3000	3000–5000	Total	
Chengelpattu	121103	264410	89617	475130 (32%)	1606 (32%)
Coimbatore	5936	99435	117259	222630 (15%)	752(15%)
Tiruchirapalli	18293	275292	252475	546060 (37%)	1845 (37%)
Tirunelveli	15320	116518	103976	235814 (16%)	797 (16%)
All districts				1479634 (100%)	5000 (100%)

[a] Source: Census of India ’91.

2.2. Methodology

The field survey was carried out in September 1999. Data logging and analysis for this IGIDR survey was completed in the year 2000. Out of the random sample of 5028 HH, 418 households were selected for IAQ measurement. Interviewers who had experience in door-to-door survey, particularly in rural areas, collected information on household characteristics. The questionnaire was translated into Tamil (the regional language there) from English and was translated back to check the accuracy of translation.

2.2.1. Monitoring households within a village

Air quality monitoring in small villages was done within a day, medium villages within two days and large villages within three days. Consents were obtained from the cooks as well as the heads of the HH to attach the personal samplers while cooking. Cooking times were determined at the beginning of the day so as to facilitate scheduling of monitoring. Separate samples were taken during cooking and when cooking was not going on. A high volume respirable dust sampler was placed on the roof of the tallest available building within the village and run for a duration that varied between 2–10 hours, depending on the availability of power.

2.2.2. Monitoring within a household

Samplers were placed inside and outside the houses during a two-hour cooking period. The measurements were also repeated when cooking activity was not going on. Subsequently filters were changed for sample collection during cooking. One sampler was attached to the cook in each household while cooking. Exposure for the cook while cooking was always assessed with the aid of battery powered personal samplers attached to the cook. Since the availability of samplers did not permit attaching a sampler to each and every member of the household, measurements in the same area using the same samplers were taken as surrogates for exposure for the other members of the household. The possible locations are illustrated in Fig. 1, which characterises four types of kitchen, namely:

- Indoor kitchen without partition (Lockit1),
- Separate kitchen inside house (Lockit2),
- Separate kitchen outside house (Lockit3) and
- Outdoor kitchen (Lockit4).

The methodology of area measurements is given in Appendix A1.

Since the average cooking period was two hours in the sample, hence the IAQ measurements were taken for two hours. The regression analysis is carried out using mean values of two hours due to two main reasons. Firstly, due to administrative as well as experimental problems monitoring could be done only for the cooking period, namely two hours, rather than 24-hour or 8-hour periods. Secondly, it is worth measuring during the cooking period as the particles attain maximum concentrations during cooking [16,17].

Personal sampling (RPM_1) has the advantage of providing concentrations that are closely linked to the actual exposures of the chief cook. On the other hand the RPM_2 measurement is taken at a fixed spot mostly two metres away from the stove. This gives an indication of the concentration

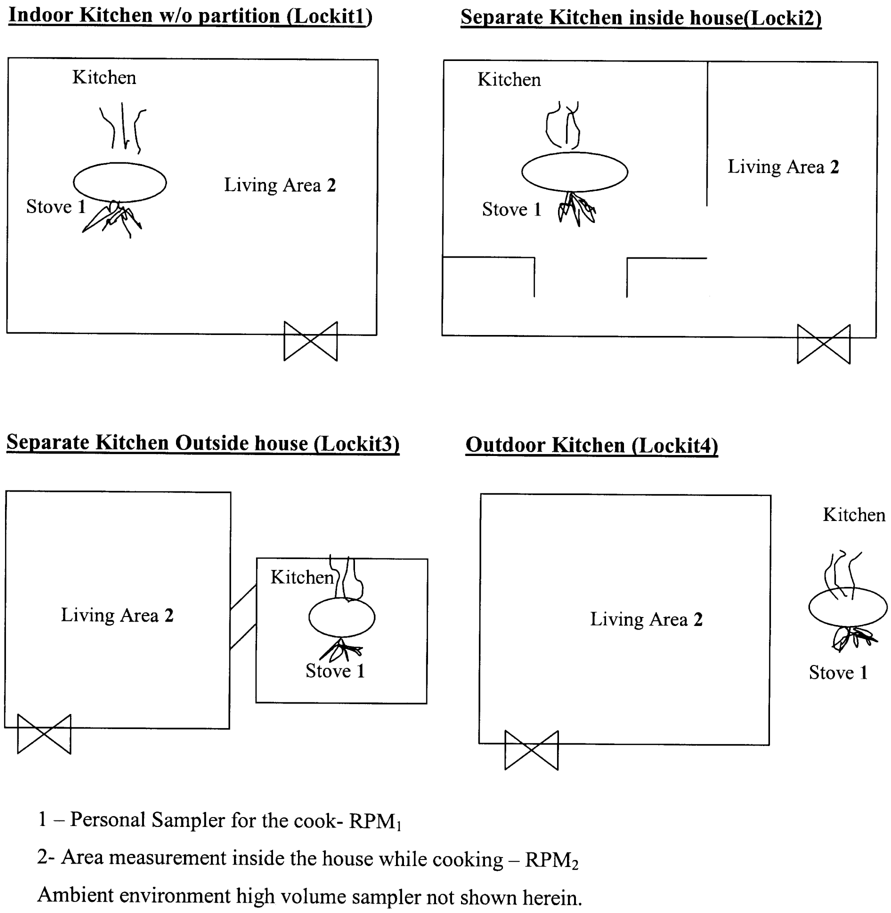


Fig. 1. The floor layout of different kitchen types and placement of samplers.

faced by the other members of the family, if they are present. One could say this is a "Passive cooking" effect.

2.3. Model specification

Although multiple measurements were taken during cooking, as well as in the absence of cooking activity, 3 variables were chosen for the analysis as indices of exposure, namely — RPM_1 (personal exposure to RPM while cooking), RPM_2 (point measurement of RPM while cooking is going on), and RPM_3 (ambient concentration of RPM) for regression analysis. The dependent variables chosen were RPM_1 and RPM_2. Since most of the households use biofuels, the exposure or concentration differed mainly because of variables such as location of kitchen, number of meals cooked per day, type of stove and respirable particles in ambient air (RPM_3). Multiple regression analysis was done to estimate the effect of various factors on the level of pollution, i.e. the level of respirable particulate matter.

The basic equation estimated is given by Eq. (1):

$$RPM_x = \text{constant} + \alpha Lockit1 + \beta Lockit2 + \gamma Lockit3 + \delta Meals/Day + \eta Stove + \varphi Fuel + \lambda RPM_3 + \varepsilon_x \quad (1)$$

where x=1, 2, RPM_1=personal exposures for respirable particulate matter while cooking in μg/m^3, RPM_2=area measurement for respirable particulate matter inside the house at two metres distance from the point of cooking, RPM_3=respirable particulate matter in the ambient air in μg/m^3, *Lockit1*=1 if cooking is done inside a kitchen without a partition, *Lockit2*=1 if cooking is done in a separate kitchen inside the house, *Lockit3*=1 if cooking is done in a separate kitchen outside the house, *Lockit4*=cooking is done in the open air, *Stove*=1 if cooking is done with biomass using a traditional chulha, *Fuel*=1 if biofuel is used for cooking, *Meals/day*=number of meals cooked by the household in a day, and ε_x=error term. The regression analysis was carried out using the SPSS package.

3. Brief profile of the sample under survey

The households selected in the survey were distributed across 30 villages and 4 districts of Tamil Nadu. In the study area about 96% of the households (see Fig. 2) used only biofuels (fuelwood, wood-chips and agricultural waste). In TN, fuelwood was most common (75% of the households) followed by agricultural waste (12% households) and wood-chips (4% of the households).[1] Of the biofuel users 36% used it in indoor kitchens without partitions, 30% in separate kitchens inside the house, 19% used them in separate kitchens outside the house and

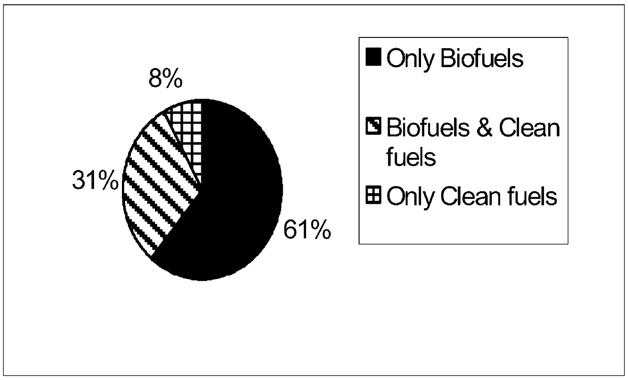


Fig. 2. Fuel consumption pattern.

[1] In rural India, 91% of the households use biofuel for cooking of which the share of wood alone is 71.7% [1].

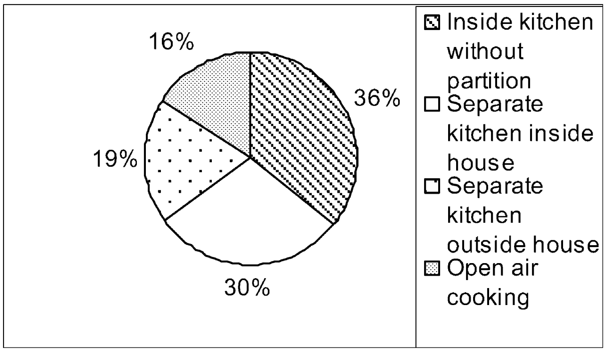


Fig. 3. Distribution of stoves.

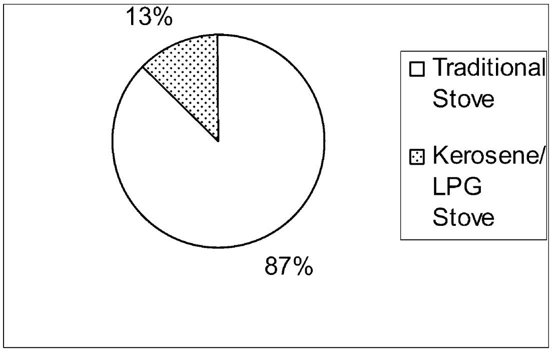


Fig. 4. Types of kitchen in the sample.

16% used them in open air cooking (see Fig. 3). Less than 10% of the households used clean fuels (kerosene, LPG and biogas). Most of the households used traditional stoves,[2] which have high emission rates (Fig. 4). About 81% of the households under survey cook two meals per day (Fig. 5). The average cooking period in the sample was two hours.

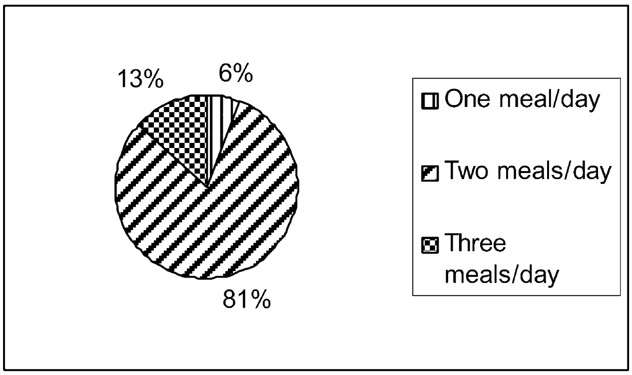


Fig. 5. Number of meals cooked per day.

[2] Traditional stoves used for cooking were generally earthen and sometimes the metal bucket type.

4. Results and analysis

4.1. Results of respirable particulate matter measurements

The results of field measurements of respirable particulate matter (RPM) show that the concentration of RPM was the highest during cooking with biofuels. Personal exposures (RPM_1) ranged from around 70 μg/m^3 for houses using clean fuel to around 2000 μg/m^3 in houses using biofuels. The average value for RPM_3 (ambient concentration) is 78.16 μg/m^3. For descriptive statistics see Table 2. The concentration at various locations during cooking with biofuels, RPM_2, depends on the type of kitchen. Agricultural waste results in the highest personal exposure. The results are shown in the bar charts (see Figs 6 and 7). Another important feature that is worth mentioning is that Tamil Nadu does not appear to have the practice of cooking with animal dung.

The measured concentrations in this study are similar to those found in other rural and urban studies [5,6,16,18]. But they are much higher than the Central Pollution Control Board (CPCB, India) standard for ambient particulate levels in rural areas which is 200 μg/m^3 per 8 hour/day.[3] The values reported here are quite different from the study of Gujarat state (western India) [16] (6800 μg/m^3) which are very high that may be due to the differences in cooking practices, fuel use, house types and so on. The uniqueness of this study has been the IAQ measurements done with different combinations of kitchen and fuel. We cannot overlook the fact that the dirty floors as well as the infiltration from the outside atmosphere could influence the RPM values.

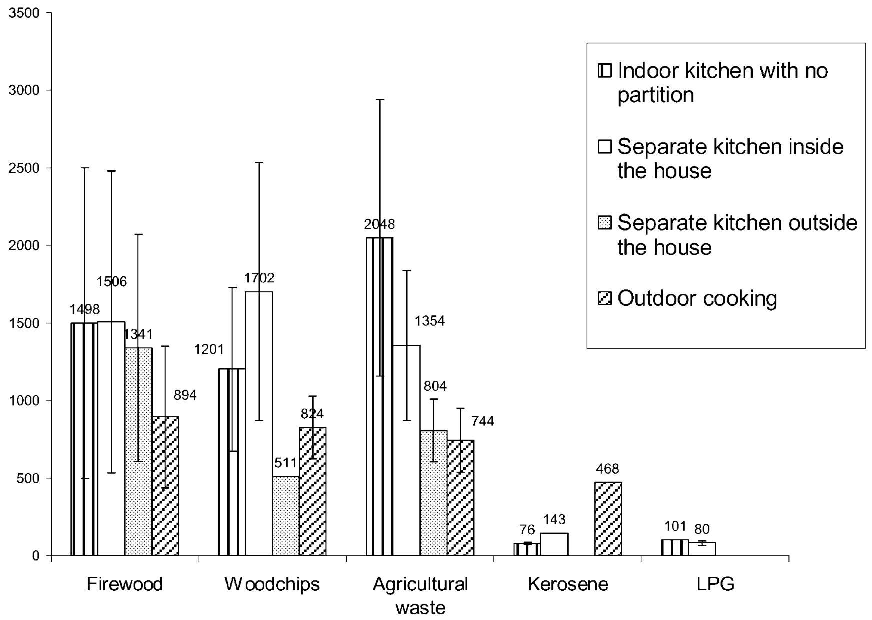
4.2. Analysis of regression results

Statistical analysis of the above measurement is done using explanatory variables. The natural log of RPM_1 was used as the dependent variable because the distribution of RPM_1 was positively skewed (see Eq. (2)). The location of the kitchen (*lockit*) is an important explanatory variable given the fact that most of them used biofuels. The exposure of the chief cook increases as one shifts from location 4 (cooking in the open air) to location 1 (cooking is done inside kitchen

Table 2
Descriptive statistics for actual measurements of *RPM* including all fuel types

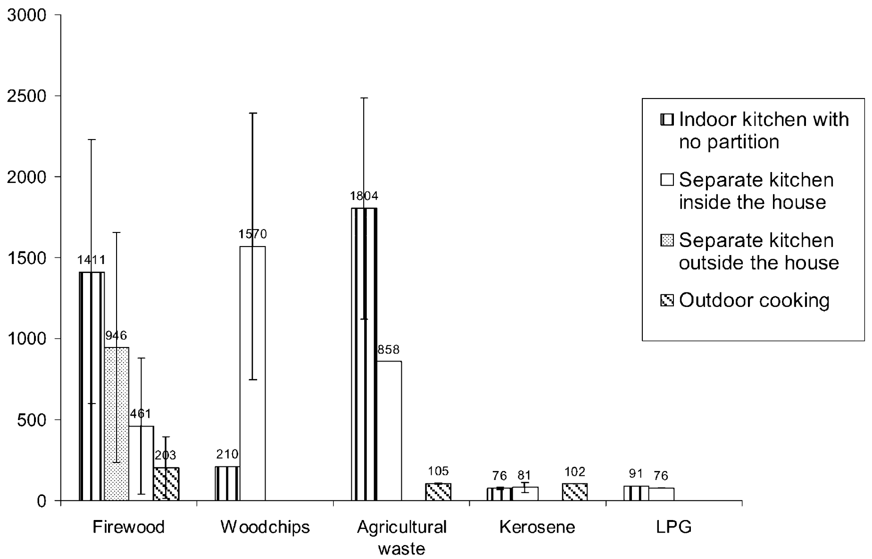
	Personal exposure	Area measurements	Ambient concentration
Mea	1167.1	856.0	76.1
Geometric	789.7	482.5	73.1
Media	1098.0	816.0	68.0
Standard Deviation	876.9	781.1	23.2
Coefficient of Variation	0.75	0.91	0.31
Range	5125.0	3509.0	76.0
Minimum	58.0	54.0	52.0
Maximum	5183.0	3563.0	128.0

[3] The WHO standard is 40–60 μg/m^3 annually or 100–150 μg/m^3 daily [3].



Source: IGIDR-SRMC report, 2000

Fig. 6. Mean personal exposures of cooks at different kitchen locations and fuel types as per sample measurements.



Source: IGIDR-SRMC report, 2000
Measurement at a location of 2 m away from stove.

Fig. 7. Mean concentration at different kitchen locations and fuel types as per sample measurements.

which has no partition). This can be explained on the grounds that in the open air the concentration of respirable particles is lower because it gets readily diffused into the atmosphere. The outdoor pollution level was found to be significant at the 5% confidence level[4] which can be explained in terms of diffusion from outside air to indoor air through the doors, windows and ventilators. Since nearly 95% of the sample households use biofuels, kitchen and stoves types differentiate the exposures. The *t*-value of the stove increased considerably with the removal of the fuel variable.

$$\text{Ln } RPM_1{=}3.5 \quad +0.44\,Lockit1 \quad +0.4\,Lockit2 \quad +0.23\,Lockit3 \quad +0.008\,RPM_3 \quad +2.62\,Stove$$

$$(T\text{–Stat})\ (23.32) \quad (5.37) \quad (4.76) \quad (2.2) \quad (6.00) \quad (28.2) \qquad (2)$$

$$\text{Adj } R^2{=}0.67$$

The number of meals cooked per day does not turn out to be a significant variable because the measurement of personal exposure was done during the cooking of only one meal that lasted for a maximum of two hours. The variable meals/day was recorded for 24 hours. Overall the variable "number of meals cooked per day" is important as this determines the exposure over 24 hours to the chief cook.

$$\text{Ln } RPM_2{=}2.4 \quad +1.96\,Lockit1 \quad +1.53\,Lockit2 \quad +0.63\,Lockit3 \quad +0.005\,RPM_1 \quad +2.34\,Stove$$

$$(T\text{–Stat})\ (11.38) \quad (18.13) \quad (13.07) \quad (4.11) \quad (2.6) \quad (18.76) \qquad (3)$$

$$\text{Adj } R^2{=}0.67$$

Estimation of RPM_2 (see Eq. (3)) gives more or less the same result in terms of R^2, which implies that the variables that explain RPM_1 also explain RPM_2. But the coefficient associated with the location of the kitchen as well as their associated *t*-value is considerably higher for RPM_2. Here also each of the variables included, except meals per day, is significant at the 5% level of significance. RPM_2 represents the exposure to the other members who could be in the vicinity of the cooking activity capturing the "passive cooking" effect. This may include the children, senior members, unemployed youth or other members who happen to be around.

4.3. Discussion

The latest World health Organisation (WHO) air quality guidelines prescribe no thresholds for health effects associated with particulate exposure. However, the national air quality standards from the Central Pollution Control Board, (CPCB) India on respirable particulate matter for 24-hours in rural residential areas is 100 μg/m^3. On studying the sample closely we observe that for various kitchen types, the pollution level is much above the specified standard during cooking hours. Only when clean fuel is used for cooking in the open air do we observe the pollution level below the specified standard.

Based on equations (2) and (3) we tried to calculate the exposure to the chief cook as well as the mean concentration at different microenvironments while cooking. The mean exposure to the chief cook when cooking is done inside the house without a partition using traditional stoves comes to 1312 μg/m^3 (the average value of RPM_3 used while calculating exposures and concen-

[4] The *t*-value was found to be 6 approximately.

trations is 78.13 μg/m^3). Similarly if the cooking is done with traditional stoves in the open air or with efficient stoves in *Lockit2* the exposures are reduced by 1.5 times. The mean concentrations are high (1187 μg/m^3) when cooking is done inside the house without a partition using traditional stoves. The people who are in the vicinity are also vulnerable. These are illustrated in Table 3 under the column head "model". As an extension to this exercise Balakrishnan et al. [19] calculated 24-hour exposures of individuals based on a time activity pattern which were in the range of 201±48 μg/m^3 for cooks using biofuels and 53±15 μg/m^3 for clean fuel users.

One of the surprising aspects of the random sample selected was the very low percentage of households using clean fuels or improved stoves, considering economic progress and the high consumption of overall kerosene compared to previous years. Our further work with a larger sample that purposively includes houses with interventions and inclusion of parameters such as ventilation, type of house and quantity of fuel would allow better judgements to be made regarding the dispersion of pollutants. In our subsequent publications we plan to draw the linkages between pollution, exposure and health, incorporating socio-economic characteristics of the households.

5. Summary and conclusions

The regression analysis of two-hour exposure reveals that there is a strong correlation between exposure to pollutants and location of kitchen. The concentration of respirable particulate matter

Table 3
Comparison between actual measurement and model estimates[c]

	Biofuels Firewood[a]	Wood-chips[a]	Ag. waste[a]	Model[b]	Clean fuel Kerosene[a]	LPG[a]	Model[b]
Personal exposure							
Indoor kitchen with no partition	1498	1201	2048	1312	76	101	96
Separate kitchen inside the house	1506	1702	1354	1268	143	80	92
Separate kitchen outside the house	1341	511	804	1070			78
Outdoor cooking	894	824	744	850	468		62
Area concentration							
Indoor kitchen with no partition	1411	210	1804	1200	76	91	116
Separate kitchen inside the house	946	1570	858	781	81	76	75
Separate kitchen outside the house	461	–	–	317	–	–	31
Outdoor cooking	203	–	105	169	102		16

[a] Represents actual measurements of *RPM*.
[b] Model represents *RPM* values worked out from Eq. (2) for personal exposure and Eq. (3) for Area concentrations.
[c] Source: IGIDR Survey, 2000.

is the highest when cooking is done inside the house without a partition using a traditional stove. The exposure to the chief cook (RPM_1) is always higher than the standard when cooking is done using biofuels at all kitchen locations. One of the important findings is that the individuals who are inside the house during the cooking activity denoted by variable RPM_2 also take high levels of concentrations. The most important variable found was the location of the kitchen followed by the type of stove and open-air emissions (RPM_3). This does not mean that outdoor cooking is advocated. It only means that the exposure to biofuels is more a problem of the poor to middle class income group rather than the extreme poor because the extreme poor generally cook in the open air, cook fewer meals and eat fewer number of dishes. The study also reveals a positive correlation between the type of fuel and type of stove used for cooking. RPM_3 that measured open-air emissions was explained by the variable "number of meals cooked per day" because the concentration of respirable particulate matter outside increases with the increase in the number of meals cooked during the day.

For future analysis we wish to incorporate other confounding variables like the type of housing (mud or cement), ventilation, income of the households, female education, etc. A better analysis is expected if one has at least 8 hour or 24 hours of exposure monitoring with some control group using clean fuels and efficient stoves.

The major strength of the study has been the determination of actual exposure for the chief cook and the pollution concentration for the other household members under a variety of microenvironments for perhaps the largest sample in such type of studies. Other members who are not involved in the cooking activity seem to face a "passive cooking effect" as concentrations are fairly high. Generally when we talk about ameliorating indoor air pollution from biofuels we speak of clean fuels and efficient stoves. However, from this particular exercise we statistically show that housing design characteristics such as location of the kitchen and including a partition can be thought of as an intervention. A similar analysis using IAQ data is being done for the state of Uttar Pradesh. Data for other variables such as disease, symptoms, lung capacity, willingness to pay, etc., will be available shortly for other states, namely Uttar Pradesh, Himachal Pradesh and Rajasthan.

Acknowledgements

We thank the Capacity 21 project of the United Nations Development Programme for providing the financial support. We wish to thank Ms A.C. Nielsen, Mumbai for collecting socio-economic and health profile data, and Sri Ram Chandra Medical College, Chennai for collecting Indoor Air Quality monitoring and measurement data. We are grateful to Dr Dilip Mavlankar and Dr Jagdish Parikh for their valuable suggestions and comments for this study.

Appendix A. Survey methodology (systemic random sampling)

In Systematic Random Sampling we select the first household with a random start and then select the subsequent households systematically with a sampling interval. The sampling interval is decided based on the total number of households in the village and the sample size we have to cover. For example, suppose from a village we like to cover 170 HHs and the village has a total 2000 HHs. (The HH quota for <1 k was 80, for a 1–3 k village it was 170 and for 3–5 k it was 265 HH.) Then we select a household at random from any corner and cover 170 households by skipping 11 HHs (i.e. 2000/170=11.76). This interval is maintained so that we have a complete spread within the village.

A.1. Details of the monitoring procedure and protocol

Area/personal samples for respirable particles were collected and analysed according to the National Institute of Occupational Safety and Health (NIOSH) protocol 0600. Briefly, samples were collected by drawing air through constant flow pumps supplied by SKC (equipped with a 10 mm nylon cyclone with a 50% cut-off of 4 μm at 1.7 litres/minute using 37 mm PVC filters (5 μm pore size)). All pumps were calibrated using an electronic flow meter on the field that was in turn calibrated using a Mini Buck soap bubble meter in the mobile laboratory before and after sampling. Ten percent of all samples were subjected to analysis as field blanks.

Gravimetric analyses were conducted at Sri Ram Chandra Medical College and Research Institute (SRMC and RI) laboratory using a Metlar Balance. All filters were conditioned for 24 hours before weighing. Respirable particulate matter concentrations expressed in terms of mg/m^3 were calculated by dividing the blank corrected filter mass increase by the total volume sampled. All blank corrected filter mass values below the limit of detection (LOD) 0.005 mg were replaced with LOD/$\sqrt{2}$.

References

[1] Tata Energy Research Institute. Teri energy data and yearbook. New Delhi: TERI publications, 1999-2000.
[2] Smith KR. Biofuels, air pollution and health. A global review. New York: Plenum Press, 1987.
[3] World Health Organisation. Air quality Guidelines. Geneva: WHO publications, 1999.
[4] Albalak R, Keeler GJ, Frisancho AR, Haber M. Assessment of PM10 concentrations from domestic fuel combustion in rural Bolivian Highland villages. Environmental Science and Technology 1999;33:2505–9.
[5] Smith KR. Hazards of the Home Kitchen, the World's second most common work place. Environment 1998;4(3):4–13 Kitchen kills more than sword: Hazards of World's second most common workplace. For presentation at the Indoor Air Quality Symposium of the American Industrial Hygiene Conference, Dallas (Texas) May 1997.
[6] Raiyani CV, Shah SH, Desai NM, Venkaih K, Patil JS, Parikh DJ, Kashyap SK. Characterisation and problems of indoor pollution due to cooking stove smoke. Atmospheric Environment 1993;27A(11):1643–55.
[7] Leach G. The energy transition. Energy Policy 1992;20(2):116–23.
[8] Smith KR, Apte MG, Yuqing M, Wongsekiarttivat W, Kulkarni A. Air pollution and energy ladder in Asian cities. Energy — The International Journal 1994;19(5):587–600.
[9] Ramakrishna J. Patterns of domestic air pollution in rural India. Thesis, University of Hawaii, Department of Geography, 1990.
[10] Behera D, Jindal SK, Malhotra HS. Ventilatory function in non-smoking rural Indian women using different cooking fuels. Thorax 1991;46(5):344–6.
[11] Mishra V, Retherford R. Cooking smoke increases the risk of acute respiratory infections in children. National Family Heath Survey Bulletin (8) 1997; http://ewcsun2.ewc.hawaii.edu/pop/misc/bull-8.pdf.
[12] Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. Bulletin of the World Health Organisation 2000;78(9):1078–92.

[13] Chen BH, Hong CJ, He XZ. Indoor air pollution and its health effects in China — A review. Environmental Technology 1992;13:301–12.
[14] Parikh J, Smith KR, Laxmi V. Indoor air pollution: A reflection on gender bias. Economic and Political Weekly 1999;34(9):539–44.
[15] Parikh J, Pandey V. Biofuels, pollution and health linkages. Economic and Political Weekly 2000;35(47):4125–37.
[16] Smith KR, Aggarwal AL, Dave RM. Air pollution and rural biomass fuels in developing countries: A pilot village study in India and implications for research and policy. Atmospheric Environment 1983;17(11):2343–62.
[17] Saksena S, Prasad R, Pal RC, Joshi V. Patterns of daily exposures to TSP and CO in Garhwal Himalaya. Atmospheric Environment 1992;26A(11):2125–34.
[18] Brauer M, Bartlett K, Regaldo-Pineda J, Perez-Padilla R. Assessment of particulate concentrations from domestic biomass combustion in rural Mexico. Environment Science and Technology 1996;30(1):104–9.
[19] Parikh J et al. Rural Energy and Health Impacts, project report no. 048 Mumbai, Indira Gandhi Institute of Development Research, 2000.