Air quality of kitchens in Jaipur city due to the use of LPG as a cooking fuel: part I—role of the exhaust fan in dissipating the pollution generated

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ABSTRACT
There is an increasing evidence of air related sickness among infants and housewives in urban India due to the use of liquefied petroleum gas. An attempt has been made in this study, to monitor kitchens of 13 houses in the city of Jaipur for possible residential indoor air pollution (IAP), i.e. carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and respirable suspended particulate matter generated during cooking. The role of the exhaust fan as an inexpensive means to dissipate these gases of combustion has also been studied. The concentrations of CO and SO_2 were found to be negligible. Levels of RSPM far exceeded the acceptable WHO guideline value and NO_2 levels exceeded the 1 h average WHO guideline in 5% of the cases. It was also observed that the use of an exhaust fan during cooking dissipated almost 30–60% of the pollution generated, but its location *vis-à-vis* the gas stove was found to have a significant effect on the efficiency.

INDEX TERMS
Cooking; Exhaust fan; Indoor air pollution; Kitchen; Liquefied petroleum gas

INTRODUCTION
Increasing incidence of air related sickness in parts of urban India, especially among infants, children and housewives who are mostly confined indoors has been reported (Behra *et al*., 1995), and, therefore, a need for a study of residential indoor air quality was felt. Since most of the combustion activities taking place in a house are primarily restricted only to the kitchen, and since in urban India, a housewife spends on an average around 6–8 h daily in the kitchen, thus being exposed to the maximum amount of pollution generated, it was deemed appropriate to monitor the levels of classical pollutants in the kitchen. More and more people who can afford a home with a confined kitchen are switching over from kerosene/coal to liquefied petroleum gas (LPG) as cooking fuel. LPG today is not only a cheap and efficient fuel, but is also easily available. It is estimated that in Jaipur city itself, more than 70% of the families which can afford a house, use LPG as a cooking medium, and this number is ever increasing. As the residential gas stove normally burns at a temperature in the range of 800°C to 1200°C (Nevers, 1995), the air reacts with the flame producing a variety of gases, mostly the classical pollutants, i.e. nitrogen oxides (NO_x), CO and SO_2 and respirable suspended particulate matter (RSPM). Among these three types of gaseous pollutants, it is the nitrogen oxides which are of highest concern as the concentrations of CO and SO_2 are not significant to cause any harm. Thus, the main emphasis in this work has been laid on nitrogen oxides, especially nitrogen dioxide (NO_2) and RSPM. The present study is aimed at monitoring of gaseous pollutants namely CO, SO_2, NO_x (NO and NO_2) and RSPM in kitchens of selected houses in Jaipur and determining the effect of natural and mechanical ventilation (in the form of exhaust fans) in kitchens.

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METHODS

Gaseous Pollutant Monitoring Instruments

Digital continuous gaseous samplers were used to monitor the three major gaseous pollutants emitted during the process of combustion, i.e. CO, SO_2 and NO_x.

CO

The detection and measurement of CO in the API Model 300 was based on the absorption of infrared radiation by CO molecules at a wavelength near 4.7 μm.

SO_2

An API Model 100 A analyser which was based on the UV fluorescence principle was used to measure SO_2 levels. The lower detectable limit of this analyser was 0.4 ppb.

NO_x

An API model 200 A analyser was used to measure the concentration of NO, NO_x and, by calculation, NO_2. The instrument measured the light intensity of the chemiluminescent gas phase reaction of NO and O_3. The lower detectable limit of this analyser was 0.4 ppb.

Personal Sampler for Monitoring RSPM

RSP sampling was undertaken by drawing air through a personal sampler used for exposure assessment studies. This was a handy instrument which was strapped to the subject's waist, with the inflow tube at nose-level, and run at a constant flow rate of 2 l/min. The amount of RSPM was determined gravimetrically.

Sampling Site

For this study, 13 houses (IAQ1 to IAQ13) which had different sizes of kitchens were chosen. The different sizes were also indicative of the economic background. The houses were also selected based on their location: four were located in the walled city of Jaipur, which is primarily a commercial market area; six houses were located in the residential colony of Gandhi Nagar; three houses were located in the MNIT campus. They represented varying degrees of human activities, the market area being the most crowded and with the highest traffic density and the MNIT campus being the least crowded with least traffic density; thus they had very different ambient air quality composition. All kitchens except one (IAQ10) were using residential gas stoves conforming to the same standards, i.e. the Bureau of Indian Specifications: 1 large burner and 1 small burner with a total energy content of 3700 kcal/h when both burners were ignited. Eight of the 13 residences had exhaust fans installed in the kitchens.

Sampling Schedule

In an average Indian kitchen, two major meals are cooked (apart from two minor meals), one in the morning/noon hours and one in the evening/night hours. For each meal, an average Indian housewife spends approximately 2–3 h inside the kitchen inclusive of pre- and post-food preparation activities. The gas stove is on for almost 50% of this time—i.e. combustion takes place. Based on all these facts, analysers were kept in each kitchen for at least 2 h and during at least one major meal preparation time. Anyhow, the decision about monitoring a particular kitchen was made taking into account the conditions that prevailed on the day and at the time of monitoring. The readings for gaseous pollutants were recorded at equal intervals of 5 min. The monitoring was carried out in the months of September and October 1999. The average ambient temperatures were in the range of 30–37°C, with the average indoor temperature being around 25–30°C.

RESULTS AND DISCUSSION

CO

The levels of CO were found to be negligibly low in the kitchen. The average value of CO was found to be around 4.6 μg/m^3 with an instantaneous maximum value of 13.8 μg/m^3. In a similar study carried out in homes in the Korean urban area, CO was found to have a mean of 2.8 μg/m^3 with a maximum value of upto 7.1 μg/m^3 (Baek *et al*., 1997). In yet another study in the US where gas stoves are in operation, hourly concentrations of CO were generally around 6.9 μg/m^3 and often never exceeded 13.8 μg/m^3 (Samet *et al*., 1987).

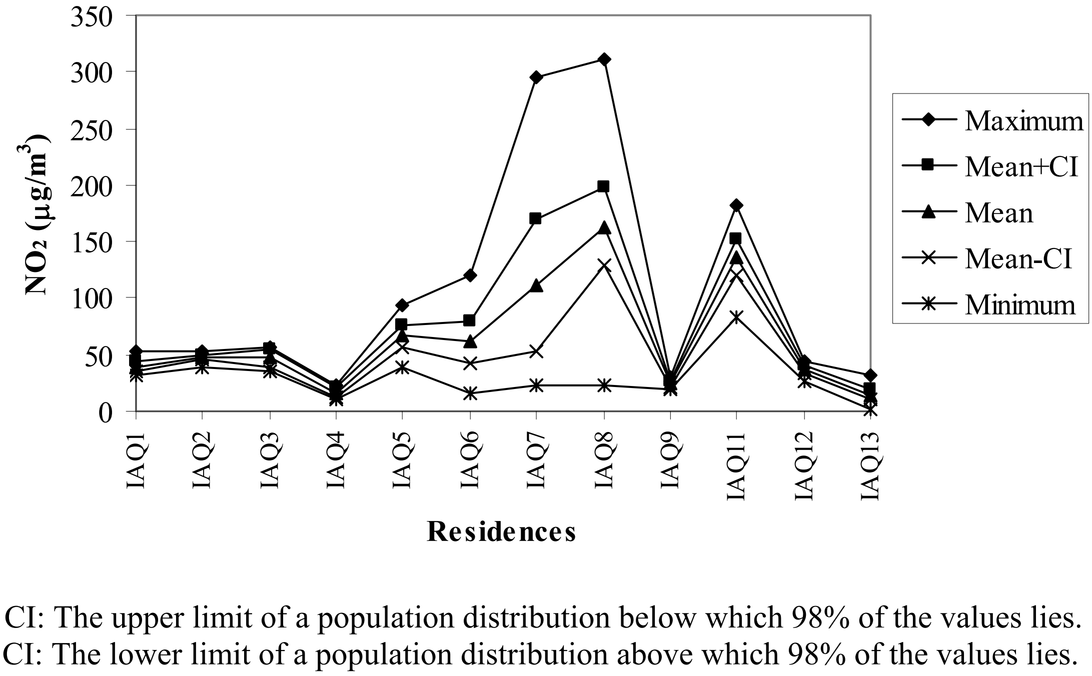
SO_2

The readings of SO_2 were also found to be negligibly low. Even the maximum 5 min average value of SO_2 was found to be 17.8 μg/m^3 in IAQ1. A fair correlation value of 0.63 was observed between SO_2 and NO_2 suggesting the same source of generation for the two pollutants. In a similar study, mean values of 149 μg/m^3 have been reported in homes equipped with both kerosene heaters and gas stoves (Leaderer *et al*., 1984).

Respirable Suspended Particulate Matter

The concentration of particulate matter was found to be extremely high, ranging from a minimum of 1.6 mg/m^3 to a maximum of 82.72 mg/m^3 with a mean value of 17 mg/m^3, which is much higher than the permissible value of suspended particulate matter concentration outdoors, i.e. 0.75 mg/m^3. However, in the absence of any correlating data between particulate mater measurement in personal and high volume sampling, such a comparison may not be justified.

Nitrogen Oxides—NO_2



Mean + CI: The upper limit of a population distribution below which 98% of the values lies.
Mean – CI: The lower limit of a population distribution above which 98% of the values lies.

Figure 1 Summary of 1 h moving averages of NO_2 along with the maxima and minima in the 12 kitchens studied (IAQ10 was not included).

The levels of NO_2 for a 5 min average duration ranged from a minimum of 1 μg/m^3 to a maximum value of 511.4 μg/m^3. The values obtained using the moving average method for other different time periods were:

10 min	505.7 μg/m^3
20 min	438.5 μg/m^3
30 min	421.8 μg/m^3
1 h	311.8 μg/m^3
2 h	230.1 μg/m^3

Figure 1 provides a summary of 1 h moving averages of NO_2 for twelve kitchens. When the maximum values of 1 h averages were compared with the WHO guideline value (WHO, 1999) for NO_2 of 200 μg/m^3, it was seen that out of 241 such values 13 exceeded the guideline limit. Out of these, the major contribution was from the kitchen of IAQ7, where out of 15 observations, 10 were above the WHO guideline. The reason for this could be the small kitchen volume and relatively less ventilation.

There have been numerous studies of indoor concentrations of NO_2. In homes with gas cooking stoves in Albuquerque, New Mexico, the 2 week average NO_2 level was found to be 63 μg/m^3 in kitchens (Lambert, 1997). On average, the normal use of a vented gas cooking range adds 47 μg/m^3 of NO_2 to the background concentration in a home (Samet *et al*., 1987). In Victoria, Australia, NO_2 concentrations with an indoor median value of 11.6 μg/m^3, and a maximum of 246 μg/m^3 were recorded (Garret *et al*., 1999). In yet another study conducted in Korea (Baek *et al*. 1997), the mean indoor concentration of NO_2 was found to be 33 μg/m^3 with a range of 9–96 μg/m^3.

In five European countries, the average NO_2 concentrations (over 2–7 days) were in the range of 40–70 μg/m^3 in kitchens, for dwellings with gas equipment and 10–20 μg/m^3 in dwellings without gas equipment. These values may be doubled in rooms facing streets with heavy motor traffic. Transient peak concentrations of NO_2 during the operation of appliances can greatly exceed average measurements. Whilst cooking with a gas range, peak levels in the kitchen may be as high as 752–1880 μg/m^3 (Spengler *et al*., 1981). As individuals operating gas ranges often stay close to the appliance, personal exposures may be even greater.

Data for the kitchen IAQ7 demonstrate an interesting fact. Kitchens of IAQ6 and IAQ7 have identical location in relation to outdoors and indoors except that a floor separates them. The volume of both the kitchens is the same, but the total area of openings in IAQ6 is double that in IAQ7. The ventilation index (VI) was calculated for all the kitchens as 'area of total openings/total volume'. Assuming a similar cooking pattern (as was the case at the time of measurements), a fairly good correlation between various parameters was seen. When a regression analysis was performed between the ratios of the same parameters between IAQ6 and IAQ7, i.e. the ratio of the area of openings with the ratio of maximum NO of IAQ6 and maximum NO of IAQ7, and the ratio of maximum NO_2 of IAQ6 and the maximum NO_2 of IAQ7 (for different averaging times), an almost perfect positive regression coefficient of 0.98 was obtained. Also the composition of NO_x in relation to NO and NO_2 was almost the same in both the kitchens, i.e. NO_x contained around 0.75 NO_2 and 0.25 NO. It could thus be concluded that openings/ventilation in a kitchen play a definitive role in dissipation of gaseous pollutants.

But when a regression analysis was performed between the ventilation index with the 5 min maximum and average concentrations of NO_x and RSPM, low but positive regression indices were obtained as shown in Figures 2 and 3. This perhaps indicates that, though the openings have a role in the dissipation of gases, natural ventilation is not enough for dispersion of pollutants. Though eight of the homes studied had an exhaust fan installed in the kitchens, these were not operated throughout the process of combustion. The exhaust fan was put on mostly during frying and that too for a short duration.

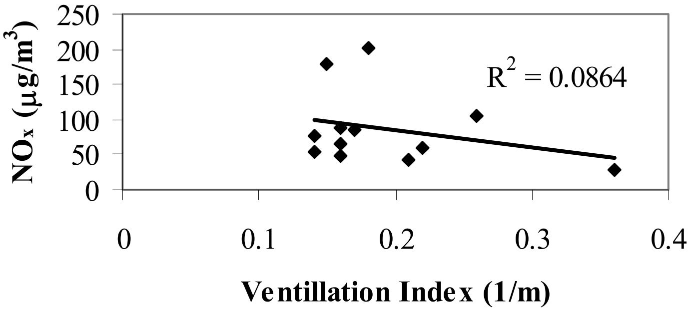


Figure 2 Effect of ventilation index on NO_x concentration.

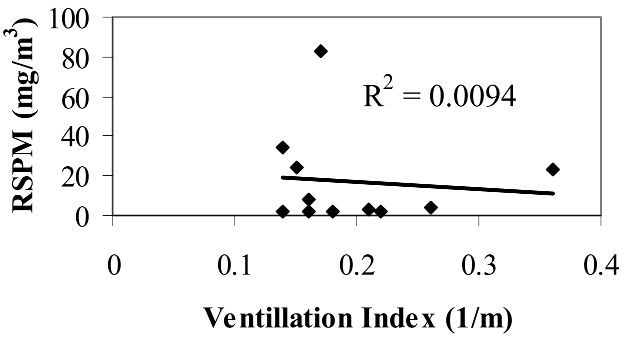


Figure 3 Effect of ventilation index on RSPM concentration.

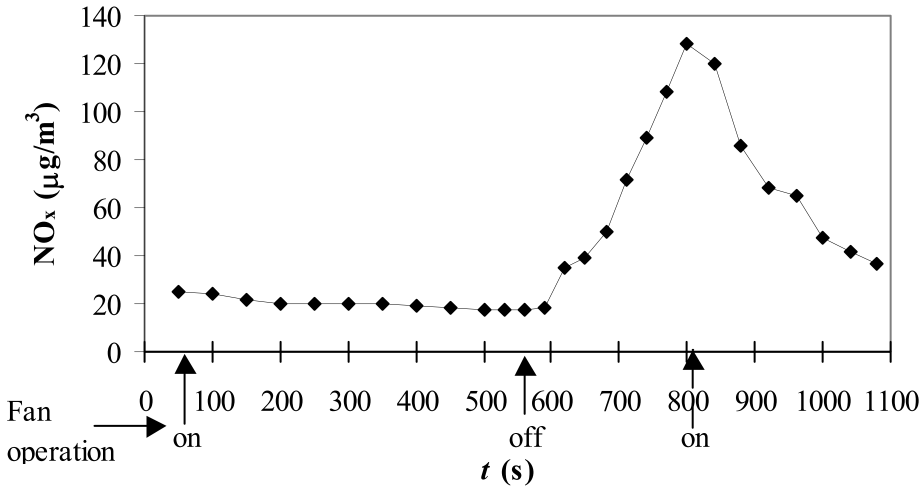


Figure 4 Effect of exhaust fan on dissipation of gaseous pollution in kitchen of IAQ9.

Effect of Ventilation/Exhaust Fan on Dissipation of Pollutants

Figure 4 is an indicator of the working of an exhaust fan and its role in the dissipation of gaseous pollutants. This study was conducted in the kitchen of IAQ9 and lasted for about 18 min. When the exhaust fan was put on at 09:28 h, the NO_x concentration started decreasing (other conditions being the same with constant rate of generation of gaseous pollutants), and in 7 min it fell by almost 30%. Afterwards when the exhaust fan was put off, a gradual increase in NO_x concentration was observed. During these 6 min, the NO_x concentration increased almost eightfold. Again, when the exhaust fan was put on at 09:42 h, a gradual decrease in NO_x concentration was observed and it reduced to almost half within 3 min. On the basis of this it can be concluded that an exhaust fan is capable of dissipating 30–60% (or more) of gaseous pollutants through its action of mechanical ventilation.

CONCLUSIONS

In the present study the concentrations of CO and SO_2 observed were non-consequential. The gaseous pollutant of concern was NO_2, which exceeded the 1 h average WHO guideline in only 5% of the cases but the levels found in IAQ7, IAQ8 and IAQ11 were high.

Proper kitchen design, i.e. volume, area of openings, orientation with respect to outdoors and indoors are all important parameters for a clean kitchen especially in this part of the world where houses mostly have only natural ventilation. This natural ventilation can help in pollution dissipation but an exhaust fan can play an important role by its action of mechanical ventilation. Appropriate capacity of the fan and its location *vis-à-vis* the cooking stove can provide the desired air exchange rates to bring down the exposure. One of the effective locations of an exhaust fan might be vertically above in the wall (at about 4–6 feet height) in front of which the stove is placed and facing the subject. It is also important that the exhaust fan should be put on for the entire duration of combustion.

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