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Full Length Research Paper

Indoor air quality in areas of different exposure: an experimental study

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The present study focuses on experimental study of indoor air quality regarding PM_{10}, $PM_{2.5}$, CO, CO_2, NO, NO_2, SO_2 in selected differently used areas. Cooking places (kitchen) at different locations using different types of cooking fuel used and living room were selected for the purpose of the measurements. For the purpose of pollutant monitoring 20 households for each having different types of kitchen using biomass fuels and LPG were selected. The indoor air quality of the living room of those households was also assessed for the purpose of comparison. The indoor environment was measured with handy portable samplers. Experimental results obtained shows that the indoor air quality of households cooking with biomass fuels is worse while the indoor air quality of the households using LPG was also found to be much above the prescribed guidelines especially in multipurpose room and in non-ventilated kitchen and on the other hand the indoor air quality of living room is little better but affected by kitchen emissions.

Keywords: Indoor air quality; pollution; indoor sources; PM; gaseous pollutants; indoor air monitoring

INTRODUCTION

Air pollution is associated with contamination of air or imbalance in composition of air, 'indoor air pollution can be defined as the totality of attributes of indoor air that affects a person's health and well being'. Breathing of polluted air is as old as mankind, particularly since the domestication of fire. Recently the air quality of indoor areas became of primary importance because of its effect on human health. In terms of environmental risks, indoor air pollution is the second most important risk factor, after unsafe water. It accounts for twice the number of deaths reported from urban outdoor air pollution (Down to Earth, July 15, 2007). The air in tight buildings, use of untested new materials, poor air exchange, burning of cooking fuels etc. drastically affects the indoor air quality. As the result of these inferences there is the increase of many

Practical implications

People generally spend most of the time indoor and is exposed to range of indoor air pollutants which poses severe health effects. Despite of its adverse effect very little is known about indoor air quality monitoring and much attention is being paid on outdoor air monitoring. Women spend much of their time in cooking places where indoor air quality remains poor due to cooking fuel emissions thus the monitoring of indoor air quality is of due importance.

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pollutant concentrations indoors such as CO, CO_2, NO_X, SO_2, PM_{10}, $PM_{2.5}$. Furthermore several studies have demonstrated that the indoor air quality depends on the location of the exposure areas (room, kitchen etc.), the ventilation characteristics and the sources of air pollution, which exists at the area while it was demonstrated that indoor air pollution levels can often exceed the outdoor levels (Assimakopoulos and Helmis, 2004; Jones et al., 2000; Edwards et al., 2001; Halios et al., 2005).

Researchers have focussed on the measurement of pollutants, concentrationds in residences, offices, shopping malls and restaurants where people spend most of their everyday time, in order to compare the different indoor environments and identify pollution sources (Junker et al., 2000; Lee et al., 1999; Wargocki et al., 2004; Synnefa et al., 2003). Kitchen is also a major exposure area where specifically women spend major proportion of their lives. There are four principal sources of pollutants of indoor air i.e. combustion, building material, the ground under the building and bio aerosols (Behera, 1998). In developed countries the most important indoor air pollutants are radon, asbestos, volatile organic compounds, pesticides, heavy metals, animal dander, mites, moulds and tobacco smoke. However, in developing countries, the most important indoor air pollutants are the combustion products of unprocessed solid biomass fuels used by the poor urban and rural folk for heating and cooking. There are many sources of indoor air pollution in any home. These include combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products; building materials and furnishings as diverse as deteriorated, asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products; products for household cleaning and maintenance, personal care, or hobbies; central heating and cooling systems and humidification devices; and outdoor sources such as, pesticides, and outdoor air pollution.

Inorganic gaseous pollutants are the major contributors to indoor quality problems. Combustion of cooking fuel is the major source of toxic gases along with other types of pollutants. The relative importance of any single source depends on how much of a given pollutant it emits and how hazardous those emissions are. In some cases, factors such as how old the source is and whether it is properly maintained are significant. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted. Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home, release pollutants intermittently. These include smoking, use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides in housekeeping. High pollutant concentrations can remain in the air for long periods after some of these activities.

MATERIAL AND METHODS

The researcher has measured the indoor air pollutants (SPM (PM_{10}, $PM_{2.5}$), CO, CO_2, SO_2, NO, NO_2) in different types of cooking places like in a separate kitchen with ventilation, separate kitchen without ventilation, cooking in *veranda* and cooking in multipurpose room with different types of cooking fuels like biomass and LPG used in Aligarh City (27º53' north latitude and 78º4' east longitude), a medium sized city, located in the western part of the state of Uttar Pradesh in the fertile Gangetic tract of a north Indian city. For the purpose of pollutant monitoring 20 households, each having different types of kitchen using biomass fuels and LPG were selected. The indoor air quality of the living room in these households was also assessed for the purpose of comparison including the whole day operational activities inside the house such as cleaning, sweeping, making of food etc. The concentration of gaseous pollutants were averaged over and recorded at 5 minutes interval each. The unit used to determine the concentration of PM_{10} and $PM_{2.5}$ was μgm^{-3} and for CO, CO_2, NO, NO_2, SO_2 was ppm.

The experimental instrumentation consisted of the following:

- For the purpose of monitoring of suspended particulate matter ($PM_{10,}$ $PM_{2.5}$), a handy sampler "Portable GRIMM Dust Monitor Series 1.109" (Grimm Aerosol technik; Dorf strabe 9; 83404 Airring-[Germany]) was used (measuring principle-90^0 light scattering; reproducibility-±2% over the whole measuring range; sample flow rate-1.2 l/min ±5% constant with controller; rinsing air rate-0.3 l/min constant with controller; sample air filter-47 mm PTFE-round filter (without supporting tissue)).
- For the monitoring of indoor gaseous pollutants like CO, $SO_{2,}$ NO, NO_2; portable YES-205 multigas monitor (Young Environmental System Inc. Vantage way, Delta, BC, Canada) was used (resolution CO-0.3ppm, NO-0.1ppm, NO_2- 0.05ppm, SO_2-0.1ppm; response-5 min operational; warm up time 20 min maximum).
- For the monitoring of CO_2 portable YES-206 Falcon IAQ monitor (Young Environmental System Inc. 140-8771 Douglas St. Richmon, B.C V6X1V2 Canada) was used (sensitivity-+/- 1 ppm; accuracy-+/- 50 ppm

Table 1: Mean concentrations of SPM and gaseous pollutants in different locations using different types of fuels.

Different exposure area	Average SPM (μgm^{-3})		Maximum SPM (μgm^{-3})		Minimum SPM (μgm^{-3})	
	PM_{10}	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**
Place of cooking (Bio)	322.86	188.77	604.4	358.35	198.80	117.1
Place of cooking (LPG)	130.41	70.96	318.00	157.08	65.28	41.90
Living room	83.84	42.41	121.1	83.30	58.70	26.80

Different exposure area	**CO (ppm)**			**CO_2 (ppm)**		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Place of cooking (Bio)	3.34	8.27	0.31	509.71	729.50	3050
Place of cooking (LPG)	0.90	1.70	0.20	398.71	564.00	238.5
Living room	0.59	0.90	0.20	311.69	399.00	228.00

Different exposure area	**SO_2 (ppm)**			**NO (ppm)**			**NO_2 (ppm)**		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
Place of cooking (Bio)	0.07	0.17	0.01	0.10	0.19	0.02	0.03	0.07	0
Place of cooking (LPG)	0.02	0.06	0	0.04	0.07	0.01	0.02	0.04	0
Living room	0.02	0.03	0	0.03	0.05	0.01	0.01	0.03	0

Average figures of place of cooking calculated in (separate kitchen with ventilation, separate kitchen without ventilation, *verandah,* multipurpose room, open air)
Source: Based on field survey, 2010

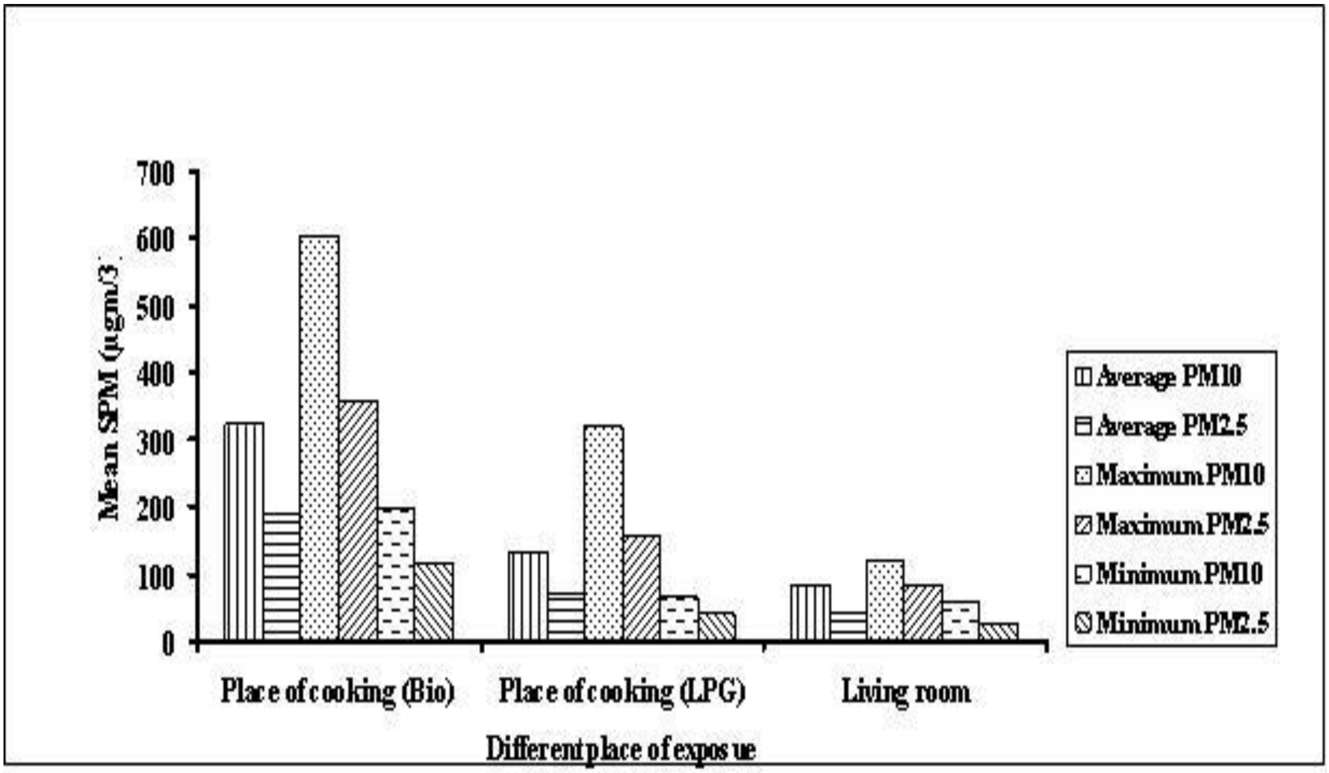
or +/- 5% of reading; warm up time-<60 seconds at 22ºC).

DISCUSSION AND EXPERIMENTAL RESULTS

The results suggest that the average concentration of indoor air pollutants were highest during cooking hours with biofuels. A perusal of table 1 and figure. 1 shows that the personal exposure of mean suspended particulate matter ranges from around 322.86 μgm^{-3} for PM_{10} and 188.77 μgm^{-3} for $PM_{2.5}$ reaching maximum upto 604.4 μgm^{-3} for PM_{10} and 358.25 μgm^{-3} for $PM_{2.5}$ and minimum upto 198.80 μgm^{-3} for PM_{10} and 117.1 μgm^{-3} for $PM_{2.5}$ for houses using biomass and from around an daily average of 130.41 μgm^{-3} for PM_{10} and 70.96 μgm^{-3} for $PM_{2.5}$ reaching maximum upto 318.0 μgm^{-3} for PM_{10} and 157.08 μgm^{-3} for $PM_{2.5}$ and minimum upto 65.28 μgm^{-3} for PM_{10} and 41.90 μgm^{-3} for $PM_{2.5}$ for houses using clean fuels (LPG). The concentration of SPM was found much lower in living room having daily average of 83.84 μgm^{-3} for PM_{10} and 42.41 μgm^{-3} for $PM_{2.5}$ reaching maximum upto 121.1 μgm^{-3} for PM_{10} and 83.30 μgm^{-3} for $PM_{2.5}$ and minimum upto 58.70 μgm^{-3} for PM_{10} and 26.80 μgm^{-3} for $PM_{2.5}$ as compared to that of different cooking places.

Table 2 shows that the concentration at various locations of cooking with biofuels depended on the type of kitchen. Personal exposures while cooking with biofuel were greatest in open air cooking where it ranged between 380.90 μgm^{-3} for PM_{10} and 249.35 μgm^{-3} for $PM_{2.5}$ followed by cooking with biofuels in *verandah*, 122.91 μgm^{-3} which ranged between 264.81 μgm^{-3} for PM_{10} and 128.18 μgm^{-3} for $PM_{2.5}$. The concentration at various locations of cooking with LPG depended on the type of kitchen. The mean exposure while cooking with LPG in *verandah* was recorded 167.7 μgm^{-3} for PM_{10} and 111.14 μgm^{-3} for $PM_{2.5}$, in separate kitchen with ventilation was recorded 122.91 μgm^{-3} for PM_{10} and 67.09 μgm^{-3} for $PM_{2.5}$ followed by 118.08 μgm^{-3} for PM_{10} and 50.94 μgm^{-3} for $PM_{2.5}$ in multipurpose room and 112.94 μgm^{-3} for PM_{10} and 54.65 μgm^{-3} for $PM_{2.5}$ in separate kitchen without ventilation. The concentration of SPM was higher in open air cooking places, in *verandah*, in separate kitchen with ventilation because a great portion of particulates originates from the outdoor air and enters the indoor environments but due to grater spaces the concentration level soon get dissipated in atmospheric air but the concentration of SPM in non-ventilated kitchen and in multipurpose room get concentrated and remain indoor for longer duration environment.

Figure. 1: Mean concentrations of SPM in different kitchen locations using different types of fuels.



Bio- Biomass
LPG- Liquid petroleum gas
Source: Based on Field Survey, 2010

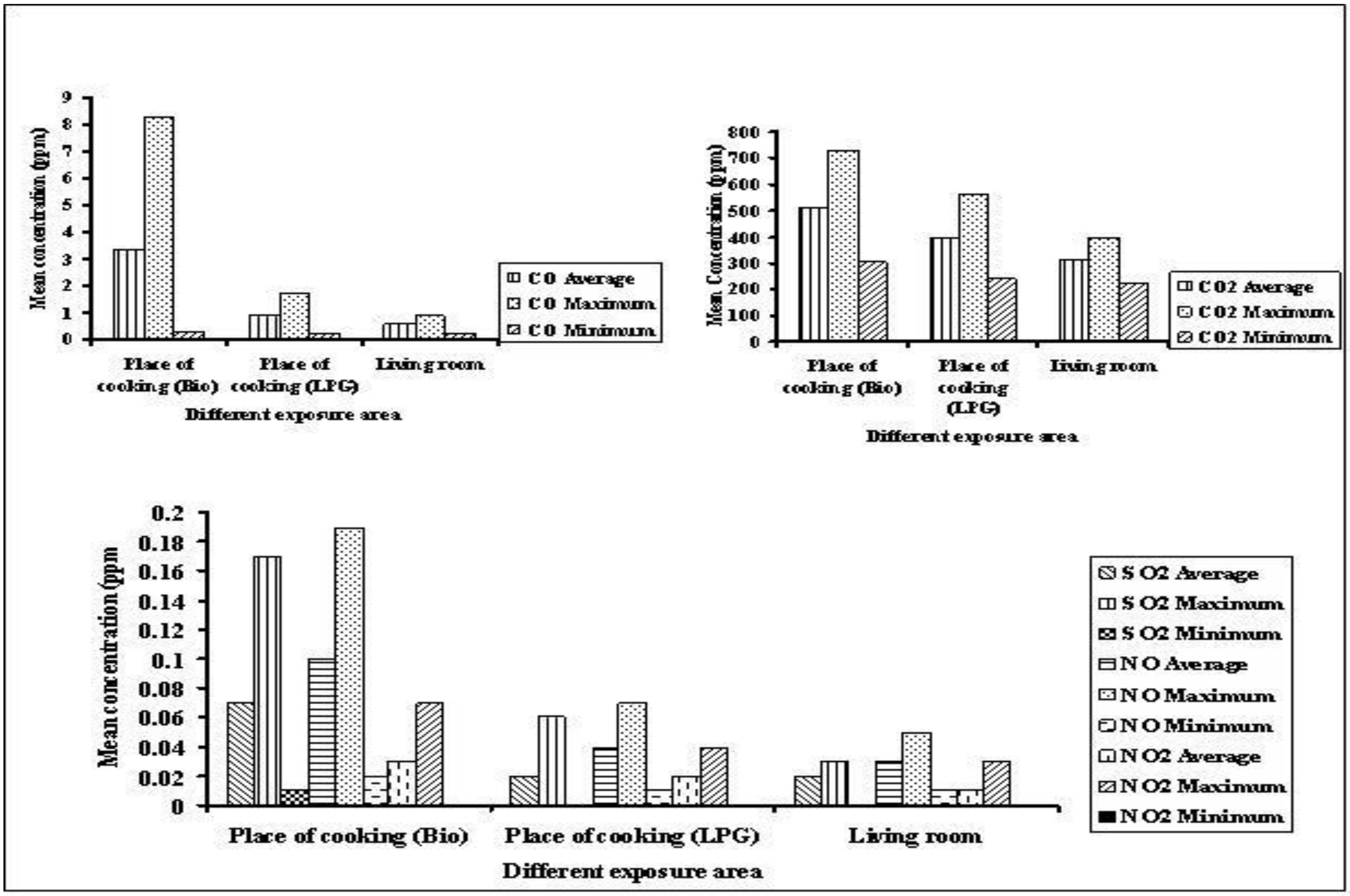
Table 2 : Mean concentrations of SPM and gaseous pollutants in different types of kitchen locations using different types of fuels

	Mean exposure during cooking (μgm^{-3})				
Type of kitchen with different fuel use	PM_{10}		$PM2_{2.5}$		
Verandah (biomass)	264.81		128.18		
Open air (biomass)	380.9		249.35		
Separate kitchen wthout ventilation (LPG)	112.94		54.65		
Separate kitchen wth ventilation (LPG)	122.91		67.09		
verandah (LPG)	167.7		111.14		
Multipurpose room (LPG)	118.08		50.94		
	Gaseous pollutants (ppm)				
Type of kitchen with different fuel use	CO	CO_2	SO_2	NO	NO_2
Kitchen (biomass)	3.34	509.71	0.07	0.10	0.03
Ventilated kitchen	0.89	395.71	0.02	0.04	0.02
Non-ventilated kitchen	0.9	401.71	0.02	0.04	0.02

Source: Based on field survey, 2010

Similarly table 1 and figure. 2 shows that the personal exposure of mean gaseous pollutants ranges from around 3.34 ppm, 509.71 ppm, 0.07 ppm, 0.10 ppm, 0.03 ppm for CO, CO_2, SO_2, NO, NO_2 reaching biomass and from around an daily average of 0.90 ppm, 398.71 ppm, 0.02 ppm, 0.04 ppm, 0.02 ppm for maximum 8.27 ppm, 729.50 ppm, 0.17 ppm, 0.19 ppm, 0.03 ppm for CO, CO_2, SO_2, NO, NO_2 and minimum upto 0.31 ppm, 305.0 ppm, 0.01 ppm, 0.02 ppm, 0.00 ppm for CO, CO_2, SO_2, NO, NO_2 for houses using CO, CO_2, SO_2, NO, NO_2 reaching maximum upto 1.70 ppm, 564.00 ppm, 0.06 ppm, 0.07 ppm, 0.04 ppm for

Figure. 2: Mean concentrations of gaseous pollutants in different kitchen locations using different types of fuels.



Average figures of place of cooking calculated in (separate kitchen with ventilation, separate kitchen without ventilation, *verandah,* multipurpose room, open air)
Source: Based on field survey, 2010

CO, CO_2, SO_2, NO, NO_2 and minimum upto 0.20 ppm, 238.5 ppm, 0.00 ppm, 0.01 ppm, 0.00 ppm for CO, CO_2, SO_2, NO, NO_2 for houses using clean fuels CO, CO_2, SO_2, NO, NO_2 reaching maximum upto 0.90 ppm, 399.00 ppm, 0.03 ppm, 0.05 ppm, 0.03 ppm for CO, CO_2, SO_2, NO, NO_2 and minimum upto 0.20 ppm, 228.00 ppm, 0.00 ppm, 0.01 ppm, 0.00 ppm for CO, CO_2, SO_2, NO, NO_2 as compared to that of different cooking places.

Table 2 shows that the gaseous pollutants varies at different cooking locations with different types of fuel used for cooking. The highest concentration of gaseous pollutant was found in kitchen using biomass fuel for cooking i.e. 3.34 ppm, 509.71 ppm, 0.07 ppm, 0.10 ppm, 0.03 ppm for CO, CO_2, SO_2, NO, NO_2 followed by non- ventilated kitchen using LPG which was recorded 0.9 ppm, 401.71 ppm, 0.02 ppm, 0.04 ppm, 0.02 ppm for CO, CO_2, SO_2, NO, NO_2 and ventilated kitchen which was recorded to be 0.89 ppm, (LPG). The concentration of gaseous was also found much lower in living room having daily average of 0.59 ppm, 311.69 ppm, 0.02 ppm, 0.03 ppm, 0.01 ppm for 395.71 ppm, 0.02 ppm, 0.04 ppm, 0.02 ppm for CO, CO_2, SO_2, NO, NO_2.

The study reveals that the concentration of indoor pollutants especially particulate matter, carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxide, nitrogen dioxide is maximum when cooking is done using biomass. The exposure to chief cook is very high in all types of kitchens (whether cooking in *verandah* or in open air) when cooking is done using biomass. Another important finding is that the household members who are inside the house during the cooking hours also face the effects of high exposures. This is because most of the households using biomass burn them in open fires/ *chulhas* that release most of the smoke into the house. The resulting indoor air pollution is a major threat to health, particularly for women and young children who may spend many hours close to the fire. Much higher levels of pollutants are released during cooking hours. This can be seen from experimental results. Furthermore, the reliance on biomass and inefficient *chulhas*/stoves has other far

reaching consequences for health, the environment and economic development. Cooking process also affect concentrations in the adjacent living area. Therefore use of a particular fuel, location of kitchen and ventilation in the kitchen are very important determinants of exposure not only for the person involved in cooking but also to other members of the household.

The amount and characteristics of pollutants produced during the burning of cooking fuels depends on several factors including composition of fuel, combustion conditions (temperature and air flow) mode of burning and shape of combustion chambers (Smith, 1987). Hundreds of harmful chemical substances are emitted during the burning of biomass fuels in the form of gases, aerosols (suspended liquid and solids) and suspended droplets. Smoke from wood burning stoves contains 17 pollutants (USEPA, 1997). The pollutants include carbon monoxide, small amount of nitrogen dioxide, aerosols (particulates) in the respirable range (0.1-10 µm in aerodynamic diameter) and other organic matter including polycyclic aromatic hydrocarbons such as benzo (a) pyrene and other volatile organic compounds such as benzene and formaldehyde.

The use of biomass fuels results in higher pollutant levels (much higher than health based guideline values available for the outdoor setting) and the women and children face the biggest risk of high exposure because of their proximity to the fire/smoke during the cooking period.

CONCLUSION

The indoor air quality of differently used areas, living room, cooking in *verandah*, open air, multipurpose room, separate ventilated kitchen, separate non-ventilated kitchen using different types of cooking fuel

(biomass, LPG) were assessed. It seems that the indoor air quality of households cooking with biomass fuels is worse i.e much above the prescribed guidelines while the indoor air quality of the households using LPG was also found to be much above the prescribed guidelines especially in multipurpose room and in non-ventilated kitchen and on the other hand the indoor air quality of living room is little better but affected by kitchen emissions. It means that the location of exposure area plays the important role in determining the indoor air quality.

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