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Evaluation of Indoor Air Pollution in Urban Homes: A Case Study from Isfahan, Iran

Loghmani F[1]*, Jones C[2] and Hertel O[3]

[1]Department of Environmental Science, Faculty of Natural Resources, Isfahan University of Technology, Iran
[2]Department of Environmental Sciences, National Institute of Integrative Medicine Hawthorn, Victoria, Australia
[3]Department of Environmental Science, Faculty of Science and Technology, Aarhus University, Denmark

Abstract

Burning fossil fuels has a significant effect on indoor air quality. In this study, the concentration of SO_2, NO_x, NO_2, NO, CO was measured in five houses at Isfahan focusing attention on kitchens as a source of indoor pollutants. Selected houses differed in terms of kitchen type and finish, presence or absence of a range hood, and type of stove heating. Samplings were done over three days at a fixed time window for each location. Results showed that in closed kitchens without a range hood, the 1-h concentration of pollutants was higher compared to kitchens having open and semi-open range hoods. Minimum pollutant levels were seen for kitchens using an electric stove with a range hood.

Keywords: Indoor air pollution; Kitchens; Gas stove; Hood range

Introduction

Since the dawn of humanity, humans have always had a constant struggle about indoor air pollution. Due to its importance, scientists have tried to evaluate the effects of air pollutants on human's health and diminish their harmful risks in the best way possible. The World Health Organization (WHO) has reported that indoor air pollution is one of the most significant environmental factors that threaten human's health [1]. Generally, Indoor Air Pollution (IAP) is defined as air quality within and around the structures of buildings which leads to discomfort and/or health problems for the occupants or residents [2]. Carbon Monoxide (CO), Particulate Matter (PM), Nitrogen Dioxide (NO_2), formaldehyde, black carbon, Polycyclic Aromatic Hydrocarbon (PAH) are just a few of the more common indoor pollutants that are generated by incomplete burning of fuels for heating purposes like cooking [3-6]. Pratali et al. [7] stated that during cooking, fumes will be generated from fuel burning, oil heating and food processing at high temperature. The generated particulate matter cloud indexed by $PM_{2.5}$ contains organic compounds and hazardous chemicals, like metals, polycyclic aromatic hydrocarbons, carbonyl compositions, benzene and quinines.

Epidemiological estimates show that about 4.5 million deaths caused by indoor air pollution including pneumonia, stroke, Ischemic Heart Diseases (IHD), Chronic Obstructive Pulmonary Diseases (COPD), and Lung Cancer (LC). White et al. [8] showed that exposure to air pollution including PM, NO_2, and NO_X enhances the incidence of breast cancer. In other study, Ritz et al. [9] showed that exposure to air pollution can increase the risk of Parkinson's disease. In two studies about the effect of air pollution on human's health, it was concluded that NO_2, $PM_{2.5}$, and O_3 increase the non-accidental mortality rate in a large population of Canadians [10]. The main concern about indoor air pollution is that individuals like women, children and older adults spend such a large proportion of time inside the home, estimated at up to 90% [11,12]. In a study Singh [13], indicated that more than half of women cooking with traditional cooking stoves experience health problems.

In order to reduce this healthcare burden, National Health Policy tries to reduce environmental hazards through practical control measures for decreasing air pollution. But, to better address this, more research should be conducted into fundamental concepts and descriptions of air pollution, their sources, and negative effects on human health in a localized context. This is because indoor air quality usually varies between different locations depending on human activities, use of consumer products and household installations, building materials, infiltration of outdoor air sources and overall ventilation [14].

Iran is considered a place that has abundant gas resources. Therefore, natural gas is widely used for heating houses. According to the report from the NIGC (National Iranian Gas Company), in 2005, 11.6 million families are covered by the gas distribution network [15]. Burning natural gas for heating the indoor room volumes and water is the main reason that increasing pollutant concentrations may develop in the home environment, particularly, during cold seasons. The aim of the present study is to measure the concentration of gaseous pollutants such as NO_2, SO_2, CO, NO, NO_x in kitchens of houses having different structural building features and kitchen types and the potential correlation between these features in different parts of Esfahan province, to assess exposure to indoor air pollution.

Materials and Methods

Description of study area

Isfahan has an arid climate with low average rainfall and is in the center of Iran. Sample locations are shown in Figure 1 where the five homes were selected. These buildings varied in area (m^2), year built, single or double story, and flooring type as described in Table 1. Regarding the buildings, each had the same number of bedrooms and all were naturally ventilated from standard windows. All windows and other ways for outdoor air penetration were blocked during sampling. To calculate realistic levels of pollutants, monitoring was done without any control or interference with the normal activities of the residents. From Table 2, three homes had an open kitchen and two others had an enclosed kitchen. Open kitchens were integrated with the living room and connected to other rooms in the home through interior doorways. Cooking appliances had several differences in term of stove type and range hood. In three homes, venting range hoods used in the kitchens were installed above the cooktops.

***Corresponding author:** Loghmani F, Department of Environmental Science, Faculty of Natural Resources, Isfahan University of Technology, Isfahan, Iran, Tel: +9809305017978; E-mail: Loghmanifarid@gmail.com

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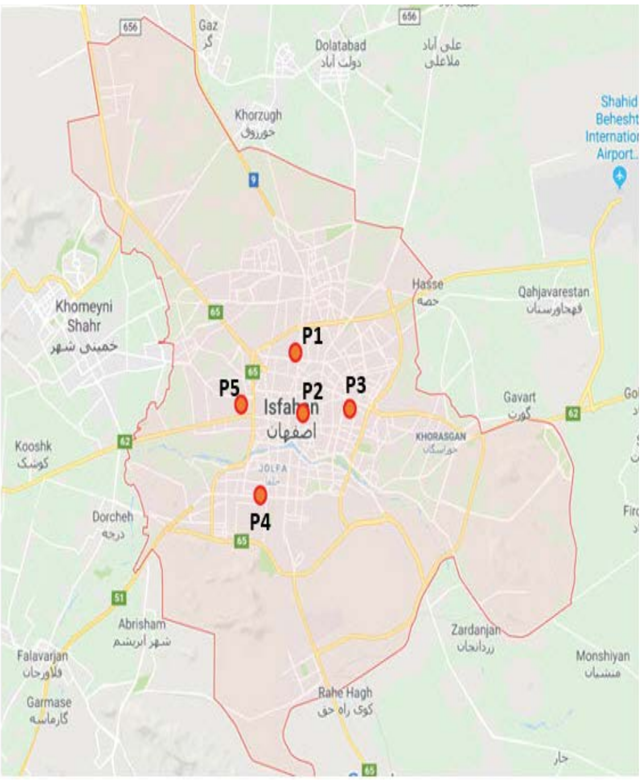

Figure 1: The locations of monitoring in Isfahan city.

ID	Area (m^2)	Year built	Level	Flooring
P1	180	1978	1	Carpet
P2	175	2005	1	Carpet
P3	120	2009	1	Ceramic-carpet
P4	210	1990	2	Ceramic-carpet
P5	160	2014	2	Parquet

Table 1: The studied places information.

ID	Kitchen Design	Stove Type	Ventilator	Venting Range Hood
P1	Enclosed	Gas	N	N
P2	Semi-open	Gas	N	Y
P3	Semi-open	Gas	N	Y
P4	Enclosed	Gas	N	N
P5	Open	Electric	N	Y
(Note: Y= Yes; N=No)				

Table 2: Kitchen design and cooking type and features.

In homes P_1 and P_4, a direct heating system (gas heaters with various thermal power), and a storage water heater were used to warm the room volumes of living rooms, bedrooms, and for water. These systems generate heat by burning natural gas as fuel. In the other homes, the interior room volumes and water were heated through central boilers that circulate hot water through pipes to radiator units positioned strategically around the house. Table 3 details the heating systems and types for each location. General information about residents in term of family's members, the number of males and females, and their habits including whether residents smoke or not, and the dominant methods of preparing food are shown in Table 4.

Air quality measurement

The monitoring was carried out in selected households during winter with continuous sampling over 3 days, in 20-21 o'clock. The concentration of SO_2, CO, NO, NO_2, and NO_x were monitored via portable gas analyzer MRU Vario Plus. The values reported for NOx are based on the sum of NO_2 and NO [16-18]. temperature and relative humidity were measured continuously during cooking time (1 hour) by HTC-1 thermometer-hygrometer. Air samplings were done in kitchens. During measurement process all doors and windows were closed to make the effect of outdoor pollution least.

Results and Discussion

Environmental variables

During measurement, the outdoor Relative Humidity (RH) ranged from 10-30% and Temperature (T) varied from -1-8°C. The HTC-1 thermometer-hygrometer was used in order to determine indoor temperature and humidity. Results showed that indoor temperature was 25-28°C and Relative Humidity (RH) was 30-51%. The highest Relative Humidity (RH) was recorded in P_3 and the highest temperature was measured at P_4.

Pollutants concentration

Nitrogen oxides concentration measurement: As expected, the concentration of NO, and NO_2 increased quickly in kitchens when

ID	Heating system	Fireplace	Heating System Type	
			Air	Water
P1	Direct heat	N	Gas-fired space heater	Storage water heater
P2	Central heat	N	Boiler	-
P3	Central heat	N	Boiler	-
P4	Direct heat	N	Gas-fired space heater	Storage water heater
(Note: Y= Yes; N=No)				

Table 3: Air and water heating systems of studies locations.

ID	Occupant		Habits
	Number	Gender	Smoking
P1	4	2M+2F	N
P2	4	3M+1F	N
P3	4	1M+3F	N
P4	3	2M+1F	N

Table 4: General information of about residents.

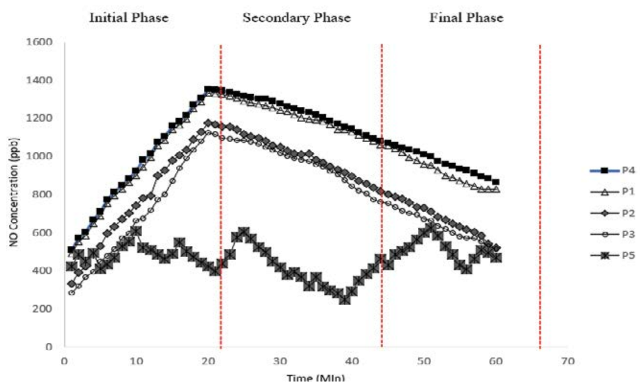

Figure 2: NO concentration during 1 hour.

cooktops were working with the highest flame, continuously. Hence, there is a direct relationship between burning natural gas through gas stoves and the concentration of NO_2 at home environment [19]. After finishing cooking events, concentrations started to decline, gradually, in P_1 and P_4 through air exchange with other parts of homes and after a period remained constant because gas fired space heaters fired regularly in bedrooms and the living room. Figure 2 represents NO concentration during cooking for each of the five locations.

Mainly, the process of cooking in the different homes studied places followed three main phases. During the initial phase of cooking, the food material becomes semi-cooked. Here, stoves burn the most amount of natural gas in order to create maximum heat. The greatest concentration of pollutants is produced during this phase. In the secondary phase, the process of cooking becomes relatively complete. Compared with the previous phase, the least amount of natural gas is burnt because this phase occurs gradually. The final maintenance phase is where the prepared foods are kept warm. In this phase, minimum heat is generated by stoves. Here, the lowest amount of fuel is consumed and similarly, the lowest concentration of generated pollutants is produced. From the graph, the concentration of NO raised in first 20 min (Initial phases) and eventually reach to highest point. In next two phases, NO concentration declined gradually which was related to reduction of consumed natural gas.

Measurements in the P_2, P_3 where kitchens were open and semi-open indicated that concentrations reduced with rapid pace because of higher air exchange with other sections of home and using range hood. These days, many studies have referred to the importance of range hood on the concentration of pollutants. Hänninen et al. [20] investigated the infiltration level and fine particle concentration of housing and found that the ventilation rates by infiltration were proportional to the indoor $PM_{2.5}$ generated non-environmental tobacco smoke concentration. Gens et al. [21] stated that improvements made to the air tightness of buildings without enough air exchange rate can have unintended adverse health effects.

Also, these houses enjoyed central heating system where the boiler is located outside occupant's environment. In this regard, the boiler had little influence on the indoor concentrations of NO, NO_2. Another important point in these locations is that NO_2 concentrations in P_3 were lower than P_2 which might relate to the its higher relative humidity content. Francisco et al. [22] stated it is more likely that the wide range of NO_2 decay rates is due to the amount of water mists in the air. However, this explanation is not supported completely.

P_5 showed a different pattern as compared to other homes because of the use of an electric stove. The amount of emitted NO and NO_2 were not surprisingly lower than the other indoor environments. Although studies have reported higher concentrations of nitrogen compounds in homes with natural gas cooking burners compared to homes with electric cooking [23], in this location, a fireplace which was burning natural gas, plays such a prominent role in emission of pollutants like NO_2 and NO. During cooking time, the concentration of both NO_2 and NO remained constant. Such pollutants were generated by the fireplace and some particles which traveled from living room to the kitchen, were driven out via range hood and thermally diffusive flow from their source.

Figure 3 shows the highest 1-hour concentrations of NO_2. The NO_2 level in all house types were higher than the 100-ppb threshold assigned by the EPA. Almost all the homes had NO_2 levels exceeding 50-ppb. Hence, it is concluded that unexpected emissions might occur in homes where natural gas stoves are used. Additionally, the average NO_x concentration in cooking time is calculated by the sum of the concentration of NO and NO_2 and represented in Figure 4.

Concentration measurement: Emitted CO in the home environment is associated with residential appliances, and type of fuels used for cooking, and heating purposes [24-26]. A large proportion of people in developed countries use electric stoves, however, in developing countries particularly like Iran that enjoy plentiful oil and gas resources, gas stoves are preferred. Increasingly, research is focused on measuring indoor CO concentration [27] monitored indoor CO concentrations over a 1-hour interval at different homes. The results varied between 6-8 mg/m^3. Figure 4 represents the average 1-hour concentration of CO during cooking process. These results measurements indicated that CO concentrations were lower than WHO standard which are set at 30.55 ppm for 1-h [1]. Based on Figure 5 the highest concentration of 1-hour CO were measured at P_1 and P_4 in kitchens not having a range hood and enclosed type of kitchen and more importantly continuous use of gas heaters.

However, CO had an unpredictably lower concentration in P_3. One of the most significant justifications was related to method of cooking. Generally, two methods of cooking including frying and boiling are common among Iranian families. At P_3, boiling is preferred to prepare food ingredients. In contrast, in P_1 and P_4 both boiling and frying are used, and at P_5, frying is more common. Depend on fuel type, cooking methods and ingredients which are used in kitchens, the type and amount of air pollutants generated by cooking can be varied [28-30]. Huboyo [31] reported that cooking type can play a crucial role in generated CO. During boiling of water, the CO concentration was at lowest point because water particles can absorb emitted CO. Lee [32] found that the most amount of pollutants are generated during barbecuing. Jiang [33] stated that water mists can diminish both CO and CO_2 concentrations during cooking.

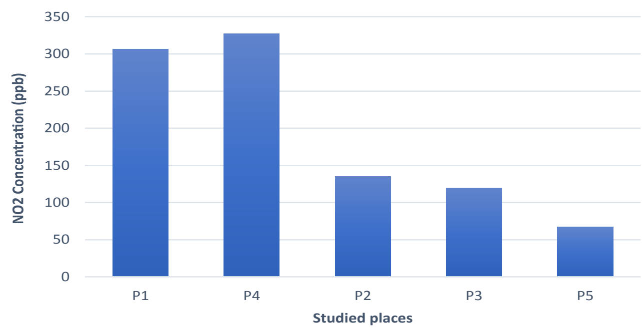

Figure 3: The average 1-hour concentration of NO_2 (ppb).

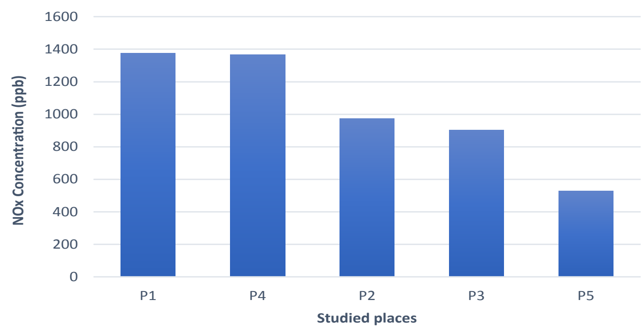

Figure 4: The average 1-hour concentration of NO_X (ppb).

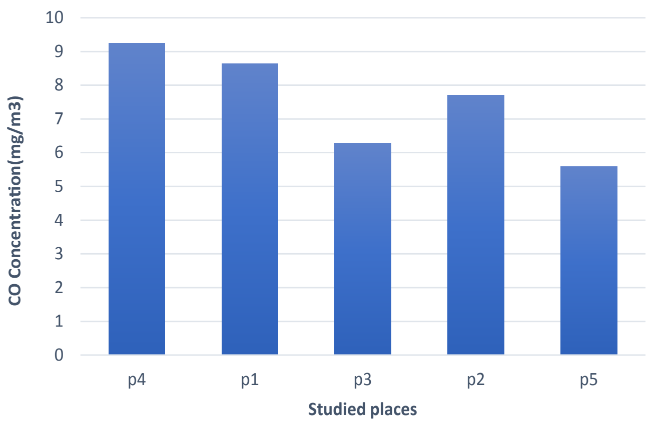

Figure 5: The highest 1-hour concentration of CO (mg/m³).

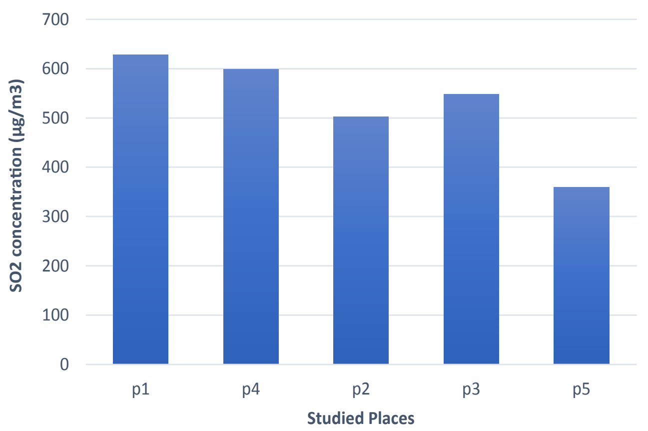

Figure 6: 1-hour average SO_2 concentration (µg/m³).

According to the EPA, standard levels in houses without using gas stoves are 0.5-5 ppm, and with gas stoves are 5-15 ppm (EPA 2009). Lee [32] found that cooking methods in restaurants had various emissions of particles and CO. The highest levels of pollutants are generated during barbecuing. Zhao [11] state that the cooking method can have a significant impact on emissions from Chinese cooking. Oil-based cooking produces air pollutants at much higher levels than water-based cooking. CO in P_5 mainly generated by fireplace and then because of air exchange spread out in kitchen.

Concentration of SO_2: The average concentrations of SO_2 in kitchens are presented in Figure 6 Like the other kinds of pollutants; generated SO_2 heavily depends of the type of cooking appliances and fuels [34]. Obviously, the concentration of SO_2 in P_1 and P_4 kitchens were relatively higher than others. The lowest concentration of SO_2 was recorded at P_5. Generally, four locations had SO_2 concentration near the national standard of AIQ (0.50 mg/m³, 1 h-avarage), and one location had a lower SO_2 concentration. In similar investigation, Cichowicz studied the concentration of NO_2, NO_x, O_3, SO_2, CO, PM_{10}, $PM_{2.5}$, and C_6H_6 in selected city, town and rural sites. [35].

Conclusion

This work was conducted under ordinary living conditions and without any control over the occupant's normal daily activities. Smoking did not take place by any occupants and all sampling was performed during winter. Selected pollutants were measured using continuous monitoring and allowed us to calculate the concentration of SO_2, NO, NO_2 and CO. Our results support the expectation that the concentration of indoor air pollutants grows dramatically during cold seasons because of the extra requirements for heating. They found out that the highest concentration of these pollutant occurred in winter. Importantly, in traditional kitchens (enclosed and semi-open), pollutants had a higher concentration. Therefore, residents particularly housewives, could be more affected by indoor pollution in such kitchens. Stove and fuel type, ventilation, method of cooking, heating system, and human activities, are other factors which play a crucial role in the concentration of indoor pollutants within enclosed spaces. To minimize the negative effects of indoor pollution and control them, it is suggested that efforts should be made to provide incentives and opportunities for using clean energies like electric instead of fossil fuels.

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