COMPARISON OF INDOOR AIR QUALITY IN RESTAURANT KITCHENS IN TEHRAN WITH AMBIENT AIR QUALITY

***M. Ghasemkhani, F. Naseri**

Department of Occupational Health, School of Public Health, Medical Sciences/University of Tehran, Tehran, Iran

Received 12 September 2007; revised 25 November 2007; accepted 26 December 2007

ABSTRACT

The indoor air quality of 131 restaurant kitchens in Tehran was investigated from May to September 2006. Gas stoves use in restaurant kitchens is a major source of indoor combustion, product carbon monoxide and nitrogen dioxide. The study focused on one of the busy zones located in the southwest and central part of the city. Measurements were done for indoor and outdoor air pollutants, carbon monoxide and nitrogen dioxide; ambient temperature and relative humidity were also measured. Result indicated that the mean levels of CO and NO_2 in restaurant kitchens were below the recommended limit of 25 and 3ppm, respectively. Correlations between indoor and outdoor air quality were performed consequently. Results of the mean ambient temperature and relative humidity were above the guideline. In this study the mean levels of CO and NO_2 gas cooking in restaurant kitchens were found to be lower compared with the similar studies.

Key words: Indoor air quality, restaurant kitchens, gas stove, cooking, CO, NO_2

INTRODUCTION

Air pollution is a major environmental health problem, affecting developed and developing countries around the world. Although the indoor air database is weak due to the scarcity of monitoring results, these estimates indicate that a serious indoor air problem may exist in developing countries. In developed countries, pollutant concentrations indoors are similar to those outdoors, with the ratio of indoor to outdoor concentrations falling in the range 0.7-1.3. Concentrations of combustion products in indoor air can be substantially higher than those outdoors when heating and cooking appliances are used (WHO, 2000). Recently, a number of studies have evaluated the correlation between indoor and outdoor air pollution (Lee *et al*., 1999).

Generally nitrogen dioxide (NO_2) and carbon monoxide (CO) are emitted from indoor combustion sources. These comprise tobacco smoke, woodstoves and fireplaces, gas appliances or gas stoves and kerosene heaters (CEC, 1989 and Phillips, 1997). The predominant sources of indoor pollutants are gas cooking (and heating) appliances, which produce complex mixtures of volatile organic compounds, sulphur dioxide, water vapor, particulates, carbon dioxide, carbon monoxide and oxides of nitrogen *(*Chauhan, 1999). When we cook with a gas stove, toxic gases like CO, carbon dioxide (CO_2), sulfur oxides (SOx), nitrogen oxides (NOx) and all these compounds remain in the kitchen.

In developed countries indoor levels of NO_2, for example, are affected by gas heaters and cooking ranges (used in 20-80% of houses in some countries). In five European countries, the average NO_2 concentrations (over 2-7 days) were in the range of 40-70μg/m^3 in kitchens. Peak values of up to 3800μg/m^3 for 1 minute have been measured in the Netherlands in kitchens with unvented gas cooking ranges (Harlos, 1987). The most important indoor source of nitrogen dioxide is the use of unvented gas appliances (Moran *et al*., 1999). Indoor NO_2 concentrations were measured in the kitchen of 612 houses in two different areas in the Netherlands. It was determined that gas appliances inside the house are the most important

*Corresponding author: *ghasemkh@sina.tums.ac.ir*
Tel: +98 21 6695 4226, Fax: +98 21 6641 9984

factor with respect to NO_2 exposure (Fischer *et al*., 1986). Gas stoves are among the major contributors to indoor NO_2 exposure. Studies conducted in New York (Palmes *et al*., 1977) and London (Mella *et al*., 1978) showed that NO_2 concentrations in the kitchens of homes with gas stoves (49.1 and 72.3ppb, respectively) were higher than in the kitchens with electric stoves (8.3 and 9.5ppb, respectively).

A number of factors can affect indoor CO concentrations: the presence of a source and its use pattern, pollutant emission rate, ambient air concentrations, infiltration through the building envelope, air exchange rate (AER), building volume, and air mixing within the indoor compartments. Dangerous levels of CO have been noted in cases where the venting system leaked or was improperly installed. Because gas cooking ranges are used intermittently for cooking purposes, it is not likely that the use of gas ranges would result in substantial increases in CO over long periods of time (Slack and Heumann, 1997). In general, average short-term CO values at kitchens with gas stoves in developed countries of up to 15mg/m^3 have been measured (Harlos, 1987).

The body attempts to maintain a constant temperature of 37°C at all times. In hot weather, the body produces sweat, which cools the body as it evaporates. As the humidity or the moisture content in the air increases, sweat does not evaporate as readily. Sweat evaporation stops entirely when the relative humidity reaches about 90 percent. Under these circumstances, the body temperature rises and may cause illness (CCOHS, 2004).

The objective of the present study was to measure carbon monoxide (CO) and nitrogen dioxide (NO_2) levels during the operation of cooking in restaurant kitchens that use gas or natural gas in Tehran.

MATERIALS AND METHODS

Restaurants

One hundred thirty one restaurants were chosen randomly from a list of 276 restaurants in five different geographic regions two in the central region, one downtown and two in the southwest (urban commercial, residential) of the metropolitan Tehran, in summer 2006. These places are noted as having a representative sample of most varieties of restaurants in the nation. The potential outdoor sources of pollutants at these restaurant kitchens included motor vehicles, while the indoor sources were from gas stoves. All these restaurant kitchens were different in size and ventilated using by canopy hood and fan systems. The ventilation system is used to capture the heat, odor, vapor and indoor pollutants emitted during cooking process and to contain it until the fan can exhaust them outdoor. All restaurant kitchens used gas for the operation of cooking. Information was gathered regarding the patron capacity of the restaurant, the age of the establishment, the frequency of ventilation equipment service, the length of time the ventilation system was on or off and the frequency of readjusting the temperature in summer.

Sampling and analytical methods

The air pollutants investigated in this study included: nitrogen dioxide and carbon monoxide. CO concentration in parts per million (ppm) was measured frequently by a real-time analyzer portable Compur Monitors, München (Monitox plus Type 5306 505). The analyzer's detection level ranged from 0–60ppm with accuracy of ±10%. NO_2 concentration (ppm) was measured frequently by a real-time analyzer portable compur monitors, München (Monitox plus Type 5306 504). The analyzer's detection level ranged from 0–2ppm; accuracy: ±10%. The analyzers were originally factory calibrated as part of routine maintenance. Air measurements was carried out between 9.00 AM and 14.00 PM at the restaurants. Simultaneous indoor and outdoor air sampling was done at each sampling site. Indoor air samples were collected in the proximity of the employee's breathing zone and near to the gas stove as possible, especially while cooking. At the same time, outdoor air samples were taken at streets in close proximity.

Ambient air temperature and humidity

Ambient air temperature in degrees Celsius (ºC) and relative humidity in percent (%) were obtained using a sling psychrometer (Model Whirling Hygrometer, Casella CEL UK).

RESULTS

Table 1 summarizes the specifications of the 131 restaurants that investigated in the study. Number of regions included were 5. The results of this study showed that %83 and %68 kitchens had local exhaust ventilation and fan system, respectively.

The statistical summaries for the concentrations of the studied air pollutants in indoor and outdoor air are shown in Table 2. The average CO and NO_2 concentrations at the indoor kitchens ranged from 5.4 to 10.5ppm and 0.04 to 0.13ppm, respectively. Also, the average CO and NO_2 concentrations at the outdoor restaurants ranged from 5.8 to 9.5ppm and 0.01 to 0.07ppm, respectively. The highest indoor CO level obtained in region 1 was 42.3ppm and NO_2 level in region 2 was 0.53ppm. While the highest outdoor CO level obtained in region 2 was 33.3ppm and NO_2 level in region 5 was 0.53ppm. Statistical analysis also showed that for each region kitchens and for all region kitchens combined, the outdoor CO and NO_2 levels were significantly lower than the CO and NO_2 levels indoor. The results showed that the indoor/outdoor (I/O) ratios of CO and NO_2 at all of the surveyed kitchens were often greater than 1.

Table 1: General information for restaurants

Specification	Restaurant region					Total
	1	2	3	4	5	
No. of restaurants	25	47	23	12	24	131
Average of occupancy capacity	107	79	83	40	102	86
No. of employees	69	165	75	31	47	
Average age of establishment	17	20	20	24	18	19.5
Average area of kitchen(m^2)	37	134	27	23	18	29
Food type (famous as)						
Meat- n (%)	1(4.0)	47(100)	0	0	6(25.0)	54(41.2)
Chicken- n (%)	0	0	4(17.0)	0	18(75.0)	22(16.8)
Stew- n (%)	11(44.0)	0	19(82.6)	3(12.0)	0	42(32.1)
Other- n (%)	13(52.0)	0	0	0	0	13(9.9)
Canopy hood system						
Yes-n (%)	3(12.0)	47(100)	23(100)	12(100)	32(100)	109(83.3)
No- n (%)	22(88.0)	0	0	0	0	22(16.8)
Fan system						
Yes-n (%)	19(76.0)	30(63.8)	15(65.2)	8(66.7)	21(67.7)	89(67.9)
No- n (%)	6(24.0)	17(36.2)	8(34.8)	4(33.3)	10(32.3)	42(32.1)

Table 2: CO and NO_2 levels (ppm) in indoor and outdoor air of kitchens

Region	Pollutant	Indoor			Outdoor			I/O Ratio	R^2
		Mean	S.D.	Min-Max	Mean	S.D.	Min-Max		
1	CO	9.7	7.9	3.0-42.3	9.1	4.7	3.3-20.0	1.07	0.78
	NO_2	0.11	0.09	0-0.40	0.07	0.06	0-0.17	1.49	0.48
2	CO	10.5	7.5	1.0-33.0	9.5	6.7	1.3-33.3	1.17	0.74
	NO_2	0.13	0.10	0-0.53	0.05	0.04	0-0.10	2.08	0.86
3	CO	5.4	3.3	2.0-16.7	6.1	3. 1	1.7-13.0	0.94	0.73
	NO_2	0.04	0.06	0-0.2	0.01	0.03	0-0.10	1.33	0.66
4	CO	9.8	12.1	1.0-41.3	8.9	6.6	2.0-26.3	1.0	0.72
	NO_2	0.04	0.07	0-0.20	0.03	0.04	0-0.10	0.75	0.52
5	CO	7.5	6.6	1.0-22.0	5.8	4.3	2.0-20.0	1.28	0.74
	NO_2	0.09	0.09	0-0.47	0.06	0.11	0-0.53	1.25	0.27
Total	CO	8.9	7.6	1.0-42.3	8.1	5.6	1.3-33.3	1.10	0.75
	NO_2	0.10	0.10	0-0.53	0.05	0.06	0-0.53	1.60	0.57

In the study, the range of the average I/O ratios for CO and NO_2 in regions observed were 0.94-1.28 and 1.25-2.08, respectively. Among these two pollutants, CO had an R^2 larger than 0.7 (range of R^2=0.72-0.78), which means that the indoor CO concentration is well correlated with the corresponding outdoor level. NO_2 was less correlated with their corresponding outdoor concentrations (range of R^2=0.27-0.86).

The results CO and NO_2 levels at the indoor kitchens with on and off ventilation system for food cooking are shown in Table 3. The overall temperature ranged from 29°C-48°C, with a mean of 36.6°C, and the overall relative value (RH) ranged from 23-91 percent, with a mean of 67 percent.

Table 3: Environmental conditions in kitchens

Region	Parameter	Mean	S.D.	Min-Max
1	Temperature (ºC)	35.8	2.7	30.5-43.0
	Relative Humidity (%)	62.5	11.8	42.0-84.0
2	Temperature (ºC)	36.9	3.8	31.0-48.0
	Relative Humidity (%)	62.0	19.2	23.0-91.0
3	Temperature (ºC)	35.8	3.4	30.0-47.0
	Relative Humidity (%)	75.5	6.8	65.0-87.0
4	Temperature (ºC)	38.5	3.4	3.05-46.5
	Relative Humidity (%)	76.8	5.0	68.0-85.0
5	Temperature (ºC)	36.3	3.2	29.0-41.5
	Relative Humidity (%)	66.1	11.4	48.0-88.0

DISCUSSION

Restaurant recruitment and field data collection for this project were more challenging than expected. Restaurant owners/managers were reluctant to participate in the study, believing it might interfere with customer service and business, or that it might slow down the servers. Some owners/managers voiced concerns about legal ramifications. Unfortunately, there are only few studies intended to characterize and compare indoor levels of air pollutants identified in different kitchen cooking styles of restaurants. Little data are available on the general understanding of indoor air quality at restaurants. Therefore, we focused on the situation indoor the kitchen: cooking as a source of air pollutants, the presence of different sources of combustion products. Elevated levels of pollutants generated by combustion, particularly nitrogen dioxide and carbon monoxide in indoor spaces, usually result from unvented, improperly vented or poorly maintained combustion appliances. Gas cooking stoves and ovens also release these products directly into the indoor air. Carbon monoxide is only formed during incomplete combustion, which often takes place when the appliances are not well maintained, or when there is not enough fresh air supply (Lebret, 1985). The most extensively studied indoor air pollutant is nitrogen dioxide (Chauhan, 1999), which can be formed during high temperature combustion processes (Brunekreef, 2001). Melia *et al*., (1990) reported that the presence of a gas cooker was associated with significant increases in the levels of NO_2. Using gas for cooking did not lead to significantly higher mean concentrations of NO_2 (Willers *et al*., 2006). The influence of various factors on the NO_2 levels has been studied; the results indicated that the influence of gas cooking was also apparent but less important (Noy, 1987). Dennekamp *et al*., (2001) has reported that very high concentrations of oxides of nitrogen may also be generated by gas cooking. Maximum brief (minutes to 1h) concentrations in kitchens are in the range 0.12–1.09ppm during cooking (Harlos, 1987). In the kitchen, short peak concentrations have sometimes exceeded 100ppm (US EPA, 1991).

The results of this study showed that the mean concentrations of CO and NO_2 with gas stoves for food cooking in restaurant kitchens were below the standard which established as TLV-TWA=25 and 3ppm, respectively by the American Conference of Governmental Industrial Hygienists (ACGIH, 2005).

On comparing average values it was found that indoor CO and NO_2 concentrations were more than the outdoors. The high CO and NO_2 levels were probably due to the use of gas stoves for cooking food in the kitchens. The study of Lee *et al*., (2001) reported that elevated CO level was most likely to be associated with the use of gas stove for hot pot cooking. Also, Lee *et al*., (1999) showed that indoor CO concentrations were systematically higher than those outdoors on weekdays. But measured NO_2 had indoor concentrations lower than outdoor. The trend of increased CO and NO_2 indoor pollution during winter months implies that several factors influence indoor air quality during the winter in addition to outdoor air and meteorological factors. Such factors include indoor activities, duration of human occupancy and inadequate ventilation (Baek *et al*., 1997b).

The results showed that all outdoor CO concentrations were lower than, or approximately equal to recommended limit, established as the 8h primary standard level of 9ppm, by the Environmental Protection Agency- National Ambient Air Quality Standards (US EPA, 2000); also all outdoor NO_2 concentrations were lower than, or approximately equal to recommended limit which established as for outdoor=0.053ppm as the average 24h limit by the same agency (US EPA, 1993).

One of the objectives of this study was to investigate the I/O relationship between indoor and outdoor CO and NO_2 at 5 regions in restaurant kitchens. The I/O ratio is an indicator for evaluating the difference between indoor and outdoor levels, and their correlation can imply a source relationship between indoor and outdoor environments. The I/O ratios of CO and NO_2, were larger than 1 when there were indoor sources. High correlations of these two pollutants in regions were found because indoor air quality at different regions is affected by different indoor sources and some regions are only affected by outdoor sources. The considerably high I/O ratio (2.08) of NO_2 in region 2 might come from the incomplete combustion of gas stove. Lee *et al*., (1999) reported that poor correlation of indoor and outdoor pollutants was obtained because the sources affecting indoor air quality are inconsistent in all public places. Lee *et al*., (2001) show of that the I/O ratios of CO at all of the surveyed restaurants were greater than one. The range of the average I/O ratio in this study was higher than in previous studies (Lee, 1997).

The American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has established guidelines for selected indoor air quality parameters. Temperature and RH together are important determinants of people's perceptions of thermal comfort and ASHRAE guidelines recommend ranges for temperature and RH that most (90% of people) will find comfortable. ASHRAE guideline recommends a 23°C–26°C temperature range and between 30%-60% RH in summer. Relative humidity below 30% is unacceptable because of the effect of dry air on the eyes, skin, and mucous membranes, while relative humidities above 60% may support growth of pathogenic or allergenic microorganisms (ASHRAE, 1992).

The averages for temperature and RH frequently did not meet ASHRAE guidelines in restaurant kitchens (ASHRAE, 1992). 100% of temperature and 69% of RH measurements were above the guideline. Bayer *et al*., (2002) showed that an active humidity system provided better ventilation than systems without active humidity control and led to improved comfort.

In conclusion the present study:

1- Indoor CO and NO_2 concentrations were generally within the ACGIH acceptable ranges.
2- The mean levels of CO and NO_2 indoor were upper than the CO and NO_2, outdoor the restaurants.
3- The mean levels of CO and NO_2 outdoor the restaurants were lower than, or approximately equal to recommended limit which were established by EPA.
4-Average I/O ratios of CO and NO_2 approximately ≥ 1, the indoor air quality, result from the incomplete combustion of gas stove sources.
5- Temperature and relative humidity were generally greater than the ASHRAE guidelines recommended ranges.
6- Generally, improved methods of cooking besides appropriate ventilation of all indoor combustion appliances, including gas stoves, should be adopted in industrial kitchens.

ACKNOWLEDGEMENTS

The study was supported by the Research Grant of the Deputy Research of Tehran University of Medical Sciences. Special thanks to Dr. Kamal Azam, Assistant Professor, Department of Epidemiology and Biostatistics, for the statistical assistance.Finally, the authors thank A. Safari, Z.

Ardaneh and M. Karamkhani for their assistance in the performance of this study.

REFERENCES

American Conference of Governmental Industrial Hygienists., (2005). TLVs and BEIs Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH, Cincinnati, OH.

American Society of Heating, Refrigerating and Air Conditioning Engineers., (1992). Thermal Environmental Conditions for Human Occupancy. Atlanta GA, (ASHRAE Standard 55-1992)

Bayer, C. W., Hendry, R. J., Crow, S. A., Fischer, J. C., (2002). The relationship between humidity and indoor air quality in schools. in: Indoor Air 2002, the 9th International Conference on Indoor Air Quality and Climate, Monterey, Calif. Espoo, Finland: ISIAQ., 818–823.

Brunekreef, B., (2001). NO_2: the gas that won't go away. Clin. Exp. Allergy, **31**: 1170–1172.

Canadian Centre for Occupational Health and Safety (CCOHS)., (2004). Humidex rating and work. http:// www.ccohs.gov/ohs answers humidex.

Chauhan, A. J., (1999). Gas cooking appliances and indoor pollution. Clin. Exp. Allergy, **29**: 1009–1013.

Commission of the European Communities., (1989). Report No. 3 Indoor Pollution by NO_2 in European Countries, Published by CEC, ltaly.

Dennekamp, M., Howartha, S., Dick, C. A. J., Cherrie, J. W., Donaldson, K., Seaton, A., (2001). Ultrafine particles and nitrogen oxides generated by gas and electric cooking. Occup. Environ. Med., **58**: 511-6.

Fischer, P., Brunekreef, B., Boleij, J. S. M., (1986). Indoor NO_2 pollution and personal exposure to NO_2 in two areas with different outdoor NO_2 pollution. Environ Monit. Assess., **6**: 221-229.

Harlos, D. P., (1987). Continuous nitrogen dioxide monitoring during cooking and commuting: personal and stationary exposures. in: Indoor air, 87: Proceedings of the 4th Int. Conference on Indoor Air Quality and Climate. Volatile organic compounds, combustion gases, particles and fibres, microbiological agents. Berlin, Institute for Water, Soil, and Air Hygiene., **1**: 278–282.

Lebret, E., (1985). Air pollution in Dutch homes: an exploratory study in environmental epidemiology, PhD thesis, Wageningen, Wageningen Agricultural University.

Lee, S. C., (1997). Comparison of indoor and outdoor air quality at two staff quarters in Hong Kong. Environ. Int., **23**: 791-797.

Lee, S. C., Chan, L.Y., Chiu, M.Y., (1999). Indoor and outdoor air quality investigation at 14 public places in Hong Kong. Environ. Int., **25**: 443-450.

Lee, S. C., Li, W. M., Chan, L.Y., (2001). Indoor air quality at restaurants with different styles of cooking in metropolitan Hong Kong. Sci. Total Environ., **279**: 181-193.

Melia, R. J., Chinn, S., Rona, R. J., (1990). Indoor levels of NO_2 associated with gas cookers and kerosene heaters in inner city areas of England. Atmos. Environ., **24** B: 177–180.

Mella, R. J., Florey, C., Du, V., Darby, S. C., Palmes, E.D., Goldstein, B. D., (1978). Differences in NO_2 levels in kitchens with gas or electric cookers. Atmos. Environ., **12**: 1379.

Moran, S. E., Strachan, D. P., Johnston I. D. A., Anderson, H. R., (1999). Effects of exposure to gas cooking in childhood and adulthood on respiratory symptoms, allergic sensitization and lung function in young British adults. Clin. Exp. Allergy, **29**: 1033–1041.

Noy, D., (1987): Persoonlijke blootstelling aan NO_2 in Nederland. Publikatiereeks Lucht 62, Ministerie VROM (in Dutch).

Palmes, E. D., Tomczyc, C., DiMattio, J., (1977). Average NO_2 concentrations in dwellings with gas or electric stoves. Atmos. Environ., **11**: 869.

Phillips, S. D., (1997). Outdoor air pollution and issues of quality. in: Occupational Industrial and Environmental Toxicology. Mosby-Year Book, Inc., *pp*: 419.

Slack, H. H., Heumann, M. A., (1997). Use of unvented residential heating appliances—United States, 1988-1994. Morb. Mortal. Wkly. Rep. **46**: 1221-1224.

US Environmental Protection Agency., (1991). Air quality criteria for carbon monoxide. Washington, DC. US Environmental Protection Agency, Office of Research and Development, (publication no. EPA-600/B-90/045F).

US Environmental Protection Agency., (1993). Air quality criteria for oxides of nitrogen: Final Report. U.S. Environmental Protection Agency, Washington, D.C., EPA/ 600/8-91/049aF-cF.

US Environmental Protection Agency., (1996). Air quality criteria for particulate matter. Research Triangle Park, NC: National Center for Environmental Assessment-RTP Office; report nos. EPA/600/P-95/001aF-cF. 3v.

Willers, S. M., Brunekreef, B., Oldenwening, M., Smit, H. A., Kerkhof, M., De Vries, H., (2006). Gas cooking, kitchen ventilation and exposure to combustion products. Indoor Air, **16**: 65–73.

World Health Organization., (2000). Guidelines for air quality, Geneva, Switzerland, published by WHO.