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Carbon Monoxide Concentrations in Kitchens of Gas-fired Burners, Karachi, Pakistan

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Abstract. In this study, gas-fired kitchens of 54 bungalows and 25 apartments were studied using stationary indoor carbon monoxide (CO) monitoring. The levels of CO were measured in each kitchen for a period of 24 h with a 1 min resolution using data logger EL-USB-CO300. Hourly, 8 h and 24 h, CO means for all the kitchens were calculated. Hourly and 24 h CO means of kitchens for bungalows were 3.72±6.26 ppm and 3.72±3.16 ppm, respectively, while those apartments have 3.74±6.96 ppm and 3.74±2.17 ppm, respectively. 8 h CO means of night, day and evening in the kitchens of bungalows were 2.62±3.22 ppm, 4.85±4.66 ppm and 3.53±3.30 ppm, respectively, while in apartments 2.13±2.02 ppm, 3.79±3.86 ppm and 5.29±4.17 ppm. The mean difference between the 8 h CO concentrations during the evening in bungalows and apartments was 1.76±0.87 ppm ($P<0.01$). 20% of kitchens apartment and 16.67% of bungalows which exceeded the WHO guidelines for daily exposure limit.

Keywords: carbon monoxide, indoor pollutant, natural gas, cooking, Karachi

Introduction

Carbon monoxide (CO) is an indiscernible gas since human sensory organs cannot detect its presence even if it is in one's immediate vicinity at a concentration that can be lethal. Consequently, thousands of people are killed annually across the globe due to the inhalation of odourless, tasteless and colourless carbon monoxide contaminated air (Dirlik and Bostancıoğlu, 2017; Tejada-Vera, 2017; Hampson, 2016; Uysal, *et al*., 2013). Many researchers refer to CO as a silent killer (Byrad, 2019; Long and Flaherty, 2017; Yan, 2016). The binding affinity of carbon monoxide with hemoglobin is 200-250 times greater than that of oxygen (Vale and Meredith, 1988), which causes deficiency of oxygen, resulting in many physiological dysfunctions of human organs and organ systems including hypoxia, headache, nervous, respiratory and cardiac complications (Prockop and Chichkova, 2007).

Furthermore, carbon monoxide is one of the most prevalent air pollutants in the indoor and outdoor human environment (Raub, 1999) mainly because it is emitted during fossil fuel combustion, tobacco smoking, burning of firewood, dung cake, charcoal and crop residue. Fossil-fuel-fired cooking appliances are an important indoor source of carbon monoxide emissions in Pakistan. Consequently, the indoor concentrations of carbon monoxide have widely been studied (Cushen *et al*., 2019; Francisco *et al*., 2018; Wilson *et al*., 2018; Christie *et al*., 2016; Fazlzadeh *et al*., 2015; Ochieng *et al*., 2013; Keshishian *et al*., 2012; Mohankumar *et al*., 2012; Dianat and Nazari, 2011; Barnett *et al*., 2011; Ryhl-Svendsen *et al*., 2010; Montoya *et al*., 2008; Ayodele *et al*., 2007; Wilkinson, P., 2006; Croxford *et al*., 2005; Bruinen de Bruin *et al*., 2004; Horner and Hutchings, 2001; Naeher *et al*., 2001) due to the fact that the CO gas causes a wide range of clinical effects on human health.

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In Pakistan, 28,000 deaths and 40 million respiratory diseases are reported annually due to indoor air pollution (World Bank, 2006), which obviously reveals the magnitude of indoor air pollution. However, the published literature on the indoor air quality of urban areas of the country is scarce (Colbeck *et al*., 2010). Siddiqui *et al*. (2009) reported an 8 h daytime concentration of carbon monoxide in 95 kitchens (51 wood and 44 natural gas users) of a semi-rural neighborhood of Pakistan. They found that the kitchens having wood-fired cooking appliances exhibited an arithmetic mean of 29.4 ppm, while those having gas-fired appliances demonstrated arithmetic mean of 7.5 ppm carbon monoxide. Despite many fatalities and indoor air pollution-related issues in the urban areas of the country (Qureshi, 2019; Dawn, 2019 and 2020), ambient carbon monoxide concentrations in the homes, especially in the kitchens of the urban areas have been marginally studied.

The present study investigates the indoor CO concentrations in the kitchens of single-unit bungalows and multistorey apartments, which are located in the central district of Karachi to characterize the indoor CO concentrations of the kitchens.

Material and Methods

Study area. The present study was conducted in the district central, Karachi, which is a city of over 18 million inhabitants. This is the third-largest city on earth (Citymayors Statistics, 2017). It has a moderate subtropical arid climate, having short cool winters and long warm summers.

The study area is located between N24°54′ to N24°58′ and E67°00′ to E67°06′, which is inhabited by the middle to high-income residents of the city (Federal Board Revenue, 2019). The people live both in single-unit bungalows and six to seven storeyed apartments in this area. It is predominantly a residential area. However, the area has many commercial centers, hotels and restaurants, which provide day-to-day needs for the people. The present study investigated the carbon monoxide concentrations in the kitchens of middle-income inhabitants.

Data collection and analysis. We continuously measured ambient carbon monoxide concentrations in the kitchens of randomly selected 54 2/3 room bungalows and 25 2/3 room apartments for 24 h, that is from midnight to midnight by data logger EL-USB-CO300 of Lascar Electronics Ltd., United Kingdom. The device was placed one meter above and half a meter rightward from the stoves on a rack in each kitchen, avoiding any damage to the sensor of the device due to heat or flame. The data logger has an electrochemical metal and oxide sensor that has an expected life of 4 year. The sensor does not need calibration during its expected life. The device uninterruptedly measures and stores the ambient CO concentration ranging from 0-300 ppm with an accuracy of ±4%. It was set to record the reading of every minute with a resolution of 0.5 ppm. The data logger was employed in this experiment to record the CO concentrations of every single minute of 24 h duration, which was, subsequently, interfaced with a computer by EasyLog software to transfer the data in Excel format for analysis.

A total of 1440 measurements of CO gas concentration were recorded in each kitchen all through 24 h since the data logger records and stores the CO concentration with a one-minute interval. Similarly, 480 measurements against every of the 480 min of the night, day and evening CO mean concentrations of every kitchen were separated for the calculation of their 8 h mean values. The data for night mean values were taken from 12:00 midnight to 8:00 a.m., while those of day mean values from 8:01 a.m. to 4:00 p.m. and evening mean values from 4:01 p.m. to 12:00 midnight. Hourly mean was calculated by averaging 60 measurements of every single hour of 24 h. The 8 hourly mean was calculated by averaging 480 measurements of night, day and evening, while the daily mean, was calculated by averaging 1440 measurements, which are compared with WHO guidelines of maximum permissible CO levels for time-weighted human exposure. Percentile of hourly and 8 h means for the kitchens of bungalows and apartments were calculated separately.

Mann-Whitney-Wilcoxon test was applied to determine whether the CO concentration of the kitchens of bungalows and apartments differ significantly, using IBM SPSS version 25. Moreover, CO concentrations between days, nights and evenings of apartments and bungalows were also compared to demonstrate their statistical differences. Kruskal-Wallis test by ranks is applied to determine the statistical difference among the CO concentrations of night, day and morning hours.

Results and Discussion

Box-and-Whisker plot of hourly carbon monoxide concentrations for the kitchens of 54 bungalows are constructed and presented in Fig. 1, while those for the kitchens of 25 apartments are presented in Fig. 2. Hourly mean concentration in the kitchens of the apartments ranged from 0.0 ppm to 64.80 ppm, while those in the bungalows ranged from 0.0 ppm to 59.67 ppm. The higher hourly CO mean in the kitchens of the apartments compared to those in the bungalows may be due to higher outdoor CO concentrations, which are produced by vehicular traffic and roadside catering. Of 600 h CO means that were measured in the apartments, ten hourly means (0.017%) exceeded 30 ppm, the WHO guidelines for a maximum permissible limit of 1 h exposure (WHO, 2010). While of 1296 h CO means, which were recorded in bungalows, eleven hourly means (0.008%) exceeded

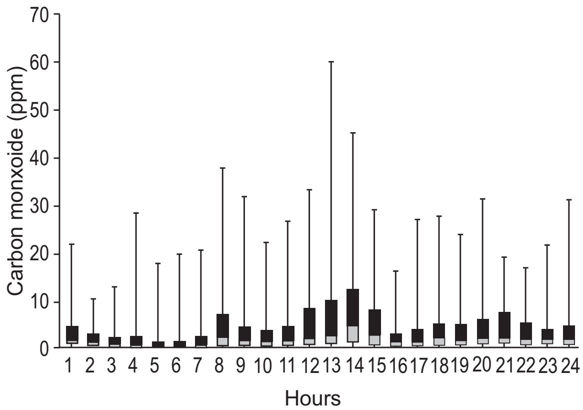

Fig. 1. Box-and-Whisker plot of CO concentrations for each hour in the kitchens of bungalows. It shows median (middle line in the box), upper quartile (end of black box), lower quartile (end of gray box), maximum and minimum values.

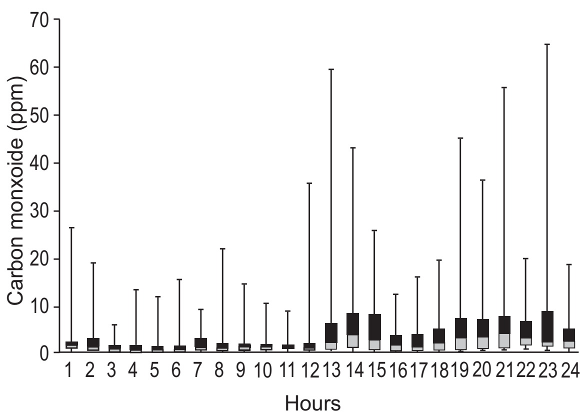

Fig. 2. Box-and-Whisker plot of CO concentrations for each hour in the kitchens of apartments. It shows median (middle line in the box), upper quartile (end of black box), lower quartile (end of gray box), maximum and minimum values.

the WHO guidelines for 1 h exposure. The average of the hourly mean CO concentrations was found to be 3.74±6.96 ppm and 3.72±6.26 ppm in the kitchens of apartments and bungalows, respectively (Table 1). Mann-Whitney-Wilcoxon test demonstrated a non-significant difference (P=0.18) between hourly mean CO concentrations of the kitchens of bungalows and apartments.

Figure 3 presents Box-and-Whisker plots of CO concentrations for the night, day and evening hours in the kitchens of bungalows and apartments. 8-hourly mean concentration in the kitchens of the apartments ranged from 0.13 ppm to 18.60 ppm while those in the bungalows ranged from 0.0 ppm to 18.55 ppm.

Figure 4 shows the 24 h mean of CO concentrations for each kitchen of 25 apartments and 54 bungalows. The 24 h CO concentrations in the kitchens of apartments ranged from 0.94 ppm to 8.53 ppm, while those in the bungalows varied from 0.37 ppm to 12.79 ppm. Five (20%) kitchens of the apartments while nine (16.67%) kitchens of the bungalows exceeded 6.11 ppm, the WHO guidelines of carbon monoxide for a maximum permissible limit of 24 h human exposure (WHO, 2010).

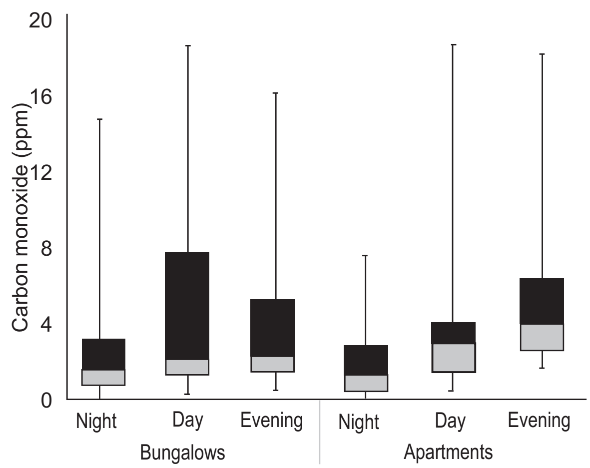

Fig. 3. Box-and-Whisker plot of CO concentrations for night, day, and evening hours in the kitchens of bungalows and apartments. It shows median (middle line in the box), upper quartile (end of black box), lower quartile (end of gray box), maximum and minimum values.

Table 1. Time-weighted average concentration of carbon monoxide (ppm)

Averaging duration	Apartments mean ± SD	Bungalows mean ± SD
1 h	3.74±6.96	3.72±6.26
24 h	3.74±2.17	3.72±3.16
8 h (Night)	2.13±2.02	2.62±3.22
8 h (Day)	3.79±3.86	4.85±4.66
8 h (Evening)*	5.29±4.17	3.53±3.30

*significant difference

The average of the 24 h mean CO concentrations was found to be 3.74±2.17 ppm and 3.72±3.16 ppm in the kitchens of apartments and bungalows respectively (Table 1). Mann-Whitney-Wilcoxon test revealed a non-significant difference (P=0.67) between daily mean concentrations of the kitchens of two different housing categories.

Figure 5 demonstrates the 8 h CO concentrations for the night, day and evening times in the kitchens of 54 bungalows. The 8 h CO concentrations of four (7.41%), eleven (20.37%) and four (7.41%) kitchens exceeded 8.73 ppm during the night, day and evening respectively, the WHO guidelines for a maximum permissible limit of 8 h CO exposure (WHO, 2010). The averages of 8 h mean CO levels of night, day and evening were 2.62±3.22 ppm, 4.85±4.66 ppm and 3.53±3.30 ppm, respectively. Kruskal-Wallis test revealed that the CO concentrations of night, day and evening in the kitchens of bungalows were significantly different (P<0.01).

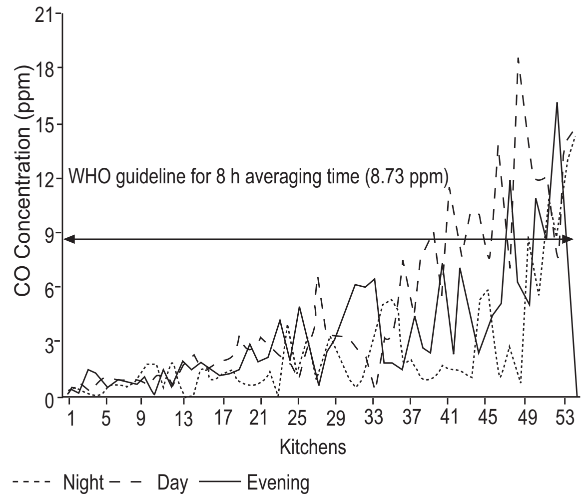

Fig. 5. 8 h mean concentration of carbon monoxide during the night, day and evening in kitchens of 54 different bungalows.

Figure 6 exhibits 8 h mean CO concentration each night, day and evening of the kitchens of 25 apartments. 8-hourly CO means for night hours in the kitchens of all the apartments were below 8.73 ppm, the WHO guidelines for the maximum permissible limit of 8 h CO exposure (WHO, 2010). However, its concentrations exceeded the guidelines in one kitchen (4%) during the day and 3 kitchens (12%) during the evening. The averages of 8 h mean CO levels of night, day and evening were 2.13±2.02 ppm, 3.79±3.86 ppm and 5.29±4.17 ppm respectively (Table 1). Kruskal-Wallis test demonstrated that the CO concentrations of night, day and evening in the kitchens of apartments were significantly different (P<0.01).

Figures 7a and 7b show the percentile of 1 h mean CO concentrations in the kitchens of bungalows and apartments during the night, day and evening hours. The analysis reveals that the CO levels in the kitchens of bungalows were greater during day hours than those

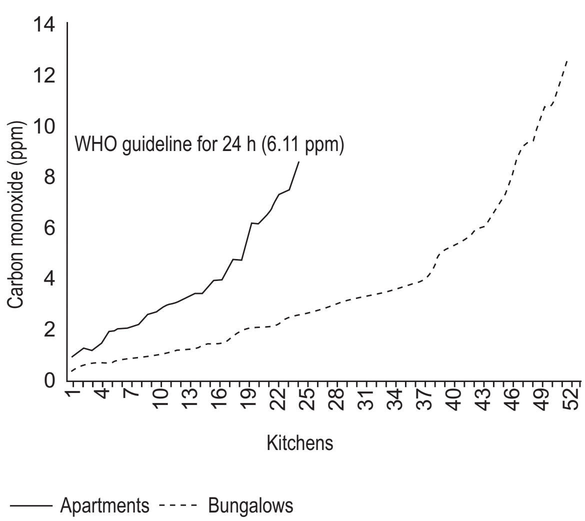

Fig. 4. 24 h mean CO concentrations in 54 kitchens of bungalows and 25 kitchens of apartments.

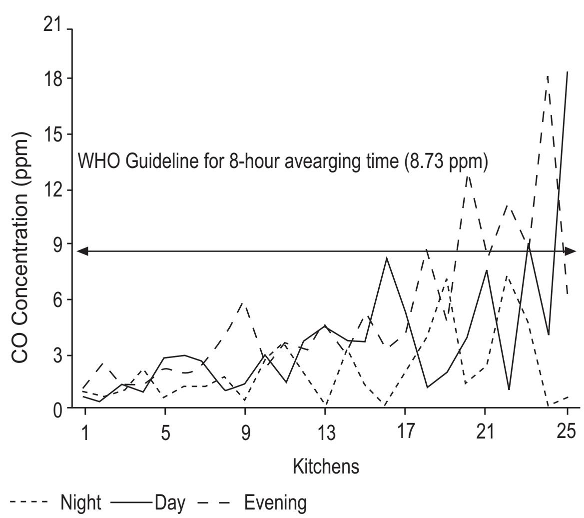

Fig. 6. 8 h mean concentration of carbon monoxide during Night, Day, and Evening in kitchens of 25 different apartments.

in the kitchens of apartments, while the CO levels in both categories of kitchens were lowest during night hours. Figures 8a and 8b demonstrate the percentile of 8 h mean CO concentrations in the kitchens of bungalows and apartments during the night, day and evening hours. The bungalows' kitchen demonstrated the highest percentile during the day hours, while apartments' kitchens showed the highest percentile during the evening hours. The analysis further revealed that the night hours demonstrated the lowest percentile in both categories of kitchens.

The results demonstrate that the indoor air of most of the kitchens of both the bungalows and apartments met the WHO guidelines for time-weighted maximum permissible limits of carbon monoxide for 1 h, 8 h and 24 h exposure. Nonetheless, 20.37% kitchens during day hours and 7.4% kitchens each during the evening and night hours of bungalows exceeded the WHO guidelines (Fig. 5) while only 4% of kitchens during day hours and 12% of kitchens during evening hours of apartments exceeded the WHO guidelines for 8 h (Fig 6). Altogether, the average of all the CO means for

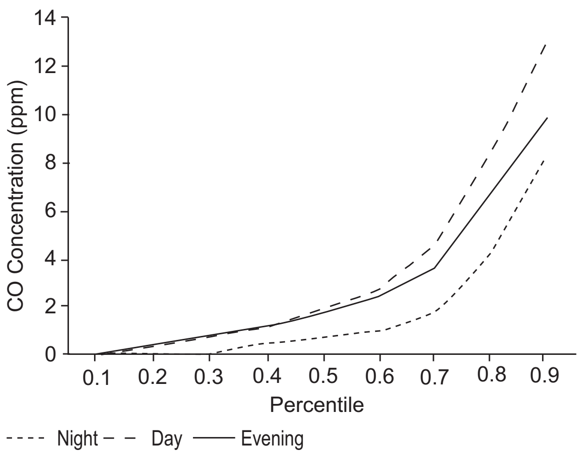

Fig. 7a. Percentile of 432 values each of night, day and evening of 1 h mean concentrations of carbon monoxide in 54 bungalows.

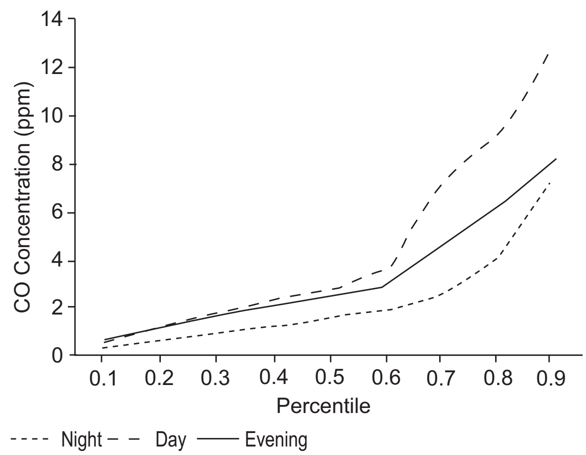

Fig. 8a. Percentile of 54 values each of night, day and evening of 8 h mean concentrations of carbon monoxide in 54 bungalows.

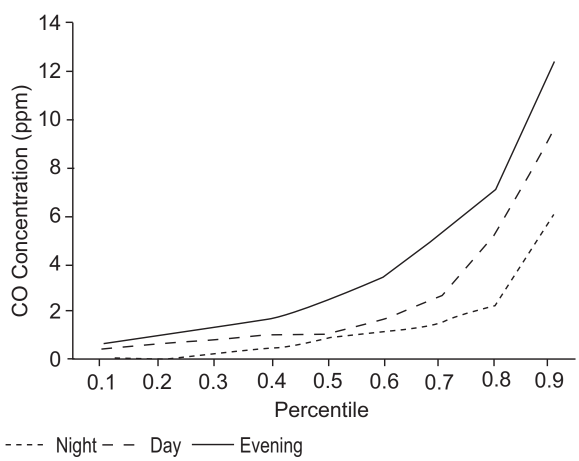

Fig. 7b. Percentile of 200 values each of night, day and evening of 1 h mean concentrations of carbon monoxide in 25 apartments.

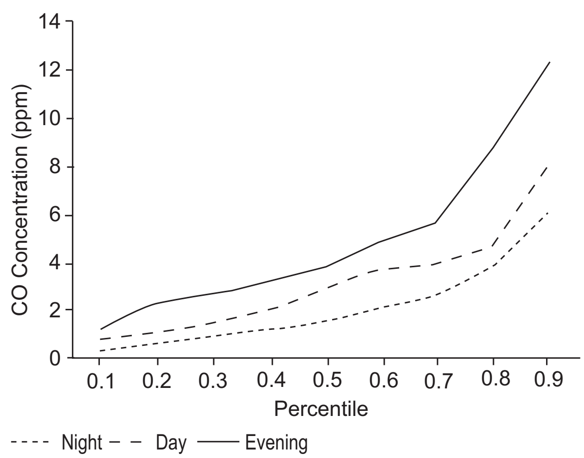

Fig. 8b. Percentile of 25 values each of night, day and evening of 8 h mean concentrations of carbon monoxide in 25 apartments.

1 h, 8 h and 24 h of the kitchens for the bungalows and apartments were lower than the WHO guidelines for a maximum allowable limit of each category (Table 1).

While, comparing different data sets, the Mann-Whitney-Wilcoxon test exhibits the non-significant difference between CO concentrations of the kitchens of bungalows and apartments in both the hourly and daily CO means categories (Table 1). Furthermore, non-significant differences were found between the 8 h day CO means of apartments and bungalows ($P<0.62$) and between their 8 h night CO means ($P<0.76$). However, a statistically significant difference was found between the evening CO 8 h means of the apartments and the bungalows ($P<0.01$).

Kruskal Wallis Test divulges a significant difference among the 8 h CO means of night, day and evening of the apartments ($P<0.01$) as well as among those of the bungalows ($P<0.01$). The highest 8 h mean (5.29±4.17 ppm) was recorded in the evening hours of the apartments' kitchens. However, the same kitchens demonstrated the lowest 8 h mean (2.13±2.02 ppm) during night hours, which may be due to the removal of the indoor polluted air by wind after the closure of burners.

CO concentrations of every single minute of 24 h were measured in the study, which included both the cooking and non-cooking hours. However, the presence of carbon monoxide in some kitchens during non-cooking hours, particularly after midnight, indicates their inadequate ventilation (Croxford *et al*., 2005). Moreover, the cooking activities in the kitchens generally stop at around midnight in the study area. According to Francisco *et al*. (2018), gas-fired appliances appeared to be responsible for elevated CO concentrations usually due to insufficient ventilation. These appliances do not generally raise CO concentrations in properly vented homes.

The higher evening CO concentrations in the apartments' kitchens compared to those in the bungalows may be due to outdoor contaminated air, which is caused by fuel combustion in the motor vehicles and the burning of gas or coal in the restaurants and barbeques (Shams *et al*., 2020; Shams and Beg, 2001). Generally, the apartments are located along the main roads of the study areas while the bungalows are situated on the inner smaller streets. The main roads carry heavy vehicular traffic. Traffic congestion and traffic jam are very common on the main roads along their sidewalks during evening hours due to extensive business activities, particularly cooking and catering. Most of the restaurants and barbecues are located on the ground floor of the apartments. These activities are more common all through the evening hours around apartments compared to those around the single-unit bungalows, which may have increased the indoor CO concentrations in the kitchens of the apartments. The restaurants in the study area generally close their activities at midnight. Moreover, the number of kitchens and the residents per square yard are greater in multi-storeyed apartments than those in single unit bungalows, which may be the cause of greater CO concentrations in the kitchens of the apartments compared to bungalows. These factors were not recorded during our data collection.

Keshishian *et al*. (2012) reported a substantial increase in carbon monoxide concentrations inside the apartments, which were built above restaurants. According to them, charcoal-burning tandoor ovens (traditional cooking method) enhanced the CO levels in the homes built above the restaurants. This traditional cooking method is not uncommon in our study area and may have contributed to raising the indoor CO levels during the evening in the apartments.

For comparing the present analysis, hourly and daily means of the kitchens are not available from any area of Pakistan. Siddique *et al*. (2009) revealed 8 h daytime means of carbon monoxide in the kitchens of a semi-rural area (Rehri Goth), which is located 50 km away from the city. The 8 h CO mean value of the kitchens of Rehri Goth was 7.5±4.4 ppm, which was greater than those divulged in all categories of the present study. In the present study, 5.29±4.17 ppm was recorded as the highest 8 h CO mean value, which was in the apartments' kitchens during evening hours (Table 1). The lower 8 h CO mean values in our study may be due to spacious and ventilated homes and kitchens compared to those in Rehri Goth, where smaller, less ventilated and overcrowded homes appeared to be responsible for a higher 8 h mean of carbon monoxide. Furthermore, the present study was predominantly conducted during summer while Rehri Goth was studied during winter when the ventilation is generally compromised due to cold outdoor air. However, the results of the present study may be compared with those conducted elsewhere (Croxford *et al*., 2005; Horner and Hutchings, 2001), which demonstrated somewhat similar results. However, the indoor-outdoor ratio of CO concentrations of both housing categories was not evaluated since outdoor CO concentrations were not measured in the current study.

Conclusion

In the present investigation, we found that more than 80% of kitchens of the bungalows and apartments met the WHO guidelines of carbon monoxide for maximum time-weighted permissible limit for 1 h, 8 h and 24 h human exposures. However, CO concentrations in some kitchens were substantially higher in both the housing categories for all the time-weighted categories. The higher CO levels in some kitchens may be because of their inadequate ventilation or outdoor contaminated air. Furthermore, the kitchens of the apartments demonstrated the highest 8 h CO concentrations during evening hours, which may be due to greater fossil fuel-related business activities within and around the apartments such as roadside catering and higher vehicular traffic. Appropriate ventilation of kitchens may reduce their CO concentrations to meet the guidelines for getting out of any health-related risk. The outdoor CO concentrations can be reduced by decreasing the vehicular traffic jam and catering activities around the apartments.

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