Preliminary Assessment of Indoor Air Quality in Terrace Houses

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ABSTRACT: Four terrace houses in Shah Alam were chosen for preliminary investigation of indoor air quality in residential buildings. The concentrations of carbon dioxide (CO_2), carbon monoxide (CO) and particulate matters (PM_{10}) in indoor of houses were determined. The effects of temperature, air velocity and relative humidity on the indoor air quality were also investigated. The results indicated that all of the average indoor concentrations of CO, CO_2, and PM_{10} at the naturally ventilated residential buildings were below the limits of Malaysian guideline standards except for the indoor climate parameters. The indoor/outdoor ratios concentration of all air pollutants were found to be below one which indicates that outdoor air influences indoor air.

Keywords: Carbon monoxide, carbon dioxide, particulate matter, indoor air quality, terrace house

Introduction

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, its significance especially being its relation to the health and comfort of building occupants. In recent years, scientists and the public have put much concern about indoor air quality, since most people spend their time more than 70 - 90 % indoors (e.g. office, workplace, school, house) (Sharpe, 2004; Triantafyllou *et al.*, 2007). Many studies have found indoor pollution levels to be greater than outdoor levels (Montgomery and Kalman, 1989). Indoor air pollution has occurred since prehistoric times when people moved to live indoors and fire was brought into closed shelters for cooking and space heating (Godish, 1991).

The sources of an air pollutant is one of the factors that contribute to indoor air quality problems. Indoor air pollutants originate from a range of potential sources including cooking, smoking, vacuuming, sweeping and ventilation system. Besides, design, operation and maintenance of a building ventilation system are also considered to be the contributing factors to indoor air pollution (Gang *et al.*, 2005).

Outdoor sources may also contribute to indoor concentrations of a number of air pollutants commonly found in indoor air. Major outdoor sources of pollutant may come from traffic, industrial, construction and combustion sources (Cohen, 2000). The effect of outdoor air on the indoor air quality of a building becomes more significant when the building is situated in an urban area and is close to an industrial zone or street with heavy traffic (Li, 1994).

Maintaining good air quality of residential building environment is essential to the sick, the young and the elderly person because they spend most of their time indoor (Lee et. al., 2002; Zain-Ahmed *et al.*, 2005) and continuous monitoring of indoor air quality of residential building is particularly very important in order to understand how well the building is performing overall to mentioned occupants above. In Malaysia, there are guidelines (code of practice on indoor air quality) for indoor air quality and exposure standards to protect workers (DOSH, 2005), but no guidelines have yet been developed that apply specifically to the domestic environment (residential building).

Indoor air quality in a hot and humid climate country is a relatively new issue. Limited data is available on the general understanding about present indoor air quality of tropical regions especially for residential buildings. It is therefore important that indoor air quality be given more attention and further studies be conducted to assess the indoor air quality. Besides, the residential building in tropics can be very different from those in cool climate or temperate region. Investigation of air quality at terrace houses may be useful to characterize and for subsequent implementation of corrective measures if necessary.

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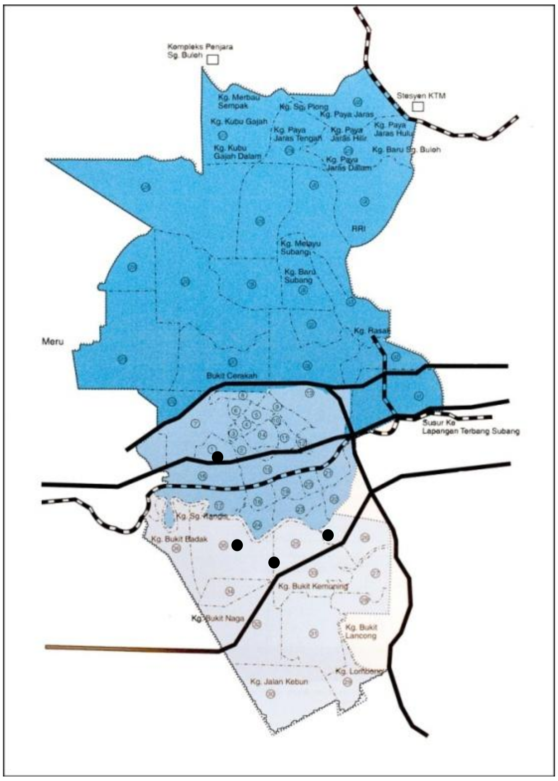
The aims of this paper are to characterize air pollution level at selected terrace houses in Shah Alam, Selangor and to compare the measured concentrations with established standards.

Methodology

Sampling Sites

This study was conducted in selected double storey terrace houses in Shah Alam, the capital city of Selangor State. Shah Alam has experienced a rapid urbanization and industrialization in the last decades, with population estimated about 600,000. The houses chosen in the study were located within a 20 km radius of the Shah Alam city in order to keep external environmental factors constant. These houses were located at four different areas; house 1 -Section 7, house 2 – Section 17, house 3 – Section 20 and house 4 – Section 24 (**FIG. 1**). The terrace houses have opposite sides exposed to the environment while the remaining two sides share common walls with the adjacent houses.



Legend: • Site sampling

FIG. 1- Shah Alam map and site sampling

The living rooms of all the houses selected were ventilated by natural ventilation through open windows or mechanical ventilation using fan.

Sample collection and analysis

Monitoring was conducted in living rooms for a 2-3 days for a period of 8 hours in each house from 9.00 am to 5.00 pm. Air velocity, CO and CO_2 were measured every 10 min using Graywolf IQ-410 and Graywolf AS-202A probe. Except for PM_{10}, all the other parameters were sampled utilizing grab sampling technique. The indoor climate parameters were also measured in each house. The parameters measured were indoor air temperature, relative air humidity, and air velocity. The air sampler instrument was placed vertically at a height of 1.2 m, at least 1 - 2 m away from any obstacle in order to avoid potential interferences during sampling. As far as possible, the air sampler instrument was located at the centre of living room inside the house. During the periods of air sampling, each of the monitored houses was occupied. The fan in living room was switched on when occupants spent their time in this area.

Samplings for PM_{10} were conducted by collecting the particulate matter onto 0.45 mm diameter filter papers by using Air Metrics mini-volume air sampler which was runs at a constant flow rate of 5 L/min. All the data obtained were subjected to descriptive statistical analysis including mean; standard deviation; maximum; minimum and analysis of variance (ANOVA) using statistical functions in Microsoft Excel and Statistical Packages for the Social Sciences (SPSS).

Results and Discussions

Indoor Climate

TABLE 1 shows the descriptive statistical data of temperature, relative humidity and air velocity for the four terrace houses. The range of mean values of indoor temperature for all houses was 27.2-30.6 ^{o}C, while the relative humidity and air velocity were 70.0-78.6 % and 0.00-0.01 ms^{-1}, respectively. Currently there is no guideline standard limit for indoor air quality for residential building in Malaysia. **TABLE 2** shows recommended standard and guidelines for indoor air quality for office building in three different countries. Compared to these guidelines or standards, the results indicated that the mean temperature, relative humidity and air velocity measured in each living room of each house were above the recommended range for acceptable indoor air quality level suggested by Singapore guidelines standard (1996).

TABLE 1- Descriptive statistics of indoor climate parameters during the measurement period

Parameters	Mean ± SD	Min	Max
Temperature (°C)			
House 1	29.1 ± 0.83	27.5	30.5
House 2	30.6 ± 2.15	26.5	33.0
House 3	29.6 ± 0.62	28.4	30.7
House 4	27.2 ± 0.15	26.6	27.4
Overall	*29.1* ± 1.42	*26.5*	*33.0*
Relative Humidity (%)			
House 1	70.0 ± 3.58	63.7	77.2
House 2	74.0 ± 4.28	68.4	86.1
House 3	67.1 ± 2.22	63.6	72.0
House 4	78.6 ± 1.88	76.4	84.4
Overall	*72.4* ± 4.99	*63.6*	*86.1*
Air velocity (ms^{-1})			
House 1	0.01 ± 0.01	0.00	0.03
House 2	0.01 ± 0.02	0.00	0.09
House 3	0.01 ± 0.01	0.00	0.03
House 4	0.01 ± 0.01	0.00	0.02
Overall	*0.01* ± 0.01	*0.00*	*0.09*

Note: SD – Standard deviation

TABLE 2- Recommended indoor air quality standard and guideline

Indoor air quality parameter	Malaysia[1]	Singapore[2]	Hong Kong[3]
Carbon dioxide, (ppm)	1000	1000	800 - 1000
Carbon monoxide, (ppm)	10	9	1.7 – 8.7
Respirable particulates (PM_{10}), (mgm^{-3})	0.15	0.15	0.02 – 0.18
Air Temperature, °C	-	22.5 – 25.5	-
Relative Humidity, %	-	70	-
Air velocity, m/s	-	0.25	-

[1] Department of Occupational Safety and Health, 2004
[2] Institute of Environmental Epidemiology, 1996
[3] Government of the Hong Kong Special Administrative Region, 2003

The climate of Malaysia in the tropical region with hot and humid condition may affect the indoor climate of terrace houses (Md Zain *et al.*, 2007). **FIG. 2** shows the indoor temperature and relative humidity profile in the selected terrace houses.

Indoor temperature was lower and relative humidity was higher for House 4 (**FIG. 2 (d)**) compared to other houses due to different weather during the measurement period. During rainy day, outdoor temperature decreases and relative humidity increases and similar pattern also are true for indoor climate in a natural ventilated building (Ismail *et al.*, 2010). In general, the indoor temperature profile increases slightly from morning to evening, while the trend is reversed for relative humidity.

Most of the natural ventilated terrace houses rely on the combination of cross-ventilation and mechanical ventilation by fan to reduce the extra heat going into a house and to achieve indoor thermal comfort. However, the findings of this study show that this ventilation strategy was difficult to achieve a good indoor climate in a terrace house type building. One of the ways the performance of indoor climate can be improved is by modifying the ventilation such as installing a solar chimney in the terrace houses (Nugroho, 2011).

Indoor Air Quality

The descriptive statistical data of CO, CO_2 and PM_{10} obtained from four different terrace houses in Shah Alam are given in Table 3. Figure 2 shows carbon dioxide (CO_2) and carbon monoxide (CO) profile in selected terrace houses. The mean concentrations at four houses range from 0.1 - 0.3 ppm, 442.64 – 549.57 ppm and 94 – 124 μgm^{-3} for CO, CO_2 and PM_{10}, respectively. The maximum value of CO was measured at House 1 with 0.90 ppm, follow by House 3, House 2 and House 4 with value of 0.60, 0.55 and 0.45 ppm, respectively. The highest concentration of CO at House 1 is due to smoking activities by the resident.

The other potential CO indoor sources was the gas stove usage in the kitchen, which was observed during the sampling period. However, the measurement was conducted in a living room, therefore it can be suggested that the sources of CO may have come from the incomplete combustion process, vehicle exhaust fume from nearby road and parking space that infiltrated into the house through the open windows and doors. The windows of all terrace houses in this study were open during day time to provide fresh air and simultaneously bring the outdoor pollutants such as CO into the building. The presence of CO in the terrace houses building may be related to the external sources such as vehicular exhaust from the nearby road. The concentration of CO in the terrace houses did not exceed the maximum limit (10 ppm) recommended by DOSH (2005).

The recommended values for CO_2 exposure was 1000 ppm for an 8-hour period as indicated by DOSH (2005), Singapore (1996) and Hong Kong (1996) for indoor air quality standards. The average concentration of CO_2 for all terrace houses did not exceed the recommended standard level. The concentrations of CO_2 were influenced by the number of occupants as the primary source of CO_2 is the human respiration in terrace houses.

The maximum concentration of CO_2 measured was in House 1 (701 ppm), while the minimum concentration of CO_2 in House 2 (317 ppm). House 1 and House 4 were occupied by seven occupants compared to House 2 and House 3 with four and five occupants, respectively.

TABLE 3- Descriptive statistics of indoor air quality parameters during the measurement period

Parameters	Mean ± SD	Min	Max
Carbon Monoxide (ppm)			
House 1	0.31 ± 0.24	0.00	0.90
House 2	0.24 ± 0.13	0.05	0.55
House 3	0.12 ± 0.21	0.00	0.60
House 4	0.25 ± 0.14	0.00	0.45
Average	*0.23* ± 0.07	*0.00*	*0.90*
Carbon Dioxide (ppm)			
House 1	539.64 ± 57.88	469.60	700.50
House 2	442.64 ± 60.79	317.00	549.50
House 3	493.25 ± 17.79	471.00	567.33
House 4	549.57 ± 19.63	504.50	581.50
Average	*506.28* ± 49.02	*317.00*	*700.50*
Particulate Matter (μgm^{-3})			
House 1	124.0 ± 16.26	106.0	137.0
House 2	94.0 ± 15.39	81.0	111.0
House 3	111.0 ± 9.87	100.0	118.0
House 4	104.0 ± 16.26	91.0	122.0
Average	*108.3* ± 12.60	*91.0*	*137.0*

Note: SD – Standard deviation

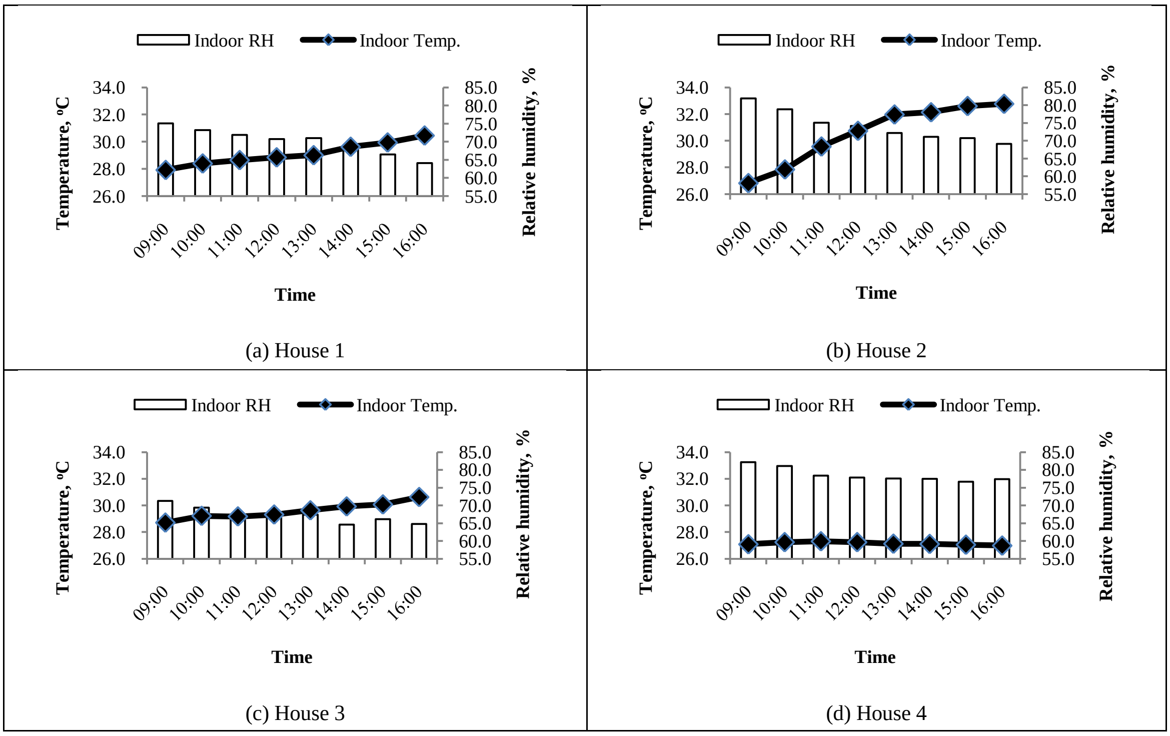


FIG. 2- Indoor temperature and relative humidity (RH) profile in selected terrace houses

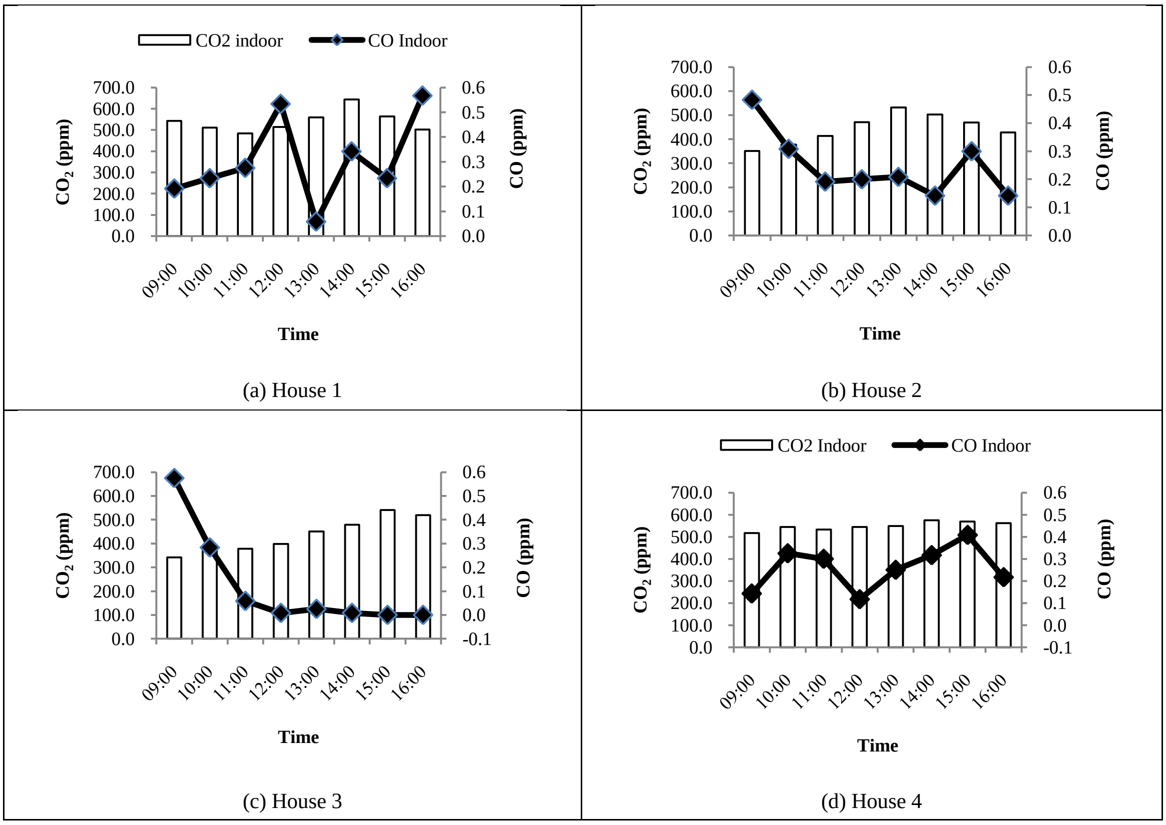


FIG. 3- Indoor carbon dioxide (CO_2) and carbon monoxide (CO) profile in selected terrace houses

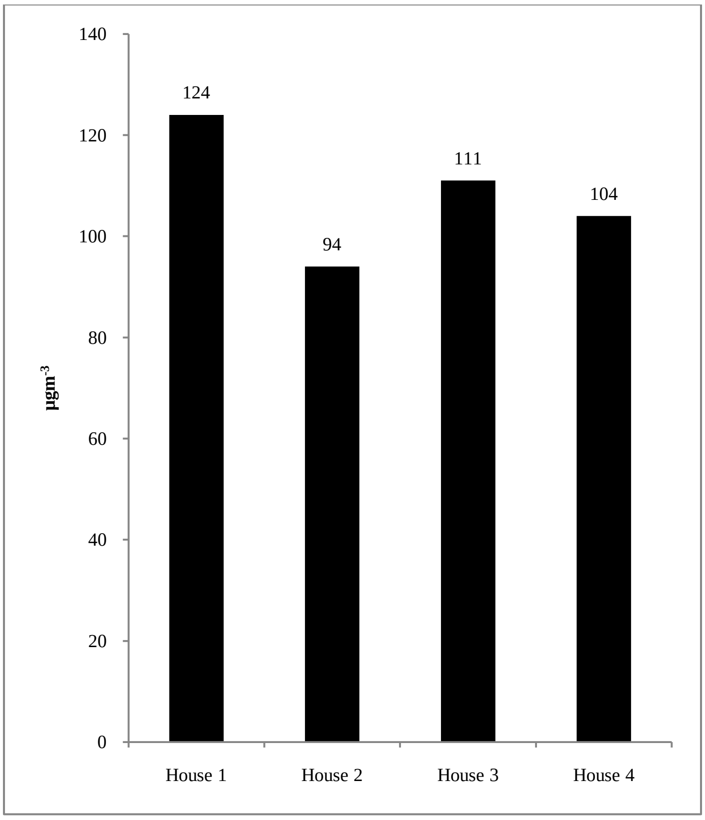


FIG. 4- Mass concentration of indoor PM_{10} in selected terrace houses

House 1 and House 4 have the same density of occupants, but CO_2 concentration at House 1 was higher than the House 4 due to the different volume size of living room. The volume size of living room at House 1 was 939.4 m^3, smaller than living room at House 4 (1125.6 m^3). The smaller room with poor ventilation facilitates the build-up of the level of CO_2 as compared to room with the same size but with good ventilation.

Figure 3 shows the concentrations of particulate indoor at selected terrace houses. The value fell within the range of 94 μgm^{-3} - 124 μgm^{-3} and was within the recommended value by DOSH (2005), Singapore (1996) and Hong Kong (1996) for indoor air quality standard. The highest mean concentration of PM_{10} (124 μgm^{-3}) was measured at House 1 while the lowest concentration (94 μgm^{-3}) was at House 2. The highest mean value of House 1 was related to environmental tobacco smoke (ETS) due to the smoking activity by the occupants. Study has shown that each cigarette smoke on average added about 1.0 $\mu g/m^3$ to indoor PM_{10} mass concentration (Breysse *et al.*, 2005). Other factors which may contribute to mass concentration of indoor PM_{10} were location of the house, ventilation system, number of occupants and their activity, and also the quality of ambient air (outdoor air).

Although the CO, CO_2, and mass concentration value varied from house to house, statistical analysis shows that there is no significant difference from each other.

Conclusion

The indoor climate including temperature, relative humidity and air velocity were identified as major problem affecting indoor air quality of terrace houses. The indoor climate parameters measured in living room of terrace house did not comply with the recommended values. The indoor 8-hours average of CO, CO_2 and PM_{10} concentrations in the terrace houses were below the recommended indoor air quality standard. Factors which may have contributed to indoor air quality of the terrace houses in this study were location of the house, ventilation system, number of occupants and their activity, and also the quality of ambient air (outdoor air).

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