Thermal Environmental Conditions and Indoor Air Quality in a Primary School Located Close to an Industrial Zone in Northern Peninsular Malaysia

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Abstract: ***This paper presents a work of field measurements on thermal environmental conditions and indoor air quality factors in a primary school located near an industrial zone in Northern Peninsular Malaysia. In this study, four rooms were chosen, and measurements were performed for eight hours from October 2014 to November 2014. The thermal environmental conditions and indoor air quality parameters were measured following class-II protocol of field measurements. This includes measurements of air temperature, globe thermometer temperature, average radiant temperature, relative humidity, air movement, particulate PM_{10}, carbon dioxide and airborne bacteria. Results were analysed and compared with existing standards on thermal environmental conditions and indoor air quality: Malaysia Code of Practice on Indoor Air Quality 2010 DOSH Malaysia; ASHRAE Standard 55; Singapore Indoor Air Quality Standard and ISO Standard 7730.***

Keywords: thermal environmental conditions, indoor air quality, primary school

1. Introduction

Indoor environmental quality (IEQ) in buildings is very important because most people spent approximately 90% of their time indoors [1]-[2]. IEQ refers to the quality of a building's environment in relation to the health and wellbeing of occupants which is determined by many factors including thermal environmental conditions, indoor air quality (IAQ), lighting and acoustic comfort. Amongst these factors, thermal environmental conditions and IAQ are amongst the important factors as it directly impacts the occupants' comfort level and health, especially in tropical climate [3]. A good thermal environmental is essential for an occupant which is related to thermal comfort. By definition, thermal comfort refers to *"that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation"*, while thermal environment is defined as *"the characteristics of the environment that affect a person's heat loss"* [4]. From these two definitions, it can be seen that there is interconnectedness between thermal environmental conditions and occupants' thermal satisfactory which would affect their performance and productivity in an indoor environment. Besides, good IAQ is a necessity to human life in giving a guarantee to the comfort of living. Thermal environment, in terms of thermal comfort is a key factor that can affect occupants' comfort, health and performance [5] which there is a contact of the thermal interaction between the body and surrounding environment including school pupils [6]. In thermal comfort, generally, there are six factors that dissemble thermal interaction, such as humidity, air speed, surrounding temperature, air temperature, metabolic rate and clothing insulation [7]. The first four factors are the thermal environmental conditions while the other two represent the personal variables.

Good or poor IAQ is indicated by the level or concentrations of several indoor air pollutants or parameters in which poor IAQ would contribute to indoor air pollution problems and sick building syndrome (SBS) in indoor environment. Indoor air pollution has been classified by World Bank as one of the most critical global environmental problem in developing countries. Human exposure to indoor pollution is highly probable to cause adverse health impacts as indoor air pollutant concentration is typically higher than outdoor air pollutant concentration [8]. In buildings, indoor air pollutants comprise of several parameters in terms of biological, physical, chemical contaminants and adequacy of ventilation. IAQ is much related to occupants' thermal comfort. Carbon dioxide (CO_2) is one of the IAQ factors, acts as a ventilation indicator that helps to ensure ventilation systems delivers the recommended minimum quantities of outside air to building occupants. The indoor CO_2 concentration acts as a replacement of the ventilation levels per occupant as well as for the indoor bio effluents concentration such as body odours [9]. Another research also has proven that low ventilation rates (high concentration of carbon dioxide) can affect people in reducing their performance [10]. Besides, frequent exposure to indoor pollution may pose long and short term health effects to pupils and staffs, decrease levels of performance, disrupt the learning environment and pupils comfort [11]–[13]. Therefore, it is important to have an adequate carbon dioxide concentration and enough quantity of fresh air by occupants. In addition, good ventilation system and maintenance will contribute to thermal comfort by controlling temperature and humidity and spread an adequate amount of air to occupants thus help in removing pollutants [14]. Therefore, optimal indoor environment is necessary for building occupants [3]. This study aimed to determine the concentration of indoor air pollutants at selected primary school close to an industrial area, and assess the measured levels by comparing with existing standards.

2. Methodology

2.1 Site Description

This study was carried out from October 2014 to November 2014 in a primary school located close to an industrial area in Northern Peninsular Malaysia. Four rooms were selected: classroom (CR), office (O), laboratory (L) and canteen (C). In order to obtain comprehensive information about the study area, preliminary data was collected in relation to physical characteristics of each room (Table 1).

Table 1: Physical characteristics of each room

	O	C	L	CR
Floor area (m^2)	38	154	87	64
Level of the room	1	Ground floor	1	2
Mode of ventilation	Ceiling fan	Ceiling fan	Ceiling fan	Ceiling fan

2.2 Field Measurements

Measurements of thermal environmental conditions and IAQ parameters were carried out in each room following standard class-II protocol of field measurement. Air temperature (T_a), globe thermometer temperature (T_g), average radiant temperature (T_r), relative humidity (RH), air movement, respirable particulate matter (PM_{10}) and carbon dioxide (CO_2) were monitored for eight-hour [15] while airborne bacteria samples were collected three times within the eight-hour period. Sampling equipment was placed at 1.2 m above floor level. A portable temperature and relative humidity system (Delta OHM, model 32.3 with accuracy of 1/3 DIN for temperature and ±2.5% for relative humidity) was used to measure thermal environmental conditions: air temperature (T_a), globe thermometer temperature (T_g), average radiant temperature (T_r), relative humidity (RH) and air movement. In order to measure CO_2 concentration, a carbon dioxide sensor/monitor (Telaire 7001 sensor: 0- 4000 ppm with ± 50 ppm measuring accuracy) connected to temperature and relative humidity with built-in data logger (Onset, 10573988) was used. PM_{10} samples were collected on a glass microfiber filter (47 mm, Whatman), using a portable air sampler (MiniVol Airmetrics). The mass concentrations of particulate matter were then determined by gravimetric analysis based on the NIOSH Method 0600. The filter papers were weighed using an analytical balance (OHAUS, with accuracy of 10 µg). Passive air sampling method was applied to collect airborne bacteria samples In this method, petri dishes containing agar nutrient media (Tryptic Soy agar media) were exposed at each sampling point for five minutes and then agar plates were incubated at 32ºC for 48 hours. Prior to measurements of PM_{10} and airborne bacteria, field blank samples were prepared for quality assurance of the collected data and all equipment were calibrated in accordance with the manufacturer's recommendations.

3. Results and Discussion

The assessment of thermal environmental conditions is summarised in Table 1. Average globe thermometer temperature ranged from 28.2 ºC to 29.9 ºC in office, from 28.0 ºC to 29.7 ºC in canteen, from 28.0 ºC to 29.5 ºC in laboratory, and from 28.4 ºC to 29.8 ºC in classroom. Average radiant temperature ranged from 27.6 ºC to 29.6 ºC in office, from 27.8 ºC to 29.7 ºC in canteen, from 28.7 ºC to 29.8 ºC in laboratory, and from 28.4 ºC to 29.4 ºC in classroom. From this assessment, it was found that the air temperature, relative humidity and air movement in all rooms were exceeded the recommended range of the ASHRAE Standard 55 [4]. Thus, to ensure a comfort level in the room which would impact the productivity and performance of primary school pupils [6], a standard that provides minimum requirements for acceptable thermal indoor environment should be complied. Too high relative humidity can affect the growth and spreading of airborne microbes especially without adequate ventilation systems [16].

Table 2: Summary of the assessment for thermal environmental conditions

Parameter	O	C	L	CR	ASHRAE Standard 55
Air temperature, ºC)	28.67	28.86	28.9	29.25	22.5 - 26.0
RH, %	75.55	76.26	70.5	73.17	30 - 60
Air movement, ms^{-1}	0.41	0.34	1.11	0.56	<0.25

The levels of PM_{10} measured in each room are shown in Figure 1. It was found that the measured particle levels were different in each room. The PM_{10} levels in this study were in a range of 24 to 203 µg/ m^3. The recommended threshold level for respirable particulates (for particulate ≤ 10 µm) in the Malaysian Code of Practice on Indoor Air Quality [17] is 150 µg/m^3. While recommended acceptable average level for respirable airborne particles in Singapore Indoor Air Quality Standard [18] is less or equal than 50 µg/m^3. High level of PM_{10} was recorded in the laboratory compared to other rooms. This was most probably due to infrequent housekeeping activity in which coincides with a study done in [14]. It was found in the study that infrequent housekeeping activities were one of the causes of a high concentration of indoor PM_{10}. However, further investigation needs to be carried out in the future to thoroughly study the impact of housekeeping activities on PM_{10}.

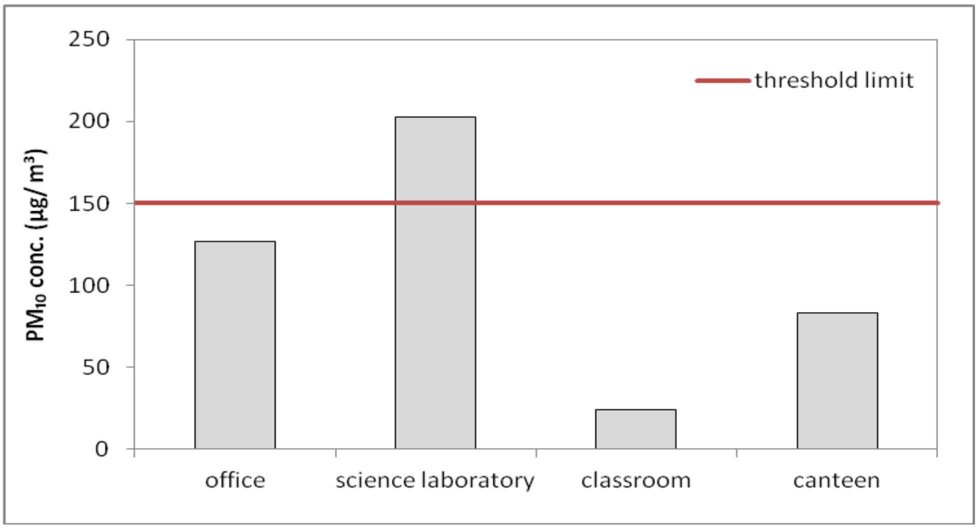

Figure 1: PM_{10} concentration in each room

It was recorded the average CO_2 levels in all rooms were below 1000 ppm which complied with the recommended value for CO_2 exposure for 8-hour period prescribed by Malaysian Code of Practice on Indoor Air Quality [17] and ASHRAE Standards 62 [19]. The CO_2 level ranged from 361 ppm to 658 ppm (Figure 2). There was a slightly difference in CO_2 level between rooms especially during school hours. This was due to the difference in numbers of occupants in each room. The concentration of CO_2 is normally associated with human occupancy [20]-[21], closing of doors and windows activity [12], [22]. High level of CO_2 also used to indicate an inadequate ventilation in the building [22].

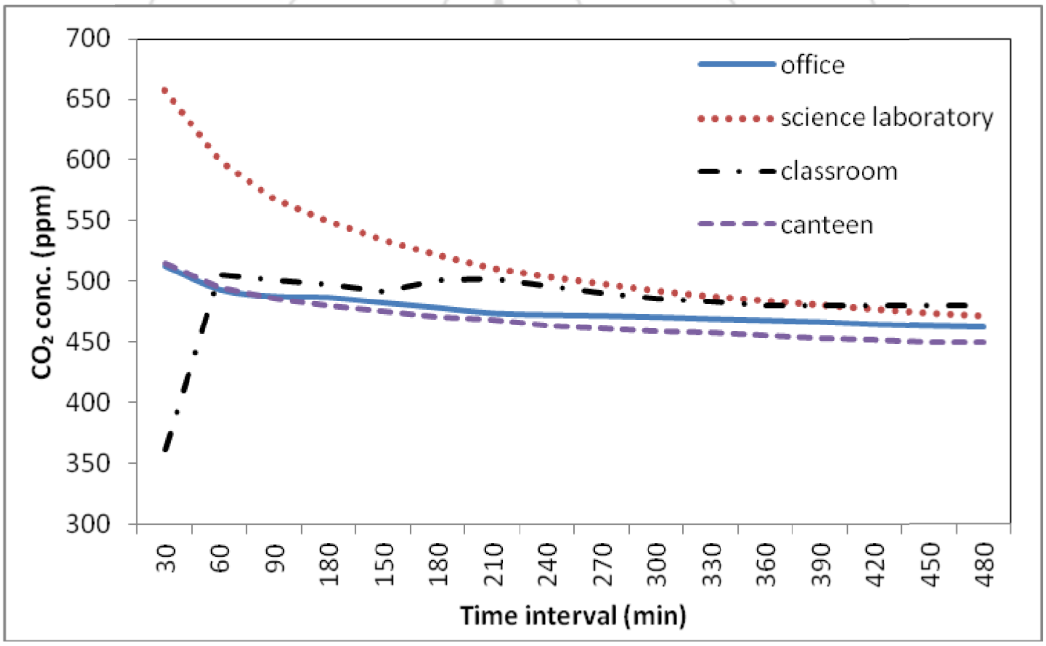

Figure 2: CO_2 concentration in each room

Table 3 shows the total bacteria count in each room sampled three times within the eight-hour period. It was observed that the average total bacteria count in all rooms were below the recommended acceptable limit of 500 CFU/m^3 in the Malaysian Code of Practice on Indoor Air Quality [17] and Singapore Indoor Air Quality Standard [18].

Table 3: Total bacteria count in each room

	O	**C**	**L**	**CR**
8 a.m.	38 CFU/m^3	96 CFU/m^3	19 CFU/m^3	19 CFU/m^3
10 a.m.	115 CFU/m^3	77 CFU/m^3	77 CFU/m^3	134 CFU/m^3
12 a.m.	38 CFU/m^3	115 CFU/m^3	115 CFU/m^3	96 CFU/m^3

4. Conclusion

The averages of thermal environmental conditions in terms of air temperature, relative humidity, and air movement in all selected rooms were above the recommended acceptable level prescribed in ASHRAE Standard 55. PM_{10} was found to be significant higher in laboratory which exceeded the recommended threshold level for respirable particulates (for particulate $\leq$ 10 µm) in the Malaysian Code of Practice on Indoor Air Quality. Control measures need to be taken in the future to ensure a comfort level in the rooms is achieved as the thermal environmental conditions would affect performance and progress of school pupils. In addition, further investigations need to be carried out in the future i) to assess the thermal comfort in the primary schools by considering both objective (thermal environmental conditions) and subjective measurements (personal factors); ii) to analyse the relationship between thermal environmental conditions and IAQ parameters.

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