Investigation of the Impact of Ventilation Scenarios on Air Exchange Rates and on Indoor/Outdoor Particle Concentrations in Lecture Room

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Abstract:
Indoor air quality (IAQ) is a term referring to the air quality within buildings and it relates to the health and comfort of building occupants. Indoor air is becoming an increasingly more concerning health hazard than outdoor air because people spend more time indoor. Ventilation scenarios are important for indoor dilution of contamination. There are five investigated scenarios involve in this study (ceiling fan plus air-conditioning, windows only, windows plus ceiling fan, ceiling fan only and air-conditioning only). Six parameters investigated in each scenario consist of the air exchange rates (ACH), less than 10 microns in diameter particle concentrations (PM_{10}), CO, CO_2, relative humidity and temperature. Each scenario has different ACH and the indoor/ outdoor particles concentration ratio was calculated and its relation with ACH was determined. The results of this study shows an expected increased of indoor/outdoor particles concentration ratio in the investigated scenarios accordingly.

1. Introduction

Particulate matter (PM) concentration in indoor air environment cause harmful health effects because it can easily penetrate into the lungs (e.g. respirable particles). Several studies found that indoor airborne particles might have harmful health effects on humans such as aggravated asthma, difficult breathing and coughing. [1]. People spend most of their time in different indoor environments (e.g. homes and offices), great consideration has been given by researchers to such environments.

The quality of air in classrooms is also very important due to the large amount of time teachers and students spend inside such space [2]. Lecture room represents high occupancy rooms [3]. A previous study has shown that the indoor air quality in a university lecture room was poor during occupancy periods [4]. However, investigations regarding PM concentrations are limited in such premises. It has been estimated that more than 50% of students have some kind of allergy or asthma, and therefore, there is a great reason to consider adequate ventilation in lecture room [4].

There are a number of factors affecting particle concentration in classrooms including indoor and outdoor metrological parameters such as air change rates and human-related activity.

This study is conducted to investigate the effect of ventilation scenarios on air exchange rates on indoor/outdoor particles concentration in UTHM lecture room.

According to recommended Malaysian Air Quality Guidelines, the CO level must not exceeding 9 ppm, CO_2 (for 8 hour) not exceeding 1000 ppm and PM_{10} not exceeding 50 µg/m^3 . The results of the study for relative humidity (RH) and temperature were compared to the Singapore Indoor Air Quality Guidelines (SIAQG). RH is between 40% to 60% and temperature level between 22.5 ^{0}C to 25.5 ^{0}C. The ACH guidelines range between 4h-1 to 12h-1 for classroom.

2. Methodology

This study was carried out at Geology Laboratory, University Tun Hussien Onn Malaysia (UTHM). It located at Parit Raja, Batu Pahat, Johor. The Geology Lab located approximately 3 km (northwest) from industrial area in Parit Raja Industrial Zone. The air quality around the university was affected by the industrial waste from the factory especially gas emission and particulate matter/dust.

Figure 1 shows the measurement point and the location of air conditioning unit, windows and ceiling fan. The dimension of the laboratory is approximately 14.6 m in length, 8.2 m width and 3.6 m height.

PM_{10} for indoor and outdoor were measured by TSI Dust Trak aerosol monitor. This device used light scattering technique for measured particle concentration. Air is continuously drawn into the instrument for particle concentration measurement. The Dust Trak was located 15 cm above the student table onto the breathing zone of the students. Four points have been chosen inside the room to get the average measurement. For outside particle concentration, the sampling site is located 1 meter from the room door, 30 cm from the ground. PM_{10} was measured inside the Geology Lab and outside the lab. These two conditions were selected to exclude the influence of student activities on particle concentrations.

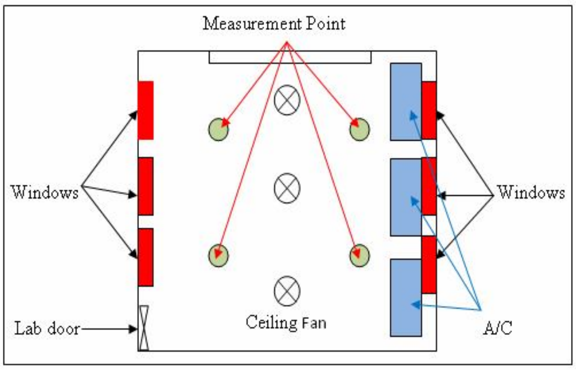

Figure 1: Measurement point and location of windows, air-conditioning and ceiling fan

Temperature and indoor carbon dioxide (from human respiration) was measured with TSI Velocicalc while the TSI Q-Trak plus monitor was used to measure the indoor relative humidity. These data were recorded for 2 hours and 40 minutes (average class hours) with 5 minutes interval time to get the average measurement. 15 university students had volunteer as room occupant in this study.

The tracer gas techniques would be the best option for measuring accurate air exchange rate (ACH). However, due to non availability of the suitable devices, ACH in this study was measured using indoor and outdoor carbon dioxide concentration based on steady state carbon dioxide concentration calculation as shown in equation (1) and (2). In which in equation (1), *Q* is the ventilation rates *(l/s)*, *G* is the CO_2 generation of 0.005 *l/s* per person suggested by ASHRAE standard [5], *Ci* is the indoor CO_2 concentrations *(ppm)* and *Co* is the outdoor

CO_2 concentration *(ppm)*. While in equation (2), *ACH* is the air change rates (h^{-1}), *Q* is the ventilation rates *(cfm)* and *V* is the volume of the space *(ft³)*.

Although the value of ACH through this calculation may not accurately portray the actual ACH values, the value calculated would give baseline idea on the ACH of each scenarios investigated. The measurement was taken on the selected four different points to get the average values.

$$Q = \frac{G \times N}{(C_i - C_o) \times 10^{-6}} \quad (1)$$

$$ACH = \frac{60 \times Q}{V} \quad (2)$$

Measurements were done for a week from Monday to Saturday depending on the chosen ventilated scenario. There are five ventilated scenario and outdoor measurement investigated in this research as shown in Table 1.

Table 1: Ventilation scenarios and parameters investigated

Ventilation Scenarios	Time	Parameters investigated
Windows + ceiling fan (fan speed: 4)	2h 40m	CO, CO_2, PM_{10}, RH, and temperature
Windows only	2h 40m	
Ceiling fan only (fan speed: 4)	2h 40m	
Ceiling fan (fan speed : 2) + air-conditioning	2h 40m	
Air-conditioning only	2h 40m	
Outside air	10m	

3. Results and Discusion

Figure 2 shows the ACH value on each experiment conducted. The highest value of ACH was on the windows plus ceiling fan experiment with 36.84 h^{-1} and the lowest value was the ceiling fan plus air-conditioning experiment with 3.99 h^{-1}. The windows plus ceiling fan experiments significantly reduce the CO_2 concentrations inside the room hence enhance effectively the ACH value of the room. The ACH value of ceiling fan plus air conditioning experiments was lower compared to air conditioning experiments due to the movement of the ceiling distributed CO_2 across the room but do not effectively reduce the CO_2 concentrations because the fan speed was set only on 2 to give comfort to the occupants. Meanwhile the ACH value of ceiling fan experiments (fan speed set at four) was higher compare to window only experiments due to the movement of the ceiling fan help reduces CO_2 concentrations effectively and increased the ACH value.

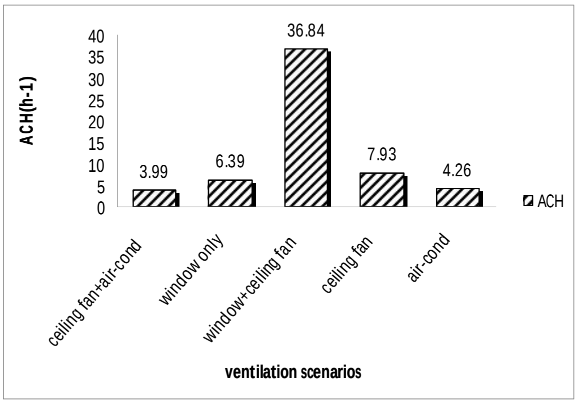

Figure 2: Average data of air exchange rate on each ventilation scenarios.

Figure 3 shows the indoor/outdoor ratio concentration of PM_{10}. From the chart, the highest indoor/outdoor ratio PM_{10} concentration was detected in the window plus ceiling fan experiment of 0.894 mg/m^3 and the lowest was during the air-conditioning only experiment of 0.596 mg/m^3. The indoor/outdoor ratio concentration of PM_{10} of ceiling fan scenario is higher compared to window only scenario due to the movement of the ceiling fan triggered the movement of the PM_{10} concentrations more dynamically hence PM_{10} was detected in much higher concentration by the measurement devices. The same case also happened in the ceiling fan plus air conditioning scenarios in which the PM_{10} is detected in much higher concentration compare to air conditioning only scenarios.

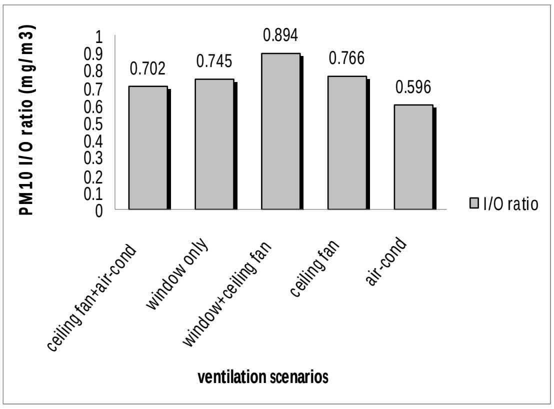

Figure 3: Average data of particle concentration on each ventilation scenarios compared to outside parameter.

Figure 4 show the relations between air exchange rate (ACH) and indoor/ outdoor particle concentration (PM_{10} I/O ratio). The windows plus ceiling fan experiment has the highest value of PM_{10} I/O ratio with highest ACH value of 36.84 h-1. The result shows that the ACH value was proportional with PM_{10} I/O ratio except for the air conditioning only and ceiling fan plus air conditioning scenarios. Although the value of ACH for ceiling fan plus air conditioning was the lowest, the PM_{10} I/O ratio was higher compare to air conditioning only scenarios. This may due to the movement of the ceiling fan which influence the PM_{10} to move across the room and detected in higher concentration by the measuring device.

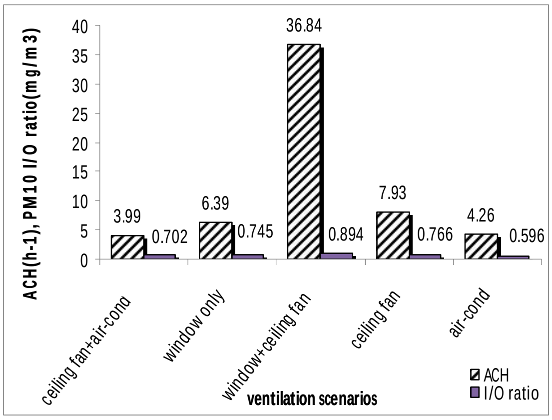

Figure 4: Correlations of air exchange rate and the indoor and outdoor particle concentration ratio.

Table 2 shows the summary of the results for all investigated ventilation scenarios. As shown in the table, the air-conditioning only experiment was the best and suitable ventilation system for the investigated room. Although the ACH value this experiment is low, the value was still acceptable (ACH value recommended for classroom: 4 to 12 h^{-1}). The CO and CO_2 level in this experiment were acceptable for classroom conditions while the PM_{10} concentration level, RH and temperature are the lowest in all ventilation experiment. This data revealed that air-conditioning system is the most suitable ventilation system for the investigated room.

Table 2: summary of results for all investigated ventilation scenarios.

Ventilation	CO (low is better)	CO_2 (low is better)	RH (low is better)	PM_{10} (low is better)	ACH (high is better)	TEMP (low is better)
Windows + ceiling fan	▲	▲	↑↑↑	↑↑↑	↑↑↑	↑↑
Windows only	↑↑	↑	↑↑	↑	↑	↑
Ceiling fan only	↑	↑	↑	↑↑	↑↑	↑↑↑
Ceiling fan + air-conditioning	↑↑↑	↑↑↑	↑	↑	▲	↑
Air-conditioning only	↑	↑↑	▲	▲	↑	▲

↑↑↑	Highest
↑↑	High
↑	Low
▲	Lowest

4. Conclusion

The impact of ventilation on the indoor air quality (IAQ) is much larger these days. With the outdoor air quality being contaminated by industrial and vehicle emission, the IAQ inside the house or classroom also affected. The long term exposure to this hazardous element may harmful to human.

The result shows the ACH value was proportional with PM_{10} I/O ratio except the usage of ceiling fan. Although ceiling fan could enhance the ACH value, it also tends to influence the PM_{10} to move across the room and detected in higher concentration by the measuring device. The result also shows, the air-conditioning ventilation is the best ventilation for the investigated lab because it keeps the PM_{10} I/O ratio to minimum and at the same time comfort people inside it with suitable temperature level with acceptable ACH value.

Thus, it is recommended the air indoor quality (IAQ) inside the class can be increased by installing exhaust fan with filter to increase the ACH (this will reduce the amount of CO and CO_2 level especially in the air-conditioning scenario) and consider optimum number of occupant inside the room for long period of time (3 hours maximum). Hopefully this study would give an insight on the different type of ventilation scenarios and their relationship to ACH and PM_{10} I/O ratio.

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