Experimental Study on Effect of the Air Flow Rate on Ventilation Effectiveness in Lecture Room

Mohd Shahrizal Salleh a, Azian Hariri a,b and Abdul Mutalib Leman a,b

a Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) 86400, Parit Raja, Batu Pahat Johor, Malaysia. Email: azian@uthm.edu.my

b Center of Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia (UTHM) 86400, Parit Raja, Batu Pahat Johor, Malaysia. Email: mutalib@uthm.edu.my

ABSTRACT

This study is conducted to investigate the effect of the air flow rate of cassette ceiling air conditioning on the ventilation effectiveness in lecture room. This study was done by analyzing the measurement data based on experiments conducted in the lecture room using measuring equipments such as Velocicalc, Accubalance Capture Hood and Q-Trak. Parameters consider in this study is CO₂, CO, relative humidity (RH), air flow rate, air velocity and temperature. Nine points had been selected to calculate the average parameters value and the experiment was carried out repetitively with different air flow rates (low, medium and high). Despite of 80 students occupied the room with two out of ceiling cassette air-conditioning in these experiments were not unable to fully operate with its maximum performance, the result obtained shows that the lecture room’s concerning parameters for indoor air quality was still under the allowable limit suggested by ASHRAE for all investigated flow rate. The increase in flow rate should increase the ventilation effectiveness, since the indoor CO₂ concentration was oppositely decreased as the flow rate increased. However, through simple mass balance calculation, the ventilation effectiveness for pollutant removal was calculated only on pollutant dispersion. This is caused by the simple mass equation derived from 1D steady state and cannot predict 3D effect such as the recirculation and stagnation zone. It is suggested to investigate this study through CFD analysis to understand the 3D effect for more accurate ventilation effectiveness analysis.

Keywords

Air flow rate, IAQ, Ventilation effectiveness, Air Conditioning.

1. INTRODUCTION

Air is a critical element to many living things. For example people may survive for two weeks without food and for two days without water. But without air, a person may only survive for two minutes. Nowadays in developed countries, an average working person spends over 90% of his or her lifetime indoors [1].

Indoor air quality (IAQ) refers to the quality of the air inside buildings as represented by concentrations of pollutants and thermal (temperature and relative humidity) conditions that affect the health, comfort, and performance of occupants. Ann Pike (2004) states air quality has been an acknowledged concern for the last 30 years and the awareness seems too had begun after the energy crisis of 1970’s [2]. Since that time, building had been constructed buildings more tightly to conserve heat and air conditioning while fresh air penetration is minimized to control costs. Hence the issue about ventilation efficiency captured more and more people’s attention.

Ventilation effectiveness is the common notion for the indices used to characterize the ability of a ventilation system to exchange the air in the room and the ability of a ventilation system to remove air-borne contaminants. Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher capital costs and energy consumption associated with increasing the ventilation rates. This amount is typically expressed as a percentage[23-24]. Ventilation effectiveness can fall below 100% because of improper supply diffuser and return grill placement. Another cause of reduced effectiveness is imperfect air mixing. The correct amount of outside air may be brought in, but the mixing process does not result in the anticipated percentage of outside air entering the occupied space [14-15].
It is useful to evaluate ventilation efficiency in order to assess IAQ and energy cost. A number of techniques are available to perform such evaluations. Among them, the measurement and analysis of CO₂ concentrations to evaluate specific aspects of IAQ and ventilation is most emphasized. CO₂ is a common air constituent but it may cause some health problems when its concentration level is very high. Normally CO₂ is not considered as a causal factor in human health responses. However, in previous literature Erdmann CA & Apte MG (2004) it has been reported that there is a statistically significant association of mucous membrane (dry eyes, sore throat, nose congestion, sneezing) and lower respiratory related symptoms (tight chest, short breath, cough and wheeze) with increasing CO₂ levels above outdoor levels [3].

American Lung Association indicates that the poor indoor air quality can cause or contribute to the development of chronic respiratory diseases such as asthma, and hypersensitivity and pneumonitis. Meanwhile the US Environmental Protection Agency Study indicates the levels of pollutants in indoor air can be up to 70 times higher than outdoor air [4].

2. LITERATURE REVIEW

From the previous research, Cheong et al., 2003; Apte,M.G. et al., 1996 states many building have poor indoor air quality especially on CO₂ concentration and the result presented by Korean Standard (1991) and ASHRAE Standard (2001 & 2004) shows that the role of ventilation is very important for more comfortable indoor environment because CO₂ cannot be removed by present air cleaning systems [5-7].

Based on Daisey, J M, Angell, W J, and Apte, M G., indoor air quality ventilation and health symptoms in schools was inadequate in many classrooms and create possible health problem [13, 18]. According to Lee,S.C & Chang,M (2003) indicate five classrooms at five different schools in Hong Kong has the value point data sample CO₂ concentration exceeded the Hong Kong indoor air quality limits due to the high outdoor concentration and inadequate ventilation when investigated the indoor and outdoor air quality [17]. Apte, M.G., Fisk, W.J., Daisey, J.M., (2000) investigated the associations between indoor CO₂ concentration and Sick Building Symptoms (SBS). From the analysis show that the regression results between maximum for one hour average indoor CO₂ minus outdoor CO₂ concentration and SBS was similar [13, 16].

Nabinger SJ, Persily AK, Dols WS. (1994) indicates the ventilation effectiveness is getting better or worse with variations of the intensity and the location of momentum source affect the residence time of air in the room. Many works contributed to use indoor CO₂ concentration to evaluate IAQ and ventilation. The operation and effectiveness of the ventilation system is evaluated to investigate the relationship between indoor CO₂ levels and air change rates. However, the assessment was done for a whole building without considering individual rooms [20]. Lawrence TM & Braun JE (2007) used parameter estimation methods to estimate CO₂ source generations and system flow parameters, such as supply flow rate and overall room ventilation effectiveness. They examined different parameter estimation methods from simulated data and the best performed method was applied to field results [21].

From previous research until now, very limited study had been done focusing on the effect of flow rate to the ventilation effectiveness [8-10]. Therefore this study will be focus and investigated the effect of the flow rate of cassette type air-conditioning on ventilation systems in lecture room.

3. METHODOLOGY

This experiment conducted in Seminar Room A-1 and Figure 1 shows the methodology chart of the research. Based on class area, 9 point is chosen as measurement point. The points are selected to represents the average value of the overall lecture room. Figure 2 shows that the dimension of this classroom is 10.4 m (L) x 9.8 m (D) x 3 m (H).

Accubalance Capture Hood is used to measure the air flow rate at supply and exhaust diffuser. The experimental study is carried out by conducting measurement of 2-hour lecture that refers to one session lectures. Measurement at each point will takes about 20 minutes by using Accubalance Capture Hood, Velocicalc and Q-Trak Meter. This experiment take about 1 to 3 hours to complete during class is being held. Apart from that, data for this experiment was taken with difference value of flow rate during experiment (low, medium and high).

Q-Trak meter and Velocicalc is used to measure the CO₂, CO, air velocity, relative humidity and temperature concentration [22]. This tool is placed in fixed position of 1.1 m from floor level representing the level of nose of sitting occupant. Data collected as much as 3 times for each point to get average value and repeated at every point that had been chosen.
This measurement is carried out for 5 minutes for each point and data will take after CO\(_2\) value become stable.

Ventilation effectiveness can be calculated by simple balance mass equation,

\[
Ev = \frac{Ce - C∞}{\bar{C} - C∞}
\]

where;

\[
Ce = \frac{nic}{nia}
\]

Where \(C∞\) is contaminant outdoor supply air (ppm), \(Ce\) is contaminant exhaust air (ppm), \(\bar{C}\) is mean concentration indoor (ppm), \(nic\) is rate of discharge from pollutant source (m\(^3\)/hr), \(nia\) is rate of supply of outdoor air (m\(^3\)/hr). \(Ev\) is ventilation effectiveness. For efficient system, \(Ev\) can be higher than 1. In case of short circuit system, \(Ev\) can be lower than 1. The default value for \(Ev\) is 1 corresponding to a perfect mixing.

![Methodology flow chart](image1)

**Figure 1: Methodology flow chart**

![Layout of the lecture room in meter](image2)

**Figure 2: Layout of the lecture room in meter**

### 4. RESULT AND DISCUSSION

Based on the results we can conclude that the data obtained is still within the standard. However, there are few inconsistent data collected because of the malfunctioning of air conditioning unit in the lecture room that unable to fully operate with its maximum performance. Figure 3 and Figure 4 shows that the average concentration of CO\(_2\) and velocity against measuring point with different flow rate. Figure 5 shows the investigated parameters comparison between different flow rates. The increased of air flow rate will reduce the amount of CO\(_2\) in the class. Figure 6 shows the summary from data calculation for ventilation effectiveness and CO\(_2\) concentration. Despite of 80 students occupied the room with two out of ceiling cassette air-conditioning in these experiments were not functioning to its maximum performance, the result obtained shows that the lecture room’s concerning parameters for indoor air quality was still under the allowable limit suggested by ASHRAE for all investigated flow rate. Figure 7 and Figure 8 shows the increase in flow rate should increased the ventilation effectiveness, since the indoor CO\(_2\) concentration was oppositely decreased as the flow rate increased.
Figure 3: Average CO₂ against measuring point with different air flow rate.

Figure 4: Average air velocity against measuring point with different air flow rate.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Flow Rate (l/min)</td>
<td>213.0</td>
<td>221.8</td>
<td>244.6</td>
</tr>
<tr>
<td>CH₂ (ppm)</td>
<td>1.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>CO₂ (ppm)</td>
<td>800</td>
<td>771</td>
<td>771</td>
</tr>
<tr>
<td>Air Velocity (m/s)</td>
<td>0.18</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>22.1</td>
<td>22.2</td>
<td>22.0</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>48.5</td>
<td>66.6</td>
<td>64.5</td>
</tr>
</tbody>
</table>

Figure 5: Comparison of the result between low, medium and high fan from air supply.

<table>
<thead>
<tr>
<th>Air Flow Rate (m³/hr)</th>
<th>Effectiveness Ventilation (%)</th>
<th>CO₂ Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (1515)</td>
<td>75</td>
<td>800</td>
</tr>
<tr>
<td>Medium (1900)</td>
<td>97</td>
<td>771</td>
</tr>
<tr>
<td>High (1910)</td>
<td>98</td>
<td>771</td>
</tr>
</tbody>
</table>

Figure 6: Summarize from data calculations.

Figure 7: Correlation ventilation effectiveness at the different air flow rate.

Figure 8: Correlation CO₂ at the different air flow rate.
5. CONCLUSION

The effect of the discharge airflow rate of the ceiling type air-conditioner on effectiveness ventilation was studied. The identified CO, temperature, air velocity, relative humidity and CO\textsubscript{2} concentration is still under the allowable limit of ASHRAE Standards. The increase in flow rate should increase the ventilation effectiveness, since the indoor CO\textsubscript{2} concentration was oppositely decreased as the flow rate increased. However, through simple mass balance calculation, the ventilation effectiveness for pollutant removal was calculated based only on pollutant dispersion. This is caused by the simple mass equation derived from 1D steady state and cannot predict 3D effect such as the recirculation and stagnation zone. It is suggested to investigate this study through CFD analysis to understand the 3D effect for more accurate ventilation effectiveness analysis.

6. REFERENCES