Effect of Air Change Rate on Airborne Particles Concentration in Hospital Operating Rooms

Keng Yinn Wong
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

Haslinda Mohamed Kamar, Nazri Kamsah, Fazila Mohd Zawawi, Muhd Suhaimi Deris
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

Abstract: Air change rate (ACH) refers to the number of times contaminated air within a room is replaced with fresh air within one hour. Studies show that the air change rate significantly affects the concentration of airborne particles inside a hospital operating room. This article presents the findings of an experimental investigation on the effects of air change rate on the concentration of airborne particles inside several hospital operating rooms. Field measurements were conducted in seven hospital operating rooms. All rooms have a positive pressure differential of about 7 Pa relative to the adjacent zones. The operating parameters such as supply air velocity, relative humidity, air temperature, and room pressure are in compliance with the ISO Class 7 specifications. The TSI 9310-02 particle counter was used to measure two different sizes of airborne particles, namely 5 µm (PM5) and 10 µm (PM10). An Alnor EBT 731 balometer was used to measure the air change rate. The results show that the air change rate of more than 30/h is capable of reducing the concentration of PM 5 to less than 200 particles/m3 and PM 10 to less than 150 particles/m3.

Keywords: Hospital operating room, air change rate, particulate matters, ISO Class 7

1 INTRODUCTION

The contaminated air inside a hospital operating room is identified as the source of surgical site infection [1]. According to Wagner et al. [2], airborne particles the size of 10 µm are classified as an infectious particle. Sadrizadeh et al. [3] also considered particles at the size of 10 µm as infectious. Chow and Wang [4] proposed that airborne particles with a diameter of 5 µm to 10 µm can be considered as infectious particles as well. Recently, Romano et al. [5] reported that airborne particles with a size of 0.5 µm to 10 µm can be considered as infectious particles. Wang and Chow [6] discovered that airborne particles with a size larger than 20 µm have a rapid settlement effect, but those with a diameter of 0.5 µm to 20 µm will remain in the air for a longer period of time. Their discovery suggests that particles with the size smaller than 20 µm is highly affected by the airflow pattern. This finding is further supported by Memarzadeh and Xu [7], who claimed that the transmission of airborne particles in an operating room is strongly dependent on airflow pattern.
As of today, there is still no consensus on the ACH value that should be implemented in a hospital operating room. The Center for Health guideline [8] recommended an ACH value of more than 15/h, in which at least 3/h should consist of fresh air. However, ASHRAE Standard 170 [9] proposed a higher ACH value of 20/h. Ninomura et al. [10] suggested minimum ACH values for Class B, Class A, cystoscopic, and laser eye operating rooms. The recommended values are 20/h, 15/h, 20/h, and 15/h respectively. Dharan and Pittet [11] also suggested an ACH value of 20/h for a modern operating room. Recently, Memarzadeh and Xu [7] conducted an extensive numerical study on air change rate for hospital operating rooms and concluded that increasing the ACH has the ability to dilute particle concentrations, but does not increase ventilation effectiveness [7]. They also found that an increase in ACH had little impact on the risk of infection. An increase in the ACH value for mixing ventilation did not reduce risks of infection. Sadrizadeh et al. [3] found that inappropriate ACH causes unidirectional airflow to shift to turbulent flow. Memarzadeh and Manning [12] also claimed that a high ACH value of 150/h causes more particle settlement on the surgical table compared to a moderate ACH value of 20/h.

This article presents the findings of an experimental study conducted in seven operating rooms. The goal of this study is to investigate the effects of air change rate on airborne particles concentration.

2 METHODOLOGY

2.1 Description of Operating Rooms

Particles and airflow measurements were conducted inside seven operating rooms of three different hospitals in Selangor, Malaysia for over a two-month period, i.e. from April to June 2015. All the operating rooms are mainly used to perform general surgeries, as well as orthopaedic surgeries. The size of each room varies from 91 m$^3$ to 143 m$^3$. The description of the operating rooms are shown in Table 1.

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of Supply Airflow</td>
<td>Unidirectional</td>
</tr>
<tr>
<td>Room Size</td>
<td>91 m$^3$ - 143 m$^3$</td>
</tr>
<tr>
<td>Exhaust Grilles</td>
<td>0.22 m W × 0.46 m H</td>
</tr>
<tr>
<td>Air-Supply Diffusers</td>
<td>1.2 m W × 0.6 m L</td>
</tr>
</tbody>
</table>

All the seven operating rooms are furnished with an identical ventilation system. For each operating room, there is a total of six air-supply diffusers that provide clean air. They are mounted on the ceiling and fitted with high-efficiency particulate air (HEPA) filters. These filters are capable of trapping 99.9% of particles with the size larger than 0.3 μm [11], [13]. The air is exhausted through four grilles mounted on the sidewalls, at the corners of the operating rooms. Figure 1 shows the simplified geometry of the operating rooms.

2.2 Measurement Procedure

In this study, the measurement of airborne particles was carried out based on the procedures stipulated in three standards, namely ISO 14644-1 [14], IEST-RP-C006.2 [15], and NEBB Procedural Standards for Certified Testing of Cleanrooms [16]. This is to ensure that the data obtained from the measurement
are valid and reliable [17]. The operating rooms were purged at least 12 hours before the field measurement was carried out. All the data were logged at a static air condition, in accordance to the ISO14644-1 standard requirements [11, 14, 17]. The measurements were focused on two types of particulate matters, namely PM 5 and PM 10. During the measurement, the measuring instruments were placed at the height of 1.1 m above the floor [18]. This is the height in which patients will undergo a surgical procedure. The same measurement procedures were followed in all the operating rooms.

Prior to determining the air change rate (ACH), the room pressure needs to be calculated. For a positive pressure operating room, the calculation of ACH has to be based on the clean air volume supplied into the room. On the contrary, the ACH for a negative room is measured based on the exhaust airflow volume [16]. In this study, the room pressure was around +7 Pa to the adjacent zones and corridor. Hence, the air change rate can be calculated via the following equation [16, 19]:

\[
\text{Air Change Rate per Hour} = \frac{\text{Total supply air (m}^3\text{/min)} \times 60}{\text{Room volume (m}^3\text{)}}
\]

(1)

2.3 Instrumentation Setup

The particulate matters PM5 and PM 10 were measured using a TSI 9510-02 particle counter at a flow rate of 28.3 L/min. Each sampling data was logged at 1-minute intervals [20]. This instrument uses a laser diode as the high-intensity light source to detect particulate matters. During the measurement, the detection probe was placed in the middle of sampling grids. A total of six sampling grids was generated for each operating room, as shown in Figure 2. The generation of the grids was based on the IEST standard [15], whereby each grid was not larger than 30 m². The measured particle concentrations were expressed in particles/m³.

The air-supply diffusers for the seven operating rooms are mounted on the ceiling. Therefore, the air supply direction and the ventilation exhaust locations are identical. Each of the air-supply diffusers is equipped with high-efficiency particulate air (HEPA) filters. As shown in Figure 3, an Alnor EBT 731 balometer with a capture hood was used to quantify the air flow rate because it is efficient in measuring direct air volume readings of vertical air-supply diffusers. Prior to the measurement of the air flow rate, all doors of the operating room were closed. To prevent potential changes in the air flow, it was ensured that there were no moving objects during the data collection.

The balometer was also used to measure the pressure difference between the operating room and its adjacent zones. The purpose of having a positive pressure is to ensure that there is no infiltration of airborne particles from the adjacent zones. All the measuring instruments were calibrated before being used in the field measurements. The specification of all the measuring instruments are given in Table 2.
3 RESULTS AND DISCUSSION

The measured air change rates are divided into three categories: low ACH (< 25/h), medium ACH (25/h < ACH < 35/h), and high ACH (>35/h). Table 3 shows the volume flow rate (m³/h), total volume flow rate (m³/h), and the air change rate (/h) for all the operating rooms.

Table 3: Airflow Conditions in All Operating Rooms

<table>
<thead>
<tr>
<th>Location</th>
<th>Volume Flow Rate (m³/h)</th>
<th>Room Volume, m³</th>
<th>Total Air Volume, m³/h</th>
<th>Air Change Rate, /h</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR 1</td>
<td>303 406 338 328 361 324 125 2960 16</td>
<td>579 579 557 557 600 603 116 3485 30</td>
<td>479 401 413 418 418 596 91 2725 30</td>
<td>697 688 705 814 732 749 114 4385 38</td>
</tr>
</tbody>
</table>

Table 2: Specification of Measuring Instruments

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Model</th>
<th>Application</th>
<th>Range</th>
<th>Efficiency Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Particle Counter</td>
<td>TSI 9310-02</td>
<td>Particle Count Sampling</td>
<td>0.3 to 25 μm</td>
<td>50 % at 0.3 μm 100 % at 0.45 μm</td>
</tr>
<tr>
<td>Biometer</td>
<td>Aeor EHT 731</td>
<td>Airflow Volume</td>
<td>42 to 4250 m³/h</td>
<td>+/− 12 m³/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure Differential</td>
<td>-</td>
<td>+/− 0.025 Pa</td>
</tr>
</tbody>
</table>

Contaminated air can be evaluated by means of microbiologic sampling or airborne particle sampling [11, 20]. However, conducting a microbiology sampling is time-consuming and requires special skills and knowledge in environmental microbiology [20]. Therefore, in the present study, only the particle sampling method was employed. In Figure 3, the y-axis represents the average concentration of particles obtained from the six sampling grids. It can be seen from the figure that the air change rate of more than 30/h leads to higher reduction in the particles concentration inside the operating rooms. This finding is in good agreement with the results reported by Li et al. [22].

Figure 3 also shows that there is no significant difference in the particles concentration between OR 3, OR 4, OR 5, OR 6, and OR 7. By comparing OR 3 and OR 4 with OR 7, the reduction in both PM 5 and PM 10 were found to be less than 3%. However, a significant difference was found by comparing OR 1 and OR 2 with OR 7. In OR 1 and OR 2, the particles concentration of PM 5 was seven times higher compared to OR 7. However, the PM 10 concentration was at least three times greater. For an operating room with a volume of approximately 130 m³, an ACH of 30/h is adequate in reducing the concentration of airborne particles to a safe level. The findings from the present study showed that an ACH of 30/h is able to reduce the concentration of PM 5 to less than 200 particles/m³ and PM 10 to less than 150 particles/m³. Wallace et al. [23] claimed...
that a high air change rate will significantly increase the consumption of electricity. Hence, an ACH value of 30/h is the optimum choice.

4 CONCLUSION

Based on this experimental study, the particles concentration in the ISO Class 7 operating rooms were found to be affected by the air change rate (ACH). The ACH of about 30/h is effective in reducing the concentration of both PM 5 and PM 10 to a safe level inside a hospital operating room that has a volume of 130m³. Increasing the ACH to values higher than 30/h will result in a less than 3% reduction in the concentration of both PM 5 and PM 10.

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