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Preliminary Assessment of Thermal Comfort in an Operating Room

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Abstract

A good ventilation system in an operating room (OR) in a hospital is important for providing clean air and thermal comfort to the medical staff members. This article presents the results of a field measurement study conducted in one of the private hospitals in Puchong, Selangor. The purpose of this study is to assess the level of thermal comfort inside the OR. The thermal comfort was assessed by determining the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD), based on the measured airflow velocity, relative humidity, and air temperature data. The two values were then compared to the corresponding limit stipulated in the ASHRAE Standard-55. It was found that the PMV indices range between -0.71 and -1.06, while the PPD indices range between 16 % and 29 %. Both indices fall outside the recommended value range of ±0.5 for PMV and ≤10% for PPD indicate that the currently employed ventilation system in the OR is incapable to provide adequate thermal comfort level to occupants. Therefore, an alternative ventilation method is needed to improve the level of thermal comfort inside the OR.

Keywords: Thermal comfort, Predicted Mean Vote (PMV), Percentage of Dissatisfied (PPD), Operating Room

Introduction

An operating room (OR) is one of the healthcare facilities that requires a sterile and clean environment. This room is used to conduct a surgical operation. The occupants consist of surgeon, assistant surgeon, anaesthetist, nurses, operating department practinioners and patient. Nowadays, unidirectional airflow is utilized in modern operating rooms to ensure good air distribution. Under normal operating conditions, the room is in positive pressure compared to the corridor and adjacent area. According to HTM 2025 standard, the pressure differential should be around 9 to 30 Pa, relative humidity 55% +/- 5 %, temperature 21 ºC and air change rate 20/h.

Thermal comfort is an important requirement in most constructed buildings, especially in hospital's OR. Thermal comfort can be defined in different expression, for instance, Deiana, et al. [1] defines thermal comfort as the sensation of a human body exchanging heat with the surrounding environment without forcing the thermoregulatory mechanisms it is equipped with. On the other hand, ASHRAE [2] defines thermal comfort as that condition of mind which expresses satisfaction with the thermal environment. The environmental factors that affect thermal comfort are relative humidity (RH), air temperature (T_a), air velocity (V_a) and mean radiant temperature (T_{mrt}) [3]. Human factors such as cloth insulation and metabolic heat rate production also affect thermal comfort.

The predicted mean vote (PMV) index and the predicted percentage of dissatisfied (PPD) index are the common thermal indices that have been used worldwide [4]. The ISO 7730, (2005) and ASHRAE Standard-55, (2013) defined the thermal comfort evaluation in terms of PMV and PPD. Many studies have been conducted to investigate indoor thermal comfort in buildings using the PMV and PPD approach [5]. PMV is expressed as "an index that predicts the mean value of the votes of a large group of the person on the seven points thermal sensation scale" [2]. This PMV model is used as a tool to evaluate particular thermal comfort conditions [6]. The equation for PMV is derived according to Fanger's model that includes six primary thermal comfort factors, which are relative humidity, mean radiant temperature, air temperature, air velocity, metabolic rate and clothing insulation [7]. Consequently, the PPD index in ASHRAE standard 55 referred to the percentage of occupants who are prone to complain about the environment and the index is related to PMV. The thermal comfort indices PMV and PPD introduced by Fanger are adopted in ISO 7730 and are calculated by empirical equations as shown. The PMV and PPD value can be calculated using Equations (1) to (6) [2]:

$$\text{PMV} = [0.303\exp(-0.036\text{M}) + 0.028]L \tag{1}$$

where, 0.303 and 0.028 are constant values, M is the metabolic rate (W/m^2) and L is the thermal load on the body expressed as follows:

L = internal heat production – heat loss to the actual environment

$$L = M - W - \{3.96 \times 10^{-8} f_{\text{cl}}[(T_{\text{cl}} + 273) \times 4 - (T_r + 273) \times 4] + f_{\text{cl}} h_c (T_{\text{cl}} - T) + 3.05 \times 10^{-3}[5733 - 6.99(M - W) - P_V] + 0.42(M - W - 58.15) + 1.7 \times 10^{-5} M(5867 - P_V) + 0.0014\text{M}(34 - T)\} \tag{2}$$

where W stands for active work (W/m^2) and fcl is the garment insulation factor (1 clo = 0.155 m^2 K/ W) expressed as:-

$$f_{\text{cl}} = \{1.05 + 0.645\text{I}_{\text{cl}} \text{for} I_{\text{cl}} > 0.078 \quad \text{and} 1 + 1.291\text{I}_{\text{cl}} < 0.078\} \tag{3}$$

The term I_{cl} stands for the resistance to sensible heat transfer provided by a clothing ensemble (I_{cl}, clothing insulates [m^2 K/W]).

The T_{cl} (°C) term is defined as the cloth temperature and is determined below as:

$$T_{\text{cl}} = 35.7 - 0.028(M - W) - I_{\text{CL}} \tag{4}$$

As in Equations 2 and 4, Tr (°C) is the mean radiant temperature, T (°C) is the local air temperature and h_c is the heat transfer coefficient between the cloth, and air (W/m²-k). The heat-transfer coefficient is given by:

$$h_c = 12.1u0.5 \quad \text{for} \quad 2.38(T_{cl} - T)\ 0.25 < 12.1 \qquad (5)$$

I_{cl} is the clothing insulation [m^2 K/W]; f_{cl} is the clothing surface area factor [e]; u is the relative air velocity [m/s]; pa is the water vapour partial pressure [Pa]; t_{cl} is the clothing surface temperature [°C].

Metabolic rate for the occupants and clothing insulation are assumed as standard values. T_a is air temperature, V_a is air velocity, RH is relative humidity, and T_{mrt} is mean radiant temperature.

The PPD is the percentage of the people who felt more than slightly warm or slightly cold (i.e. the percentage of the people who are inclined to complain about the environment). PPD is used to estimate the thermal comfort satisfaction of the occupant. PPD should be less than 10% [2]. The PPD is calculated from Equation (6) using the PMV value:

$$\text{PPD} = 100 - \exp\left[-0.03353\text{PMV}^4 + 0.217\text{PMV}^2\right] \qquad (6)$$

Thermal comfort plays an indispensable role in achieving an optimal work environment for the surgical team. However, there is only limited study addressing the thermal comfort level in an OR, especially in Malaysia. Therefore, this study utilised both PMV and PPD indices to evaluate the thermal comfort in an OR.

Case Study

The present study was conducted in one of the private hospitals located in Puchong, Selangor (Coordinates: 3.0327° N, 101.6188° E). The onsite sampling was performed at night-time, from 10 pm to 2 am (UTC +8).

The case study OR is usually used to conduct general surgeries. It fulfils the Class 7 cleanroom specification, as described in ISO 14644-1. The detail of the OR dimension is tabulated in Table 1.

Table 1: Detail dimension of case study OR

Descriptions	Details
Cleanliness specification	ISO Class 7
Types of Airflow Supply	Unidirectional
Room Size	64.3 m^3
Personnel Entrance	0.9 m (W) × 2.1 m (H)
Patient Entrance	2.0 m (W) × 2.1 m (H)
Exhaust Grilles	0.22 m (W) × 0.46 m (H)
Air Supply Diffusers	1.2 m (W) × 0.6 m (L)

Field Measurement

The field measurement was carried out by measuring the air temperature, air velocity and relative humidity inside the operation room. The measurements are 1.1m above floor level, as suggested by previous studies for thermal comfort and indoor air quality evaluation in the indoor environment [8-10]. The air-conditioning was fully operated 2 hours before the measurements. The purpose is to ensure the OR has achieved thermal equilibrium conditions. An Alnor EBT 721 balometer with an accuracy of ± 0.04 m/s was used to quantify the air velocity. A Testo 625 thermo-hygrometer was used to measure relative humidity and air temperature. The accuracy of the thermo-hygrometer on relative humidity and air temperature measurements are ± 2.5 % and ± 0.5°C, respectively. The measurement devices were outsourced for calibration prior to the onsite measurements. For each measurement grid, three repetitions of measurements were performed, and the average value was determined. Figure 1 shows the preparation of onsite measurement in the OR.

Figure 1 Preparation of onsite measurement in OR

A total of 12 measurement grids were generated in the OR, as shown in Figure 2. The minimum numbers of measurements grids were decided based on Equation 7, where each measurement grid should be smaller than 30 m^2 [11].

$$N = \sqrt{A} \quad (7)$$

where N is the minimum number of measurement grids and A is the area of cleanroom in square metres.

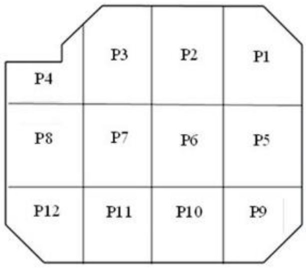
Results and Discussion

This study investigates the thermal comfort level inside the OR by using the PMV index and the PPD index. The ASHRAE Standard-55, (2013) thermal sensation scale of a psycho-physical seven points adopted to express people's feelings towards their environment and quantifying people's thermal sensation is shown in Table 2.

Table 2: People's thermal sensation scale, based on the index of PMV

Hot	Warm	Slightly warm	Neu-tral	Slightly cool	Cool	Cold
+3	+2	+1	0	-1	-2	-3

The measured data of relative humidity (RH), air temperature (T_a), air velocity (V_a), and mean radiant temperature (T_{mrt}) in Table 3 were used to calculate the PMV and the PPD indices, using Equations (1) – (6). The two personal parameters, metabolic rate and clothing insulation were estimated in accordance with the ASHRAE Standard-55. In this study, the metabolic rate was set to be 1.4 W/m^2 and the clothing insulation value was 0.60 m^2 K/W as this value an appropriate for occupants' clothing in the OR.



(a)

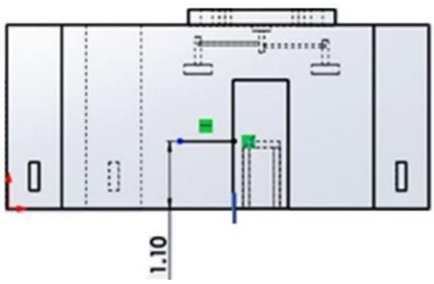


Figure 2 (a) Plan view of the generated sampling points in the OR; (b) the height of the data was measured

Table 3 shows the values of the PMV and PPD indices. The present study found that the thermal comfort of the PMV indices is between -0.71 to -1.06 and the PPD is between 16% to 29% for all points inside the room. This means that thermal comfort is a “Slightly Cool: condition. Based on the ASHRAE standard, 2004 [2], these values fall under the discomfort level. The recommended PMV range should be between -0.5 to +0.5, and the PPD should be less than 10%.

Table 3: PMV and PPD indices at seats P1 – P12

Seats	Ta (°C)	Va (m/s)	RH (%)	T_{mrt} (°C)	PMV	PPD	Sensation
P1	19.3	0.19	57	21	-0.79	18%	Slightly cool
P2	19.0	0.16	57	21	-0.73	16%	Slightly cool
P3	18.5	0.20	61	20.7	-0.96	24%	Slightly cool
P4	18.8	0.16	60	20.8	-0.77	17%	Slightly cool
P5	19.3	0.24	59	21	-0.92	23%	Slightly cool
P6	18.8	0.25	57	20.8	-1.06	29%	Slightly cool
P7	19.3	0.18	60	21	-0.74	17%	Slightly cool
P8	19.3	0.17	59	1	-0.71	16%	Slightly cool
P9	19.0	0.16	61	20.9	-0.72	16%	Slightly cool
P10	18.8	0.15	58	20.8	-0.74	16%	Slightly cool
P11	18.3	0.16	60	20.5	-0.87	21%	Slightly cool
P12	19.1	0.17	60	21	-0.74	17%	Slightly cool

Conclusion

This study investigates the thermal comfort level of medical staff members in an OR, by using the PMV scale introduced by ASHRAE 55. The PMV evaluation is based on the data obtained from onsite measurement. The field measurements indicate that the air temperature, relative humidity, and air velocity were not equally distributed in the OR, at the height of 1.1 m above floor level. The thermal comfort level is represented by the PMV indices between -0.71 to -1.06 and the PPD between 16% to 29% for all points inside the room. Both PMV and PPD indices fall outside the recommended value range of ±0.5 and ≤10%, respectively. The findings indicate that the currently employed ventilation system in the OR is incapable to provide adequate thermal comfort level to occupants. The present study suggests that further investigations on effective ventilation strategies are needed to achieve a good thermal comfort level in the OR.

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