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CFD Analysis of Thermal Comfort in Hospital Operation Room with Different Air Distribution Design and Operative Temperature

MZM Samidi[1], H Husain[1,*] and MS Meon[1]

[1]School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam 40450 Selangor, Malaysia.

*corresponding author: hazran@uitm.edu.my

ABSTRACT

The operation room is one of the most critical regions in hospital that require extra attention of air ventilation and prevention of dangerous pollutants contamination. A good level of ventilation will help to raise the productivity of workers in terms of performance and ensuring a safe surgery operation. It is obvious that today's operation rooms are completely equipped with mechanical ventilation systems. However, despite the fact that they meet the acceptable comfort standards, surgical workers have complained about thermal discomfort during operation which gives negative impact on their performance. Thermal comfort can be achieved by controlling the temperature, relative humidity and air movement. In this study, the operation room models were simulated to analyse the comfort conditions of surgical workers under 3 different air velocities of 0.2 ms⁻¹, 0.25 ms⁻¹ and 0.35 ms⁻¹, and under 5 different temperatures of 16℃ to 20℃. Additionally, there were two 3D models created with different position of exhaust vent. The thermal comfort of surgical workers was measured using Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) approaches through CBE Thermal Comfort Tool. The PMV and PPD results showed that most surgical workers were outside the acceptable range value of -0.5 to +0.5 as stated in ASHRAE Standard 55-2020. According to thermal scale index, most of the surgical workers were in a cool and slightly cool state despite the fact that computational analysis showed an acceptable simulation validated with previous research studies. Finally, it was discovered that clothing insulation, metabolic rate, mechanical equipment and air distribution design played a significant influence in providing comfort to the surgical workers.

Keywords: *thermal comfort, operation room, PMV, PPD, CFD*

Nomenclature (Greek symbols towards the end)

w/m^2	Watt per Metre Square
m/s	Metre per Second
met	Metabolic Rate Ratio
P	Static Pressure
μ	Dynamic Viscosity of a Fluid
$\rho g_x, \rho g_y, \rho g_z$	Body Forces in the x, y and z Directions
λ	Thermal Conductivity
C_p	Specific Heat
ρ	Density
u, v, w	Components of Velocity
x, y, z	Direction of Velocity
T	Temperature
α	Thermal Diffusivity
P_r	Prandtl Number

Abbreviations

ACH	Air Changes per Hour
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineer
CBE	Centre for the Built Environment
CFD	Computational Fluid Dynamics
FYP	Final Year Project
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
ISO	International Organization for Standardization
LAF	Laminar Airflow

NSE	Navier-Stokes Equation
OR	Operation Room
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RH	Relative Humidity
TAF	Turbulent Airflow

1.0 INTRODUCTION

Hospitals always require special attention in terms of HVAC system design and operation, which include hygiene, air movement and airborne transmissions control. According to a researcher, patients who are treated in regulated setting surroundings would recuperate quicker than those who are treated in an unregulated environment [1]. In the past few decades, a lot of research was conducted to improve the efficiency of surgical sites. Despite the diligent hard work, infection rate is still rising. This contamination is known as Surgical Site Infection (SSI). Researchers have discovered that various factors such as patient variables, room variables, surgical variables and the effectiveness of HVAC installation variables contribute to the impact of harmful bacteria presence in operation room (OR) [2].

The acknowledgement of these factors has resulted in the need for high-level ventilation systems which can reduce the existence of pathogens and improve the thermal comfort. It can also elevate the productivity, safety and health of the surgical workers and patient during surgery. In thermal comfort field, there are two international standards used which are ISO 7730 and ASHRAE 55. These standards work as a guideline in developing efficient ventilation system in hospital facilities as well as ensuring thermal satisfaction towards the occupants. Besides that, the factors that influence the evaluation of thermal comfort are individual (clothing insulation, metabolic rate) and environmental (air temperature, mean radiant temperature, humidity, air velocity) factors as studied by Angelova and Velichkova [3]. In other words, they are known as human thermal balance. The parameters of these factors can be gathered in delivering a desired thermal comfort condition.

Most of the operation rooms across the globe are designed based on these standard comfort criteria which are believed to have the advantage in providing thermal comfort environment. However, these criteria ring a warning bell when the dependability of executing these criteria contributes to the thermal discomfort experienced by the surgical workers. This thermal discomfort is believed to be affecting their work performance and contribute to a perception that additional design consideration must be taken into account while using these standards. Hence, the necessity of conducting analysis at the design stage is vital in order to achieve an acceptable thermal comfort level.

2.0 METHODOLOGY
2.1 Theoretical calculation

Thermal comfort is a subjective state of mind that is used to evaluate occupant satisfaction with the thermal environment. It is mandatory to install an adequate ventilation system in the OR since it gives a high degree of thermal satisfaction for surgical workers, and increase their productivity and quality of work. In other words, thermal comfort may be described as a heat transfer phenomenon that can be analysed using the fluid motion mechanism. Prior to the physical essential properties of fluids, this study employed a CFD approach which included the study of fluids in motion via computational solution [4]. Theoretically, fluid flow regimes are classified as laminar, transitional or turbulent. Despite the fact that they produce distinct formulas at the end of their derivation based on their properties, each of these regimes is fundamentally governed by the same NSE conservation principles.

This study utilized a LAF model to analyse the thermal comfort of surgical workers, implying that there was no influence of velocity fluctuation contrasted to TAF model where the velocity fluctuation was critical. Additionally, the LAF model generated a low Reynolds number which allowed the fluid to move smoothly with no interruption inside the paths. The use of CFD software in this study was based on three basic conservation laws of physics which were mass, momentum and energy conservations. This software adequately predicts the flow of fluids, heat transfer and related phenomena in the fluid region of interest by numerically solving the mathematical equations [5-6]. The final derivation of conservation principle equations is described below and the factors influencing the equations must be balanced.

$$\underline{\text{Conservation of mass}}$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \tag{1}$$

Where,

ρ = density

u, v, w = components of velocity

x, y, z = direction of velocity

Equation (1) illustrates the partial differential form of continuity equation for conservation of mass which indicates that the rate of change of mass within the control volume is equivalent to the mass flux crossing the volume surface. In order to perform simulation, this equation requires relevant inputs such as boundary conditions and initial parameters.

$$\underline{\text{Conservation of momentum}}$$
$$\text{For x-direction (U-momentum)}$$
$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) =$$
$$-\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left[2\mu\frac{\partial U}{\partial x} - \frac{2}{3}\mu\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + \rho g_x \tag{2}$$

$$\text{For y-direction (V-momentum)}$$
$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) =$$
$$-\frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y} - \frac{2}{3}\mu\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + \rho g_y \tag{3}$$

$$\text{For z-direction (W-momentum)}$$
$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) =$$
$$-\frac{\partial P}{\partial z} + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \frac{\partial}{\partial z}\left[2\mu\frac{\partial w}{\partial z} - \frac{2}{3}\mu\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)\right] + \rho g_z \tag{4}$$

Where for equation (2) to (4),

P = static pressure

μ = dynamic viscosity of a fluid

ρ = density

$\rho g_x, \rho g_y, \rho g_z$ = body forces in the x, y and z directions

u, v, w = components of velocity

x, y, z = direction of velocity

$$\underline{\text{Conservation of energy}}$$
$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial x^2} + \frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial z^2} \tag{5}$$

Where,

λ = thermal conductivity

ρ = density

C_p = specific heat

T = temperature

$\frac{\lambda}{\rho C_p} = \alpha$ = thermal diffusivity

$P_r = \frac{\mu C_p}{\lambda}$ = Prandtl number

Lastly, these equations are solved using airflow modelling which entails superimposing a grid with hundreds of thousands of cells representing physical characteristics, air and temperature inputs. In particular, those equations are solved simultaneously in a repetition form and turned into algebraic equations that satisfy the conservation principles concept. This is known as discretization and it entails splitting the operating region into

thousands of cells. As a result, the fluid flow can be observed in any part of the space as depicted in the analysis result section where the contours on the OR study plan is visible.

2.2 Numerical modelling

The 3D models portraying the OR design were designed using ANSYS Fluent software as demonstrated in Figs. 1 and 2. It is observed through the figures that the exhaust vent was located at a low level (Design 1) and high level (Design 2). These models were constructed identically in terms of their dimension which was 6m L x 7m W x 3m H. It is essential to choose adequate air diffusers that supply a downward and unidirectional airflow which covers most of the area in surgical site. ASHRAE Standard 55 [7] recommends air diffuser which is greater than 0.3m in dimension when compared to the operation table. The dimension of operation table was 1.8m L x 0.8m W x 0.8m H while the air diffuser was measured as 2.6m L x 2.4m W x 0.3m H. The air diffuser was located at the center of the OR. Meanwhile, air in the operation room was removed through 6 exhaust vents with identical dimensions of 0.9m L x 0.4m H x 0.2m W that were positioned against two opposite-facing sidewalls at the OR low level (Design 1) and high level (Design 2). The dimension of the inlet and outlet in this present study was selected from previous study performed by C. Liu et al. [8].
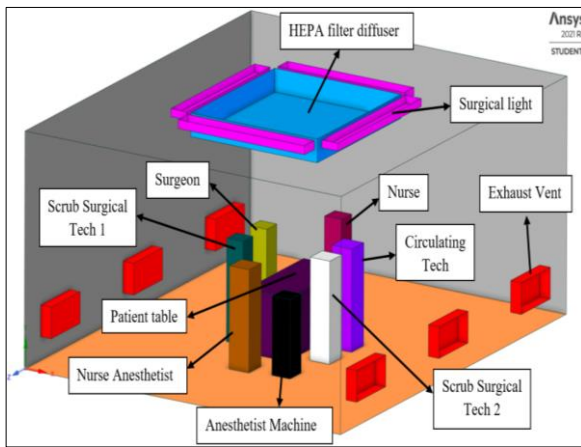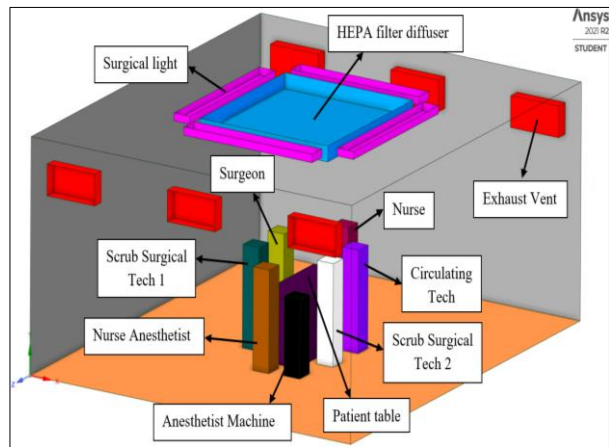

Figure 1: Operation room Design 1

Figure 2: Operation room Design 2

Additionally, there were 6 surgical workers standing around the operation table beneath 4 surgical lights. The surgical workers were surgeon, nurse anaesthetist, circulating tech, nurse, scrub surgical tech 1 and 2. The anaesthetist machine was located at the edge of the operation table, next to the nurse anaesthetist and scrub tech 2. It was essential to develop a model of human body because it gave an impact on the assessment of thermal comfort. According to previous studies [9-10], the average human skin temperature is about 33.7°C. The simplified block-shape was employed as the human structure that depicted the surgical workers. The use of simplified human block tends to overlook the convective heat transmission by 20% in a range of speed less than 0.4 m/s [10-11]. However, it was acceptable to use simplified human block since the major focus of this study examined the thermal comfort level. The dimension of the human block is listed in Table 1.

Table 1: Measurement of surgical staffs extracted from ANSYS GEOMETRY

Surgical Workers	Dimensions (m)			Area (m^2)
	Length	Width	Height	
Surgeon Scrub Surgical Tech 1	0.31	0.31	1.3	1.696
Nurse Anaesthetist Circulating Tech	0.38	0.38	1.3	2.097
Scrub Surgical Tech 2	0.37	0.37	1.3	2.073
Nurse	0.32	0.32	1.3	1.772

It was mentioned by Cong Wang [12] that boundary conditions have a crucial role in generating a reliable simulation result. F. Memarzadeh et al. [13] recommended the range of temperature in ORs between 16.67°C and 26.67°C and using a unidirectional airflow supplied from diffuser. Therefore, this study utilized an inlet temperature in the range of 16°C to 20°C with one degree increase. Three air velocities of 0.2, 0.25 and 0.35 m/s were used to study the influence of air velocity in analysing thermal comfort. The selected air velocities were in an acceptable range based on the study of Gaever et al. [14]. Draughts' discomfort may exist in surgical site if the study utilizes an air velocity beyond 0.45 m/s. Besides that, high infection rates can occur in surgical site when

using LAF ventilation at 0.45 m/s and above of air velocity as studied by [13] and [15]. Thus, this study used vertical LAF system at the mentioned air velocity values. Moreover, the relative humidity (RH) for this study was maintained at 55 % which is within the recommended range by J. M. Walker et al. [16] and Balaras et al. [17]. The ACH was maintained at 20 as referred to the standard. This study was assumed to be in a steady-state condition [12] and Table 2 summarizes the numerical boundary and thermal values.

Table 2: Numerical boundary conditions and thermal values

No.	Variables	Boundary conditions
1	Surgeon	metabolic rate = 1.6 met, clothing insulation = 0.86
2	Scrub surgical tech	
3	Nurse anaesthetist	metabolic rate = 1.4 met, clothing insulation = 0.70
4	Circulating tech	metabolic rate = 1.6 met, clothing insulation = 0.70
5	Nurse	metabolic rate = 1.6 met, clothing insulation = 0.75
6	Anaesthetist machine	Heat dissipation 150W
7	Floor	
8	Ceiling	Adiabatic
9	Walls	
10	Operation table	
11	Surgical light	Heat dissipation capacity 100W
12	Inlet	Velocity-Inlet, Air velocity = 0.2, 0.25, 0.35 m/s, Temperature = 16 – 20°C
13	Outlet	Pressure-Outlet

* Note: Metabolic rate 1 met = 58 W/m^2 and no slip condition for all elements

2.3 Evaluation of PMV and PPD

Previously, most of PMV and PPD evaluations used manual calculation to measure the comfort level. As a result, it led to a non-user-friendly approach due to its complexity. Hence, this study used a simpler interface known as CBE Thermal Comfort Tool invented by the research team from the Center for the Built Environment, University of California, Berkeley [18]. The tool requires an input value from each parameter under the environmental and individual factors. The parameters involved are air temperature, mean radiant temperature, air velocity, humidity, clothing insulation and metabolic rate. The input parameters values are illustrated in Table 2 and under the description of numerical modelling. This tool obeys two international standards which are the European and ASHRAE standards. Upon calculation, the value of PMV and PPD can be observed easily on the psychometric chart. Moreover, the recommended range values of PMV and PPD are -0.5 < PMV < 0.5 while PPD is suggested to be < 10 %.

3.0 RESULTS AND DISCUSSION
3.1 Air velocity distribution

The velocity distribution contour for Design 1 and 2 was plotted at xy plane being cut at a value of -3m as shown in Figs. 3 and 4. Each figure shows the utilization of different air velocities at 0.2, 0.25 and 0.35 m/s with five different operative temperatures for each velocity. The airflow pattern obtained from the simulation analysis was a downward unidirectional flow which greatly depended on the inlet diffuser and outlet exhaust vent position. It was observed that the air was supplied from the inlet diffuser located at the center of the ceiling and the air returned through the exhaust vent positioned at low level (Design 1) and high level (Design 2). In spite of this observation, the airflow constantly produced a vertical down-flow air pattern for both designs which contributed to the utilization of LAF ventilation system. The assigned range value of air velocity distribution contour in the operation rooms was between 0 and 0.4 m/s in order to monitor the behaviour of the air movement and speed. It was found that the greater the air velocity, the more aggressive the flow of the air inside the surgical site which gave influence in providing comfort to the occupants. These results are considerable because both designs are not showing an aggressively high displacement of the maximum velocity throughout the entire simulated operation room models. In addition, the results are still below the suggested velocity value which must be not greater than 0.45m/s [13-15].
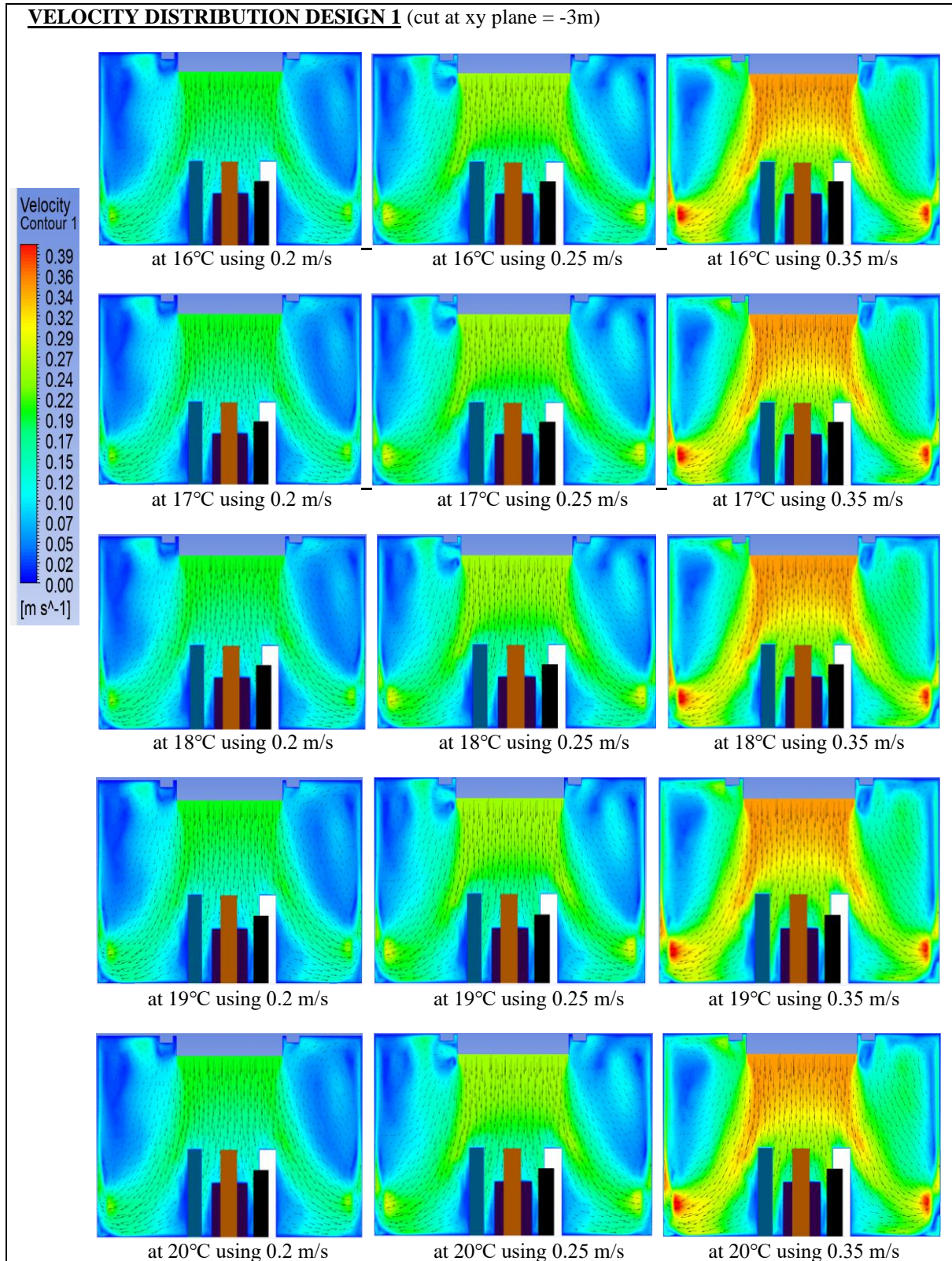
VELOCITY DISTRIBUTION DESIGN 1 (cut at xy plane = -3m)

Figure 3: Velocity distribution of the simulated surgery room Design 1

VELOCITY DISTRIBUTION DESIGN 2 (cut at xy plane = -3m)

Figure 4: Velocity distribution of the simulated surgery room Design 2

From the simulation results, it was observed that a circulation occurred at the top corner of the OR for each assigned value of velocity and temperature. These results are validated through the results of previous studies by several authors in their journals [19], [8], [12], [20-21] which happened to experience a circulation within their simulated models when utilizing a vertical unidirectional LAF ventilation system.

3.2 Temperature distribution

The contour of the temperature distribution for Design 1 and Design 2 is illustrated in Figs. 5 and 6. Both of the OR designs were analysed from the xz plane at a value of 0.7m above the floor. Each figure shows the influence of air velocity in controlling the distribution of the temperature within the OR model. Similar to the velocity distribution, each figure shows the utilization of different air velocities at 0.2, 0.25 and 0.35 m/s with five different operative temperatures for each velocity. From the simulation results, it was observed that the air velocity used completely gave an impact on the temperature distribution within the OR. The highest temperature in the simulated model was set to be at 25°C while the minimum temperature value was 16°C. The range of these temperatures used obeys the suggested value recommended by F. Memarzadeh et al. [13]. It was observed from the temperature distribution figures that the displacement of the temperature for surgical workers was reduced with the increase of air velocity. Hypothetically, this observation revealed that the lesser the displacement of temperature distribution, the more comfortable the surgical workers would feel when working under the measured temperature.

TEMPERATURE DISTRIBUTION DESIGN 1 (cut at xz plane = 0.7m)
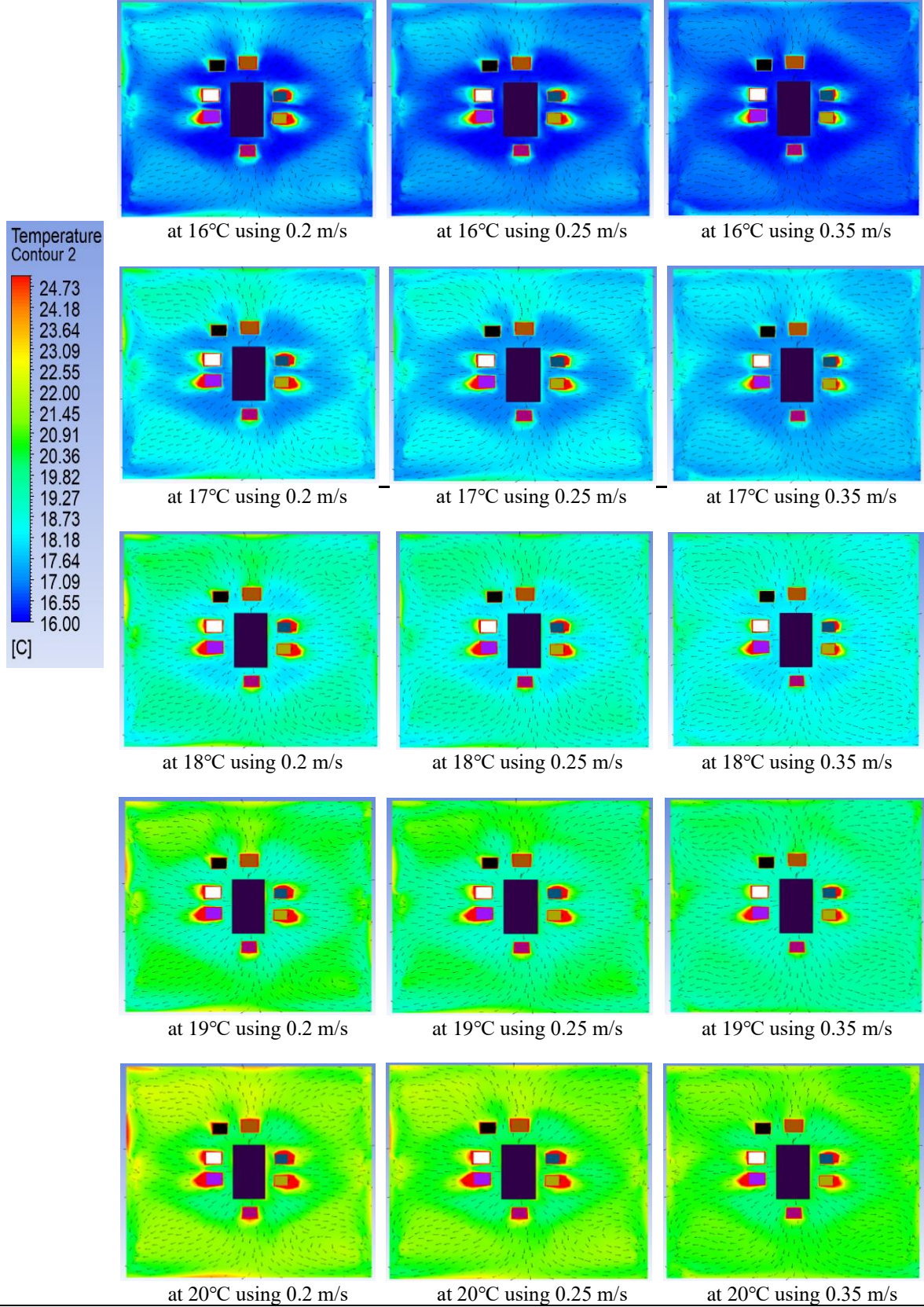

Figure 5: Temperature distribution of the simulated surgery room Design 1

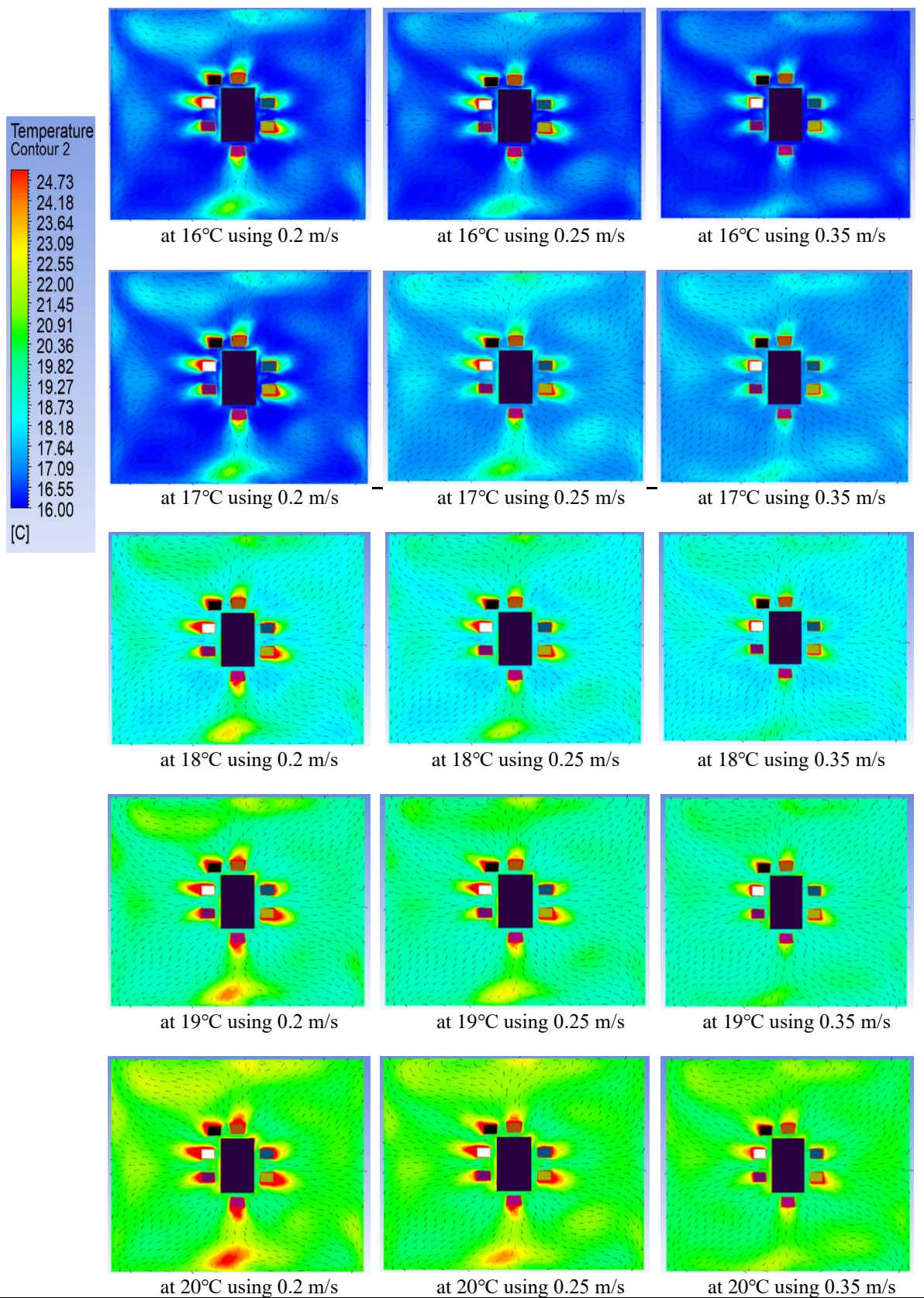**TEMPERATURE DISTRIBUTION DESIGN 2** (cut at xz plane = 0.7m)

Figure 6: Temperature distribution of the simulated surgery room Design 2

3.3 PMV and PPD Data
3.3.1 PMV

Figs. 7, 8 and 9 below show the results of PMV values obtained from CBE Thermal Comfort Tool to measure the comfort level achieved by each of the surgical workers. It was observed that nurse anaesthetist had the highest PMV value while surgeon and scrub surgical tech had the lowest PMV value throughout the 5 measured temperatures and 3 different air velocities. The PMV values for other surgical workers were between the surgeon, scrub tech and nurse anaesthetist. Furthermore, by neglecting the bar chart, it was observed that the graph of the PMV approach linearly increased as the measured temperature increased.
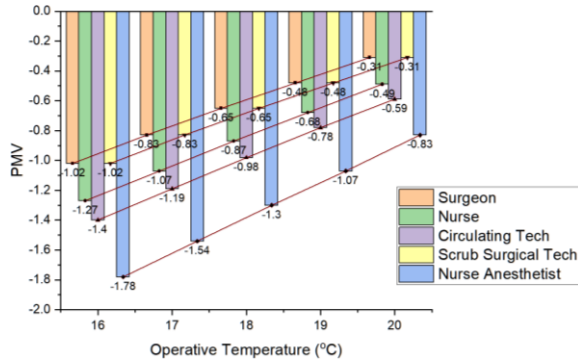
Figure 7: PMV value of surgical staffs at 0.2 m/s
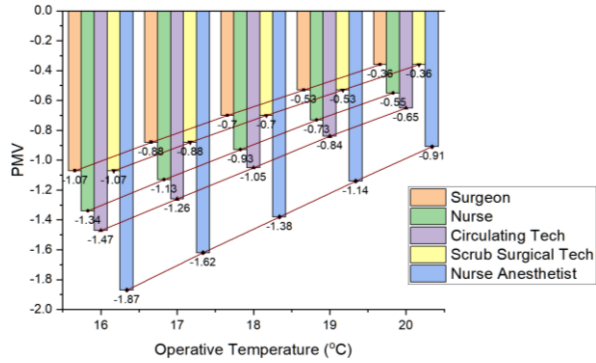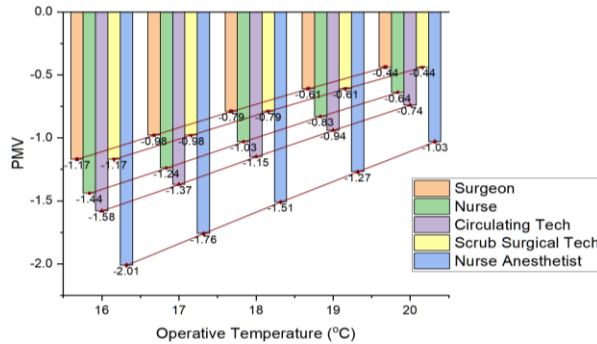

Figure 8: PMV value of surgical staffs at 0.25 m/s

Figure 9: PMV value of surgical staffs at 0.35 m/s

The comfort level of the surgical workers was measured using the standard PMV index scale guideline by ISO 7730 [22] as in Table 3. According to [23], the PMV value should be between $-0.5 \leq PMV \leq +0.5$. In relation to the problem statement, there were complaints from surgical workers who experienced thermal discomfort even when the operation room followed the standard thermal guidelines. Therefore, the recommended range of PMV value that should be met in this study was between $-1 \leq PMV \leq +1$ where this range was acceptable to provide comfort for the occupants [24]. Next, the obtained PMV results revealed that most of the surgical workers experienced a near cool sensation. It was due to several factors which influenced their comfortability such as metabolic rate and clothing insulation. In accordance to the gathered thermal parameters from previous studies, nurse anaesthetist had the lowest metabolic rate and clothing insulation. It is because nurse anaesthetist does not need to juggle around the operation room compared to other workers as he or she spends most of the time sitting in front of the anaesthetist machine. It is also set that nurse anaesthetist wears hospital scrubs which include only underwear, shoes and socks compared to the surgeon who wears gown, gloves and galoshes as well as other workers who need to wear hospital scrubs and warm-up jacket. Additionally, nurse anaesthetist is directly exposed to the heat produced by the anaesthetist machine and surgical lights that may contribute to the balance of coolness that he or she experiences.

Table 3: PMV index scale [22]

Value	Thermal Sense
-3	cold
-2	cool
-1	slightly cool
0	neutral
+1	slightly warm
+2	warm
+3	hot

3.3.2 PPD

The PPD has a strong link with the value obtained in PMV approach. If the value obtained in PMV is in neutral scale, the PPD will have a value below 10% of temperature dissatisfaction. Similar to the PMV, PPD technique also predicts the percentage of individual that feels thermally dissatisfied with the environment temperature. Referring to the PPD results obtained in Figs. 10, 11 and 12, the nurse anaesthetist had the highest dissatisfaction percentage with the surrounding temperature throughout the 5 measured temperatures and 3 different air velocities. In this study, it was recommended that the PPD value should be less than < 20 % in order to obtain thermal comfort conditions. According to the graphs below, the behaviour of the graph linearly decreased towards zero value. However, the relationship between PMV and PPD showed that even when the PMV value was zero, there was still a percentage of people that felt dissatisfied with the surrounding temperature. It was observed that majority of the surgical workers felt dissatisfied when utilizing the operative temperature of below 19℃.
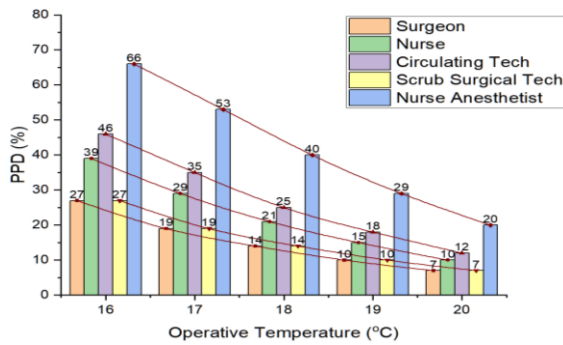

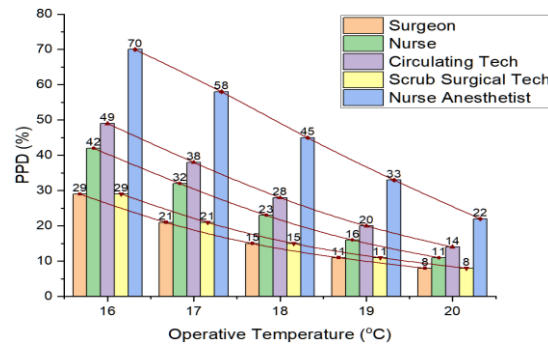Figure 10: PPD value of surgical staffs at 0.2 m/s

Figure 11: PPD value of surgical staffs at 0.25 m/s
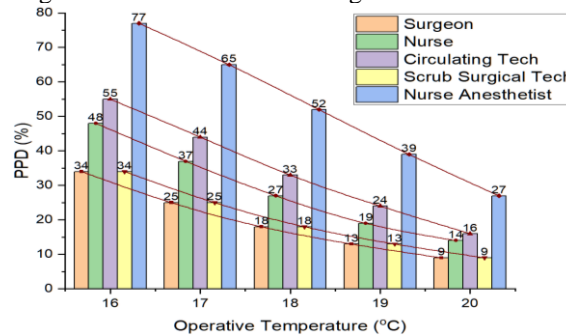

Figure 12: PPD value of surgical staffs at 0.35 m/s

3.4 Comparison of simulated designs

The CFD analysis of simulated designs was compared in terms of velocity distribution, airflow pattern, position of outlet exhaust vent and temperature distribution. Figs. 13 and 14 show the comparison of velocity distribution between Design 1 and Design 2 using identical operative temperature of 19 °C and air velocity of 0.2 m/s. It was observed that a circulation aggressively occurred at the top left and right corner of Design 1. In Design 2, the air circulation was assumed to be exhausted much easier due to the position of the exhaust vent. In terms of infection, Design 2 provided a safer environment due to the minimal air circulation in the surgical site. It is because the trapped air inside the operation room may contain bacteria or harmful microorganism which could threaten the patient during the surgery. Hypothetically, high circulating air inside the operation room may increase the chance of the patient to obtain undesired infection.
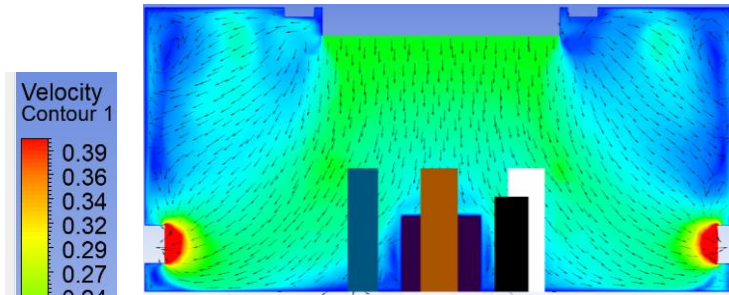
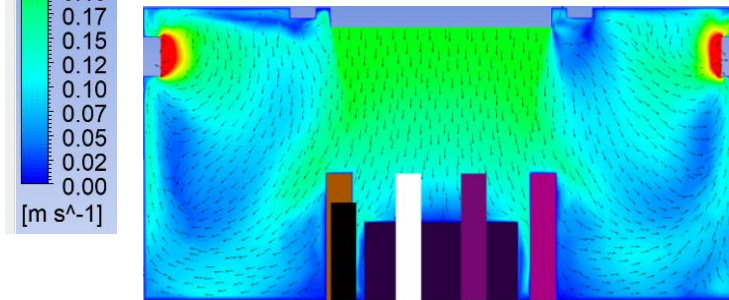Figure 13: Velocity distribution of Design 1

Figure 14: Velocity distribution of Design 2

Besides the airflow pattern and velocity distribution, the simulated designs were also compared in terms of temperature distribution. For temperature variable, it has a great relationship in monitoring the comfort level of the surgical workers. The red contour around the simplified human block models in Figs. 15 and 16 indicated the heat experienced by the surgical workers. The more aggressive the colour contour, the more uncomfortable the surgical workers feel. However, the results of this temperature distribution were set in the range of 16℃ to 25℃ which means that they may be considered in a comfortable or cool state. In previous studies, the suggested temperature for the surgical workers was between 20 and 22℃ [25-26]. Hence, the temperature below the suggested temperature may be categorized as slightly cool or cool. By comparing the temperature distribution, the position of the exhaust vent at a high level is better in reducing the red contour displacement.
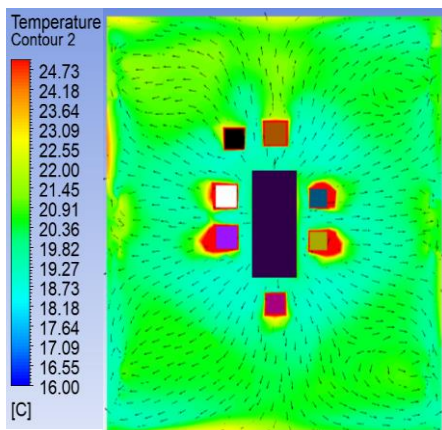
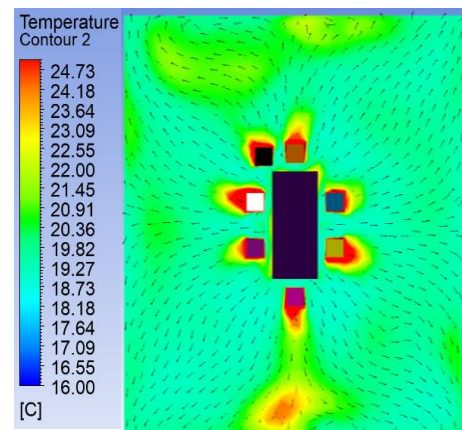

Figure 15: Temperature distribution of Design 1   Figure 16: Temperature distribution of Design 2

4.0 CONCLUSION

In a nutshell, this study focuses on the analysis of thermal comfort in operation room. The constructed models were simulated in 5 different temperatures of 16℃ to 20℃ and 3 different air velocities of 0.2, 0.25 and 0.35 m/s. The results show that the environmental and individual factors give a great influence towards thermal comfort. Generally, when observing the PMV and PPD graphs, the standard thermal indexes guidelines can still be achieved even though the measured temperature increases to 25℃. Most of the surgical workers have thermal sensation from slightly cool to neutral and from cool to slightly cool. The arrangement of the devices in the operation room is also vital role because these devices contribute towards heat into the space. In this study, the configuration is simplified and the measurements are taken and simulated. As a result, it shows that anaesthetist machine and surgical lights give a great effect towards temperature distribution. Assuming a real operation room is built, the

complexity of the device arrangement may hit above great in analysing thermal comfort. Additionally, the position of the exhaust vent plays an important role in resulting airflow pattern. It can be concluded that the operation room of Design 2, which has a high-level exhaust vent position, delivers better and safe environment due to less air circulation produced. As a consequence, the risk of patient in getting infection is reduced.

ACKNOWLEDGEMENT

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