Thermal Environment Analysis of a Scientific Laboratory using Computational Fluid Dynamics

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Abstract. University staff and students typically spend most of their time indoors. This paper evaluates the thermal environment of an air-conditioned scientific laboratory in a tertiary educational institution in Malaysia using Computational Fluid Dynamics (CFD). This computational technique has been used in analysing the indoor environments and has been found to be useful in aiding facilities management. A pilot survey was conducted to collect the required information such as indoor parameters and boundary conditions for the setting up of a CFD model of the laboratory. The model was then simulated based on the data obtained from field observations. Results indicate that the laboratory users sitting at different rows and work desks would experience different thermal sensations. The mean air temperature was below the recommended comfort zone specified in the local energy standard, but the air velocities were generally within the acceptable range. Based on the calculated predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) indices, most of the users would be thermally uncomfortable, and a warmer environment was preferred. Recommendations were made to regulate the inlet air temperature of the laboratory to improve thermal comfort of laboratory users and for energy saving purposes.

1 Introduction

Educational institutes are built to provide the public with academic services and such buildings have distinctive indoor environment design, safety, occupant load and capacity requirements. For academic buildings in Malaysia, the building design requirements are stipulated in the local Uniform Building By-laws 1984 [1]. A typical educational building has several building types catered for different uses, such as lecture theatre, classroom, academic office, laboratory, workshop and others. Among these academic structures, the laboratories are the learning areas where users are given the opportunity to implement theoretical knowledge via practical works and to avoid potential laboratory hazards, prescribed laboratory rules and procedures must be observed. Many previous studies have presented that the learning/work performance and occupant health conditions in educational institutions are closely related to the indoor environmental parameters, which include thermal comfort [2-3]. Efforts have since been sought to improve thermal comfort by incorporating new air conditioning and mechanical ventilation (ACMV) systems, improving ventilation strategy, controlling occupancy level and others [4-5]. In the hot-humid regions, more cooling and ventilation systems are used in modern buildings to improve and sustain thermal comfort, but at the cost of increasing energy use.

Studies on thermal comfort in built environment have been carried out since the past decades using different approaches, such as field survey, experimental set ups, computational tools and a combination of these methods [6]. The use of computer software like computational fluid dynamics (CFD) to simulate the thermal conditions in different building areas has yielded results with high levels of accuracies. CFD studies on office areas [7], residential homes [8-9] and other building types [10-11] have since been carried out. Many of the current literature on the applications of CFD pay particular attention to the airflow and indoor temperature of a selected building space to evaluate the thermal comfort reception of occupants as this is closely related to the workers' productivity besides ensuring good facilities management.

This study aims to contribute to this growing area of indoor thermal environment research by exploring the thermal comfort conditions of an air-conditioned university laboratory in Malaysia. The thermal environment of the laboratory was simulated and analysed by employing a CFD tool-FloEFD 12.0, and the results presented in this work provide a reference to the current application of CFD in thermal comfort analysis, especially for laboratories in the tropics.

2 Research Methods

2.1. Instruments used and pilot survey

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A handheld multifunction ventilation meter was used to measure the air velocity and temperature in the Electrical and Electronics (E&E) laboratory. This device's temperature measuring range was within -10 °C to 60 °C with an accuracy of ±0.3 °C with a resolution of 0.1 °C while air velocity within the range of 0 m/s to 30 m/s can be measured with an accuracy of ±5 % or ±0.025 m/s whichever is greater with a resolution of 0.01 m/s. The range of temperature measurement was -40 °C to 550 °C with an accuracy of ±1 % of reading or ±1 °C whichever is greater with a 0.1 °C resolution. Meanwhile, the room surface temperatures were measured using an infrared and contact temperature sensor with a measuring range of -40 to 550 °C. These electronic instruments were calibrated before it was used in field data collections. To develop the CFD model of the laboratory, a pilot survey had been carried out to obtain the data required, such as the dimensions of the laboratory, locations of the furniture and equipment, indoor air temperature, wall surface temperatures, inlet and outlet air velocities, occupancy level etc. using the calibrated instruments.

2.2 CFD Model

A CFD tool - Mentor Graphics FloEFD 12.0 was used to perform simulation works. Solidworks was incorporated in the software as the modelling module for the creation of 3D models to be studied. This CFD solver employed a modified k-ε turbulence model which is a finite volume method. The actual design and conditions of the laboratory, such as geometrical configurations, occupancy level, air and surface temperatures, equipment and furniture used that were measured and observed in the pilot survey were inserted into the CFD model to replicate the actual situations, as illustrated in Figure 1. The model was checked and ensured to be air-tight and internal CFD analysis option was chosen.

Air was the only fluid considered and the flow type was set as both laminar and turbulent. The humidity level in the laboratory was set at 60% and solar radiation from the outside environment and heat conduction in solids were not considered for simplicity purposes. The influence of gravity was taken into consideration nevertheless as the main heat transfer mode in the simulation was convection. The air pressure in the room was assumed to be 1 atm.

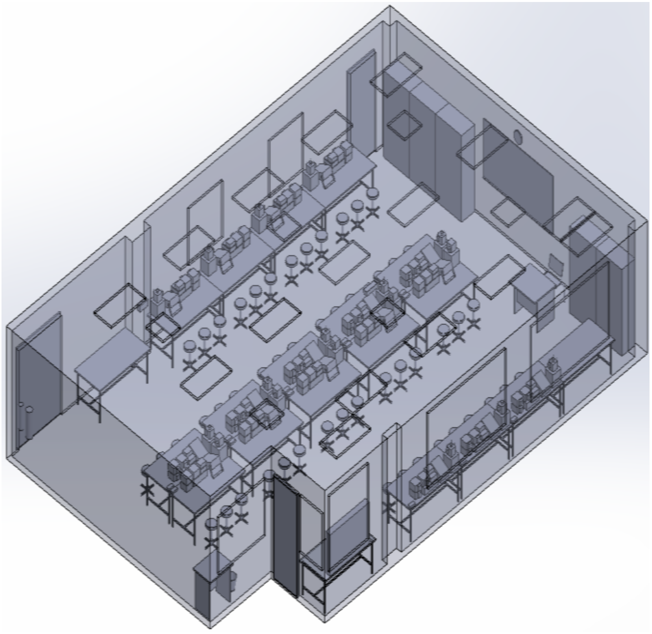


Fig. 1. CFD model of the laboratory.

2.3 Analysis of Results

The Operative temperature concept and Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) were used to analyse the simulation outcomes. The PMV-PPD indices were calculated using an Excel spreadsheet which incorporates the computer program codes for PMV-PPD estimation [12].

3 Results

3.1 Field Observation and Measurement

The occupancy level of the E&E laboratory was observed to be approximately 50% for most of the time, as the average number of students using the laboratory was about 20 people per session. As the E&E laboratory was air-conditioned, the indoor air temperature was observed to be uniform throughout the field measurement despite the changing weather conditions. The measured air and room surface temperatures are tabulated in Table 1. At each point of the room surfaces, 6 temperature readings were recorded, and the mean values were used to set the CFD model's boundary conditions.

Table 1. Surface and air temperatures of the Electrical Laboratory.

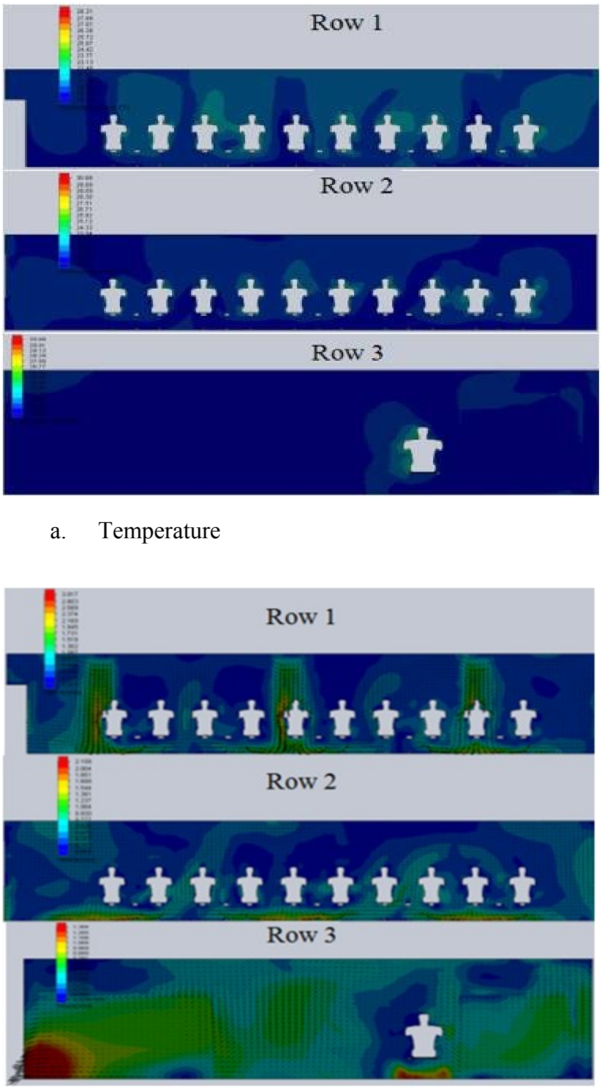
Air/Room Surface	Measured Temperature (°C)						
	Point 1	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Mean**
Walls*	22.2	22.2	22.2	22.3	22.0	22.1	22.2
Windows*	21.2	21.0	21.3	21.1	21.2	21.1	21.1
Doors*	21.4	21.3	21.5	21.4	21.4	21.3	21.4
Floor	21.3	22.0	23.1	23.5	23.2	23.2	22.7
Ceiling	20.4	20.6	21.2	21.0	21.8	20.7	21.0
Indoor Air	22.7	22.9	22.6	22.8	22.7	22.7	22.7
Outdoor Air	24.6	24.8	24.9	25.0	24.8	24.8	24.8

*Average reading for each surface/ unit

3.2 Simulation results

The CFD model of the E&E laboratory was simulated for medium occupancy level (20 participants + 1 instructor) only, mimicking the actual condition of most laboratory sessions. Figure 2a demonstrates that the air temperature ranged between 19.24°C to 23.63°C in most parts of the laboratory. The unoccupied spaces, which are at the front and back sections of the room, were found to have lower air temperatures. This can be seen at the right side of Row 2 which is at the back of the room and the left side of Row 3, the front area of the laboratory. From the simulation outcomes, several cooler spots were identified in Row 1, possibly because of the positions of the supply air diffusers which were installed directly on top of this area. The air temperatures surrounded the occupants were slightly higher than the surroundings owing to the body heat dissipation, and the temperature range was found to be within 22.06°C and 26.77°C. Without any doubt, occupants who were sitting below the air diffusers would experience cooler air temperature.

From Figure 2b, higher air velocities can be found in Row 1 in the downward direction and measured between 1.087 m/s and 2.374 m/s. The same situation can be seen at the left side of Row 3, which is where the laboratory door was located. Higher air velocity values are also found at the floor areas of Row 3 and Row 5, which may be due to the flow of circulated air from the diffusers. From the colour contours displayed, cool air is circulating mostly at the unoccupied sections of the laboratory. Besides, based on the flow trajectory shown in Figure 3, the regions with higher air movements are those near to the air conditioning supply air diffusers and the exit doors where exfiltration of air occurred. It is interesting to note that most of the air supplied by the diffusers flows towards the return air grilles and the exit doors in this study, which causes limited air movement at the centre of the laboratory where most users were seated. This is mostly attributed to the unobstructed path for air movement, which is only available at the unfurnished and unoccupied locations of an enclosed room and is also the reason for the lower floor temperature in the laboratory under study. Since this paper only presents the simulation outcomes for medium occupancy level, further studies are needed to study the laboratory's thermal comfort conditions under different occupancy levels and temperature settings.



a. Temperature

b. Air velocity

Fig. 2. (a and b) Air temperature and velocity profiles in the E&E laboratory under medium level occupancy.

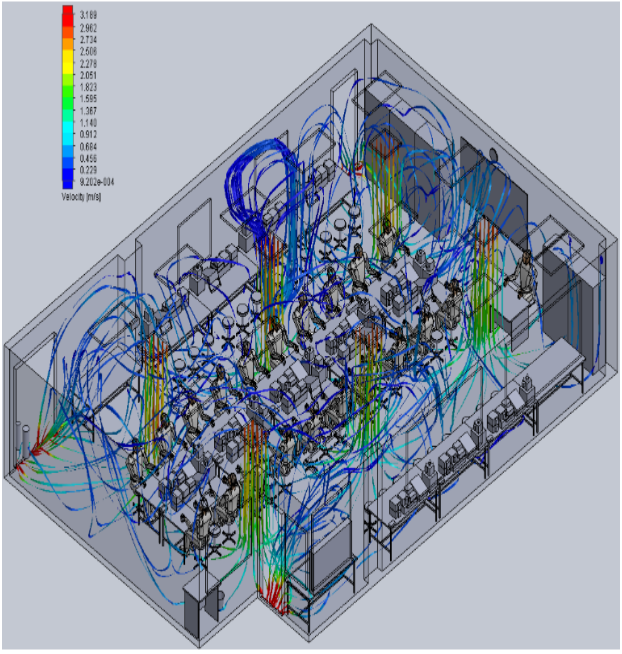


Fig. 3. Air flow trajectory.

3.3 Operative temperature and PMV-PPD

Using the results of CFD simulations, the average air temperature at the sitting areas of the laboratory was predicted to be 20.45°C, which was lower than the recommended comfort range of 24-27°C stated in MS 1525, a local energy efficiency guideline [13]. This shows that the laboratory received more cooling than required. As for the air velocity, a mean value of 0.418 m/s was calculated and that was within the acceptable comfort range [13]. The operative temperature, Top, which is defined as the temperature whereby the heat absorbed by the occupant is equivalent to the heat released, was calculated using the following equation:

$$T_{op} = XT_a + (1 - X)\, T_{MRT} \qquad (1)$$

where Ta is the air temperature and TMRT is the mean radiant temperature. The value for X differs for different air velocity values.

The operative temperature of the laboratory was calculated as 21.08°C. This has further suggested that the laboratory was overcooled. As for PMV-PPD indices, the predicted cooling sensation of the laboratory users was -1.7 while 61.8% of them were expected to be dissatisfied with their immediate thermal environment. Coupled with the other findings, there is a need to increase the supply air temperature while maintaining the air velocity rate at acceptable levels to improve the overall thermal comfort condition in the laboratory.

4 Conclusions

The thermal environment of a laboratory was analysed using CFD. The simulated results showed that users seated at different regions within the laboratory would have different thermal experience. It was observed that the temperatures at the back and sides of the laboratory were lower. The mean values for air temperature and velocity were found to be 20.45°C and 0.418 m/s, respectively. The operative temperature of 21.08 °C indicated that the laboratory was overcooled, and an increase of supply air temperature will not only improve thermal comfort but also reduces energy demand, which is important for sustainable facilities management. Besides, most of the laboratory users would feel cold while working at the laboratory and more than half of them would find their thermal environment unacceptable. In view of this, more work is required to understand the thermal perceptions of users under different occupancy levels and indoor thermal conditions.

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