Thermal Comfort Study of a Classroom in Northern Malaysia: A CFD Approach

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Abstract. A conducive environment is essential in creating an ideal condition for the impartation of knowledge. One of the essential parts of such a conducive environment is to have a thermally comfortable condition. A study was conducted to assess the thermal comfort in one of the classrooms of a university located in the northern most part of Malaysia. The particular classroom was randomly chosen from a total of 4 classrooms of the same size and condition. Measurements of the dimensions of the room together with temperature and velocity were taken to make the computational model and as boundary conditions for the Computational Fluid Dynamics (CFD) simulation. The simulation was conducted to visualize and predict the temperature distribution and flow pattern inside the classroom. The results of the simulation showed that there exists a non-uniform circulation of cold air from the air-conditioning outlet to the rest of the classroom. The distribution of the cold air seems to be limited to only the location under the air-conditioning outlet making it thermally uncomfortable there. Hence, it is recommended to either reduce the airflow velocity coming out of the air-conditioning outlet or change the size or location of the air-conditioning outlets.

1. Introduction

Thermal comfort can be defined as the condition of mind which shows or exhibits a sense of contentment and satisfaction with the thermal environment [1]. It is one of the six key metrics of indoor air quality. One may experience thermal discomfort when the whole or one particular part of the body experiences an unwanted cooling or heating. Malaysia is a hot and humid country. Most of the time, air-conditioners are used indoors to provide a certain level of comfort from the hot environment outdoors. Some of the guidelines available for tropical countries like Malaysia are given in Table 1. In terms of indoor comfort, many studies through experiment and simulation had been conducted. de Dear et al [2] conducted a study on the thermal comfort in naturally ventilated apartment buildings in Singapore together with air conditioned ones. They found that 1/3rd of the occupants of the air-conditioned apartment felt cool thermal sensation while their counterparts in the naturally ventilated apartments felt warmer than the ISO thermal comfort standards. Chong et al [3] also investigated the airflow in a lecture room by using CFD. They compared their simulation using experimental data collected. Their study was to determine the effects of using two different turbulence models namely the RNG k-e and the Reynolds Stress Turbulence models on the results of the airflow namely air distribution, velocity and temperature. Ogoli [4] conducted a study on a natural ventilated education building in America. He used both surveys and laboratory experiments to study the effects of the environment, activities, clothing, age, gender as well as knowledge and experiences of the occupants, on determining the thermal comfort level. Yan and Chew [5] studied thermal comforts at four different hospitals in Malaysia. They used survey in their studies and found that 90% of the occupants feel at ease at the neutral temperature of 26.4°C. Haslinda et al [6] meanwhile, conducted a thermal comfort study in naturally ventilated residential terrace houses in Malaysia. She used CFD to simulate the air...
flow inside the houses. From the simulations, it was found that air did not exhibit a uniform circulation inside the house and that the air velocity was well above the acceptable level of thermal comfort set by ASHRAE. Rahman and Narahari [7] in their study found that in a lecture room with 198 occupants, there was a stagnant flow at the back of the room resulting in a temperature of up to 308K. This study was performed using CFD. Jain et al [8] also conducted a thermal comfort study of an office building in India. They used simulation method to determine the effect of air inlet locations in achieving thermal comfort in offices. Using computational fluid dynamics, they found the best combination of air-conditioner and window openings in achieving an optimal cooling temperature. This paper presents a thermal comfort study on a lecture room in Perlis, a state in Malaysia which has one of the highest temperatures in the country using computational fluid dynamics.

Table 1. Guidelines for temperature, wind speed and relative humidity applicable for Malaysia.

| Guideline                  | Department of Standards Malaysia [9] | Department of Safety and Health Malaysia [10] | Chartered Institute of Building Services Engineers (CIBSE) Guide [11] |
|----------------------------|--------------------------------------|-----------------------------------------------|---------------------------------------------------------------------|
| Temperature                | 24 - 26                              | 23 – 26                                       | 25.5 - 27                                                            |
| Wind speed (m/s)           | 0.15 – 0.5                           | 0.15 – 0.50                                   | 0.1 – 0.25                                                          |
| Relative humidity (%)      | 50 – 70                              | 40 - 70                                       | 40 - 70                                                              |

2. Measured Readings and Surveys
The following readings in Table 2 are the average of the measurements taken. It can be seen that it is slightly warmer in front of the room compared to the middle. All these values are within the temperatures, relative humidities and air velocities recommended by the guidelines in Table 1. However, when a survey was conducted among 84 students in the classroom (Table 3), it was found that most of them wish to have a warmer environment in the classroom. This is in contrast to the findings in Table 2.

Table 2. The average readings in the classroom.

| Position inside room | Air Velocity | Temperature | Relative Humidity |
|----------------------|--------------|-------------|-------------------|
| Front                | 0.1 m/s      | 26 °C       | 52 %              |
| Middle               | 0.12 m/s     | 25.5 °C     | 55 %              |
| Back                 | 0.1 m/s      | 26 °C       | 52 %              |

Table 3. Thermal preference results.

| Thermal Preference | % of students |
|--------------------|---------------|
| Warmer             | 60            |
| No change          | 25            |
| Cooler             | 15            |

3. Computational Fluid Dynamics (CFD) Modeling
The classroom chosen was measured to be 3 m in height, 7.62 m in width and 11 m in length. The readings of temperature, air speed and relative humidity for the room were taken at the time when the classroom was empty. The readings were taken one hour after the air-conditioning was turned on so as to stabilize the air flow inside the room. The readings for the velocity, temperature and relative humidity directly under the air-conditioner outlet are given in Table 4. These parameters were used as initial and boundary conditions in the simulations. The geometrical model and layout of the room is given in Figure 2. The air speed is the speed of the air entering the room from the air-conditioning system. There are 3 air-conditioners inside the classroom each located at the front, middle and back of the room. A Kestrel 2000 Pocket Weather Meter was used to measure the air speed, temperature and relative humidity. The room is considered empty as the reference data collected were taken when the room was unoccupied. The door and windows of the room are not included in the computational model as the room is assumed to be closed. The properties of the materials which are used in the simulation are given in Table 5. Only two boundary conditions were used in the model; wall and velocity inlet. Velocity inlet was used for the outlet vent of the air-conditioners while the ceiling, floor, and the surrounding walls of the classroom are classified as wall boundary condition. The velocity was set to a constant value of 2.6 m/s. The side walls of the classroom are made from brick while the side wall next to another classroom is made from gypsum. Constant heat flux was assumed for the walls with the air surrounding the classroom is set to
be initially at 26 °C. The velocity of air and temperature is based on readings taken inside the classroom referring to Table 2.

### 4. Results and Discussions

To determine the distribution of the cold air inside the classroom, the air circulation at three different locations inside the classroom was obtained as shown by Planes 1, 2 and 3 in Figure 3. Plane 1 represents the location nearest to the gypsum wall; Plane 2 represents the location in the middle of the room while Plane 3 represents the location along the air-conditioning outlets. As expected the highest airflow velocity occurs at the air-conditioning outlets. The cold air only gets distributed once it reaches the floor of the classroom as evidenced by the contour plots in Figure 3 and 4. It can also be seen that the flow velocity decreases at the front and at back of the classroom resulting in low distribution of cold air at these locations. Rahman and Narahari [7] obtained about the same result where they found that the flow was stagnant at the back of the lecture room. Based on Figure 5 and 6, the warmest part of the room is walls of the classroom while the coldest is the location directly under the air-condition outlets. Based on the guidelines in Table 1, this coldest location is not within the thermal comfort guidelines outlined in Table 1. However, the rest of the room does fall within the thermal comfort temperature guideline. This would explain the findings of the survey and the measured temperature values in the previous section. The uneven temperature distribution maybe explained by the airflow velocity profile of Figure 3. Underneath the air-conditioning outlets, it can be seen that there is a rigorous circulation of the cold air, hence resulting in a concentration of cold air there. The cold air only gets distributed once it reaches the floor of the room. However, the amount of the cold air distributed and the temperature of the distributed air is higher than the air coming out of the air-conditioning outlet.

![Figure 1. Inside of the classroom.](image)

### Table 4. Readings (averaged) after one hour of switching the air-conditioners. Readings taken directly under the air-conditioning outlet.

| Parameter       | Measured value |
|-----------------|----------------|
| Wind speed      | 2.6 m/s        |
| Air temperature | 19.2 °C        |
| Relative humidity | 63%            |

### Table 5. Material Properties [12].

| Material     | Density (kg/m³) | Viscosity (kg/ms) | Thermal conductivity (W/m.K) | Specific heat (J/kg.K) |
|--------------|-----------------|-------------------|-----------------------------|------------------------|
| Air          | 1.225           | 1.7894x10⁻⁵       | 0.0242                      | 1006.43                |
| Brick        | 1600            | -                 | 0.69                        | 840                    |
| Gypsum       | 1440            | -                 | 0.48                        | 840                    |
| Carbon steel | 7833            | -                 | 54                          | 465                    |

### 5. Conclusion

It was found from the simulation that there is a poor distribution of cold air inside the classroom which led to the space in the immediate vicinity of the air-conditioner to be colder than the recommended thermal comfort guidelines. A few recommendations can be made to improve the condition of the classroom based on the results obtained. Reducing the speed of the cold air coming from the air-conditioner outlet might be able to increase the temperature of the cold spots in the room. Another possibility would be to change the location and size of the air-conditioners that would make the cold air to be distributed more evenly in the room and less cold than the current temperature. Lastly, a less practical recommendation would be to make the ceiling higher so that the length that the cold air takes to reach the floor becomes longer hence enabling the cold air to have time to get distributed to the surroundings. These recommendations need to be studied further to determine their effectiveness in
promoting thermal comfort in the room. It is worth mentioning here that the simulation did not consider the affects of relative humidity as the aim was only to assess the flow profile inside the room. Therefore, for the next phase of the project, relative humidity conditions will be included in the simulation model so that an overall thermal condition for the room may be known.

Figure 2. The geometrical model and layout of the classroom.

Figure 3. Velocity profile at selected locations in the classroom.

Figure 4. Temperature profile at selected locations in the classroom.

Figure 5. Temperature contour plots for the surrounding walls of the classroom.

Figure 6. Temperature contour plots for the chair-desk in the classroom.
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References

[1] Olesen B W and Parsons K C 2002 Introduction to Thermal Comfort Standards and To the Proposed New Version of EN ISO 7730 Energy and Buildings 34 (6) 537-548

[2] de Dear R J, Leow K G and Foo S C 1991 Thermal Comfort in the Humid Tropics : Field Experiments in Air Conditioned and Naturally Ventilated Buildings in Singapore Int J Biometeorology 34 (4) 259-265.

[3] Chong J L S, Husain A and Tuan T B 2005 Simulation of Airflow in Lecture Rooms Proceedings of the AEESAP International Conference 7-8.

[4] Ogoli D 2007 Thermal Comfort in a Naturally-Ventilated Educational Building ARCC Journal 4 (2) 19-26.

[5] Yau Y H and Chew B T 2009 Thermal Comfort Study of Hospital Workers in Malaysia Int. Journal of Indoor Environment and Health 19 (6) 500-510.

[6] Mohamed Kamar H, Kamsah N, Md. Tap M and Mohd Salimin K A 2012 Assessment of Thermal Comfort in a Naturally Ventilated Residential Terrace House, AIP Conference Proceedings 1440 247.

[7] Rahman M A and Narahari G A 2014 Analysis of Lecturing Room using Computational Fluid Dynamics Natural and Forced Ventilation Int. Journal of Engineering Research & Technology 3 (3) 653-659.

[8] Jain S K, Dadhich M, Sharma V, Sharma S K, Agarwal D and Gupta R 2015 Numerical Study on Thermal Comfort-A Case Study Using Taguchi Method Int. Journal of Recent Advances in Mechanical Engineering 4 (2) 121-136.

[9] Department of Standards Malaysia 2014 Malaysia Standard MS 1525: 2014, Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings – Code of Practice (Second Revisions).

[10] Department of Occupational Safety and Health, Ministry of Human Resources Malaysia 1996 JKKP:GP(1) 1/96 Guidelines on Occupational Safety and Health in the Office.

[11] Chartered Institute of Building Services Engineers Guide (CIBSE) Guide 1986 A Design Data London.

[12] ASHRAE: Thermal Environmental Conditions for Human Occupancy 2004 Standard 55-2004, American Society of Heating, Refrigerating, and Air-Conditioning Engineers Atlanta, USA.