Volume 3 Issue 2 (September 2023)
DOI 10.24191/jaeds.v3i2.65
eISSN 2805-5756

Journal of Applied Engineering Design & Simulation

The investigation of indoor air temperature effects for different types of window dimensions using CFD simulation

Nor Azirah Mohd Fohimi[1,3], Siti Shareeda Mohd Nasir[1,3,*], Norasikin Hussin[1], Rohidatun Mahmod@Wahab[1] and Nurulsaidatulsyida Sulong[2]

[1]Centre for Mechanical Engineering Studies, Universiti Teknologi MARA, Cawangan Pulau Pinang, Permatang Pauh Campus, 13500 Pulau Pinang, Malaysia.

[2]Centre for Mechanical Engineering Studies, Universiti Teknologi MARA, Cawangan Johor, Pasir Gudang Campus, 81750 Masai Johor, Malaysia.

[3]Advanced Mechanics Research Group, Centre for Mechanical Engineering Studies, Universiti Teknologi MARA, Cawangan Pulau Pinang, Permatang Pauh Campus, 13500 Pulau Pinang, Malaysia.

[*]corresponding author: shareeda.mn@uitm.edu.my

ABSTRACT

Windows plays an important role in heat transfer and natural ventilation in buildings. In the field of building design, the challenge is to provide a thermally comfortable indoor environment that requires the least energy consumption to maintain. One of the energy reduction alternatives that can be incorporated into modern building design is the installation of efficient windows. The windows should allow thermally acceptable indoor air quality and have a pleasant design while being energy efficient. Good thermal conditions in school buildings, especially learning spaces, promote the educational process. Unfulfilling comfort levels can reduce the lecturers' and students' physical and intellectual performance. One of the variables that affect the thermal comfort condition is indoor air temperature. The purpose of this study is to investigate the effect of different types of window dimensions on indoor air temperature by using Computational Fluid Dynamics (CFD) simulation. The selected classroom at Universiti Teknologi MARA (UiTM) Permatang Pauh, Pulau Pinang will be used as a case study. The field measurement result can be used to validate the simulation result. The simulation result will be compared to standard regulations set by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 55-2017. Three different types of window dimensions have been chosen in this study which are double, triple, and quadruple-glazed windows. The validation result shows the percentage difference in indoor air temperature between the experimental and simulation is 1.04 %. The result found double and triple-glazed windows show the value of temperature under the range set by ASHRAE Standard 55-2017. The selection of triple-glazed windows is more suitable because the brightness of the classroom meets the criteria for the absence of direct solar radiation. In conclusion, window dimension is a parameter that affects heat transfer and indoor air temperature of the classroom.

Keywords: Thermal Comfort; Indoor Air Temperature; Window Area; CFD Simulation

Nomenclature

^oC	Temperature
m	Length (Meter)
K	Temperature (Kelvin)
$W/m^2 \cdot K$	Heat Transfer Coefficient, U value
T_w	Window Temperature
T_i	Inlet Temperature
T_o	Outlet Temperature
m/s	Velocity (Meter/Second)
m^2	Area
%	Percentage

Received on 25.08.2023
Accepted on 20.09.2023
Published on 22.09.2023

Abbreviations

CFD	Computational Fluid Dynamics
UiTM	Universiti Teknologi MARA
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
IPCC	Intergovernmental Panel on Climate Change
HVAC	Heating, Ventilation, and Air Conditioning
WWR	Window-To-Wall Ratio
3D	3 Dimensional
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
BKA	Bilik Kuliah Awam
SIMPLE	Semi-Implicit Method for Pressure-Linked Equations

1.0 INTRODUCTION

Energy demand has increased widely with human needs for comfort and increasing activity indoors. The Intergovernmental Panel on Climate Change (IPCC) 6th Report indicated that the earth surface temperature rises 1.3^{o}C from 1850 to 1900 until 2010 to 2019 because of human activities [1]. Malaysia is located in a tropical region with a hot and humid climate where a large number of buildings are served by air-conditioning systems. Many studies have been conducted in buildings to reduce energy demand and consumption related to Heating, Ventilation, and Air Conditioning (HVAC) systems, mainly in hot and humid climates. The HVAC energy consumption in buildings is due to the high internal heat gains and high window-to-wall ratio (WWR). Most of the studies have been restricted to either air-conditioned buildings or buildings with one zone [2] and the knowledge of the impact of building form on energy consumption of naturally ventilated buildings is rare, especially for residential buildings and in hot humid climates.

The window creates an essential connection between indoors and outdoors and has a significant effect on the energy performance of a building, and shading devices that have been used for a long time to control solar gain and daylighting. Bre et al. [3] conducted a residential building design optimization where some rooms are mechanically ventilated, while some are naturally ventilated. In their study, a typical residential building in Argentina was selected for the case study and, as per the overall results, solar absorptance of external walls, thermal transmittance of external walls, orientation, and window area fraction for natural ventilation were considered as the important factors for reducing the cooling demand. The indoor thermal comfort can be kept up by giving fitting ventilation which depends on various segments, for example, wind power, outside temperature, enveloping building geology, stature, shape, window opening kind, size, and position. Thermal comfort is a critical index for the assessment of the indoor environment [4].

Ourghi et al. [5] provided a simplified analysis method to predict the impact of the shape of an office building on its annual cooling and total energy use. The simulations were conducted for four locations including Cairo, Tunis, Rome, and Gabes. The results showed a strong interdependency between the annual building energy use and various basic building features such as building geometry, glazing type, glazing size, and climate. On the effect of WWR and orientation on energy consumption, Alwetaishi [6] conducted research to identify the optimal WWR for educational buildings in several climatic regions and a WWR of 10 % is recommended for a hot and humid climate region. A study in Teheran suggested that the orientation can save up to 105 % of the annual energy of a building and the WWR has an important role in deciding the building orientation [7]. Hence, investigating the impact of orientation on energy efficiency is important while determining the effect of building shape on energy use.

Mirrahimi et al. [8] studied the effect of building form for the tropical climate in Malaysia, and in addition, other factors such as external walls, roofs, glazing area, and natural ventilation were also evaluated. To analyze the indoor air temperature the experiment is the common technique. For example, Atthajariyakul and Leephakpreeda [9] achieved the real-time determination of optimal indoor air condition by considering thermal comfort, air quality, and energy usage simultaneously. Experimental analysis is reliable and widely used in various environment evaluations [10,11]. Fohimi et al [12] conducted an experimental study to evaluate the performance of indoor air temperature in the laboratories. As a result, the data collected in the laboratories do not comply with the standards that have been standardized by Malaysia Standard.

With the rapid development of computer technology and numerical algorithms, CFD techniques provide an attractive alternative. In terms of thermal comfort, Nielsen et al. [13] were the first ones to apply the CFD technique to the field of ventilation and air conditioning. They measured and calculated the velocity characteristics of ventilated rooms by using laser-Doppler anemometry. Many CFD models have been successfully applied to the design and application of building environmental engineering. Many researchers studied thermal comfort from multiple aspects such as thermal comfort models [14], individual differences [15,16], and thermal comfort index

[17]. Xiang and Wang [18] evaluated the thermal comfort in a passenger compartment from several aspects such as three-dimensional (3D) temperature, PMV/PPD index distributions, and flow field by using FLUENT software. Poshtiri and Mohabbati [19] assessed the thermal comfort of a shower cooling system by using ANSYS software and a thermodynamic model. Also, they performed a parametric analysis on geometric parameters and different environmental conditions. Fuertes et al. [20] presented an experimental and numerical analysis to study the effects of building materials on the thermal comfort of the occupants. They classified the building materials using a thermal comfort parameter based on the transitory heat flow that occurs when the material comes into interaction with the human body.

The number of studies that apply CFD to educational buildings is increasing, but only a few of them have used simulations to evaluate indoor air temperature by different types of window dimensions. There is a gap in the current literature on this topic, especially for educational buildings located in hot and humid climates. The present study aims to establish a CFD model to conduct indoor air temperature analysis for a range of window dimensions. The numerical model is established using the software Fluent and validated against the experimental data. Based on the present CFD model, the effects of different types of window dimensions on the indoor air temperature in classrooms at UiTM Permatang Pauh are examined. The evaluation standard with respect to thermal comfort in the classroom is developed.

2.0 METHODOLOGY

2.1 Classroom Description

The classroom selected in this study was the Bilik Kuliah Awam (BKA) 2.10 (as shown in Figure 1) at the UiTM Permatang Pauh in Pulau Pinang, Malaysia. This classroom is located on the second floor of the civil engineering building and has two doors and four casement windows. This classroom has 15 ceiling lights, two return air grilles, four supply air conditioners, and four fans. Its dimensions are 13 m in length, 8.5 m in width, and 4 m in height. The purpose of measuring the classroom is to produce a 3D model of the classroom.

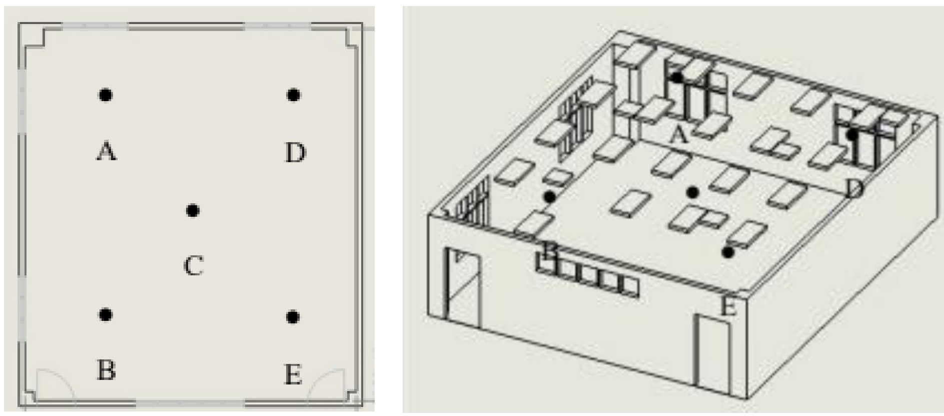
Figure 1. The view of Bilik Kuliah Awam (BKA) 2.10, UiTM Permatang Pauh

2.2 Field Measurement and Instrumentation

Measurements were made at five locations inside the classroom. The measuring instrument was placed at a height of 1.2 m from the floor. The sampling points were placed at the occupant’s breathing level which is 1.2 m above floor level. Indoor air temperature was conducted during the afternoon. The reading of variable indoor air temperature is taken in 30 minutes for each sampling point. This is the equipment used to conduct the field measurement which is a thermo-anemometer. Thermo-anemometer used to measure indoor air temperature in the selected classroom, UiTM Permatang Pauh. The percentage error of this device is less than the ±5 % range. The most accurate readings from an anemometer were obtained by holding the instrument in a vertical position. Figure 2 shows the equipment used to conduct the field measurements.

Figure 2. Thermo-anemometer used to conduct field measurements

The indoor air temperature reading was carried out at five selected sampling points, point A until E along the line intersecting between two perpendicular planes, vertical plane y-z and horizontal plane x-z (y = 1.2 m). The sampling points were placed at the occupant's breathing level which is 1.2 m above floor level according to the ASHRAE 55-2017 standard [21]. Figure 3 shows the five sampling points for taking an indoor air temperature reading in the classroom. The experimental time is 2 hours and 30 minutes and the monitoring data are collected each 1 minute. The experiment is strictly conducted according to the testing procedure, and it is repeated 3 times.



(a) (b)

Figure 3. The five sampling points for taking indoor air temperature readings (a) top view (b) isometric view.

2.3 CFD Simulation

The CFD tool is very effective and widely used to simulate the real indoor environment to study the complex indoor fluid flow. The CFD details are described in the following sections in addition to the grid sensitivity and validation studies.

2.3.1 3D Model of Classroom

A simplified geometry of the classroom was developed using the Solidwork 2021 software. According to the actual dimensions of a selected classroom, UiTM Permatang Pauh, and the distribution of equipment, the geometry model of the classroom is established and shown in Figure 4.

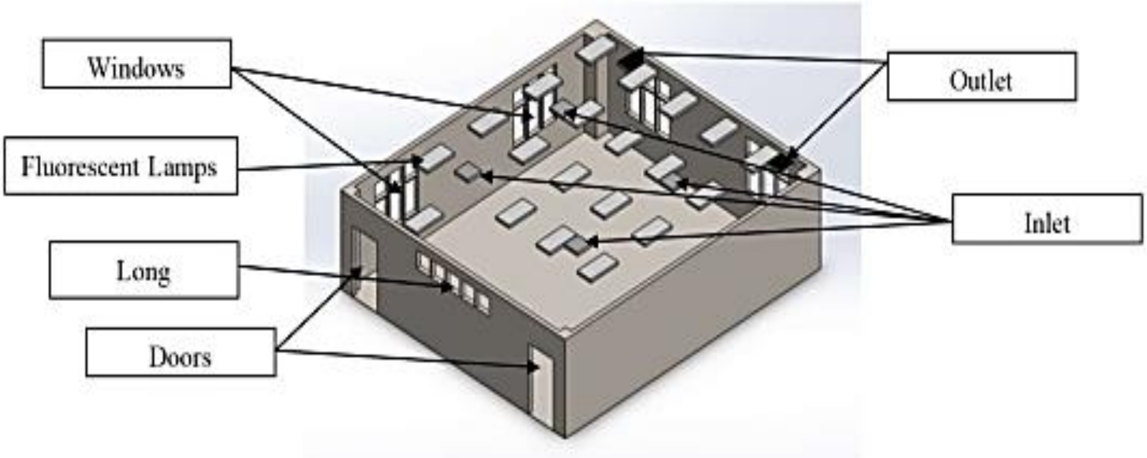


Figure 4. The details of the 3D model developed in Solidwork2021.

Considering the diversity and complexity of furniture, the classroom model is simplified reasonably. Firstly, the radiation effect of the sun on the wall is not considered. Secondly, the blade rotation of the fan is not considered to simplify the computational model. Thirdly, all cases assume the window is a closed condition, so not contribute to air velocity as natural ventilation in this study.

2.3.2 Mesh Domain

The purpose of meshing is to decompose the solution domain into an appropriate number of locations for an accurate result. A mesh divides space into elements (or cells or zones) over which equations can be solved, which gives an approximation of the solution over the larger domain. Greater numbers of elements require more computational time. The grids are generated by tetrahedral cells. The classroom model is discretized on a hybrid grid by combining both structured and unstructured grids. The computational grid is shown in Figure 5.

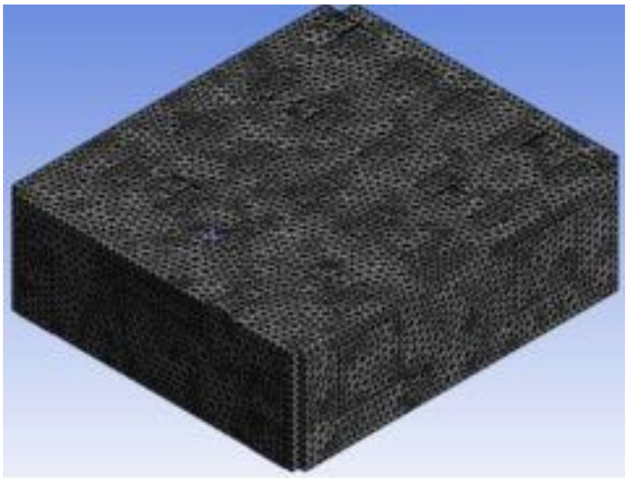


Figure 5. Computational grid of the classroom model

The mesh ranged in size from 0.2 m to 0.7 m. For the numerical model, a total of 13422 tetrahedron meshes were made to find a good balance between grid convergence and how quickly the model could be run. Table 1 shows the details of the mesh in the geometry.

Table 1. The details of the mesh in the geometry

No.	Description	Type of Mesh	Type of Element	No of Element
1.	Interior Classroom	Body	Tetrahedral	2567
2.	Wall and Floor	Face	Triangular	2057
3.	Door	Face	Triangular	217
4.	Return Air	Face	Triangular	143
5.	Supply Air	Face	Triangular	102

2.3.3 Flow Condition and Boundary Condition

The indoor fluid is viewed as a steady turbulent flow. Therefore, the steady-state standard k-turbulence model is implemented to model the classroom environment. The Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm is used to decouple the velocity and pressure. The turbulence term was treated using the second-order upwind scheme, and the diffusion terms were treated using the central difference scheme. The grid study was conducted with the standard k-ε model. The turbulence model employed by the software is the RANS which is a κ-ε model. The energy model is used to simulate the temperature variations inside the classroom because it is two extra differential equations that now need to be used as the temperature and velocity. This is again the most widely validated method and shows good performance for most practical applications.

The accuracy of CFD simulations strongly depends on the appropriate setting of boundary conditions. Boundary conditions are defined inlets and outlets for the flow. The classroom wall, floor, and door are non-permeable, no-slip boundary conditions applied there, and are also assumed as adiabatic. The details of the boundary conditions are listed in Table 2.

Table 2. List of Boundary Conditions

No.	Boundary Condition	Value/Term Applied
1.	Wall	Adiabatic
2.	Window	Isothermal, T_w = 273 K Heat Transfer Coefficient = 0.96 $W/m^2 \cdot K$
3.	Supply Inlet Temperature	Isothermal, T_i = 298 K
4.	Return Outlet Temperature	Isothermal, T_o = 299 K
5.	Velocity Inlet	0.08 m/s
6.	Velocity Outlet	4 m/s

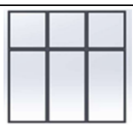
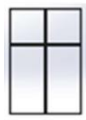
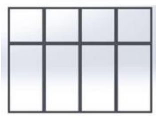
2.4 Validation of Simulation Result

Simulation validation determines the percentage difference between the measured and simulated values. According to the ASHRAE standard, the maximum acceptance percentage differences are less than 25% between the measurement and simulation result which requires satisfaction for thermal comfort. The percentage difference is calculated from the graph of indoor air temperature for both results (measurement and simulation) versus the sampling points selected.

2.5 Analysis of Different Types of Window Dimensions

The analysis of indoor air temperature is investigated on the three types of window areas. Table 3 shows the three types of window areas considered in the present study. The U value which is the heat transfer coefficient is affected by the window area. Based on the three evaluation window areas, we intend to appropriately assess the thermal environment in the selected classroom, thus finding suitable window dimensions.

Table 3. The types of window areas classroom simulation conditions

Cases	Window Area (cm^2)	Window Types	Heat Transfer Coefficient, U Value ($W/m^2 \cdot K$)
1.	Window A, 31500		0.96
2.	Window B, 21875		1.09
3.	Window C, 41125		0.83

3.0 RESULTS AND DISCUSSION

This study is to investigate three different types of window dimensions that affect the indoor air temperature inside the classroom. The value of indoor air temperature for each window area is to create a thermal environment that is comfortable for students with a design that includes four supply air inlets, two return air outlets, and four windows. As a result, three numerical cases were created in order to compare and evaluate the indoor air temperature environment as well as the air circulation within the classroom.

3.1 Indoor Air Temperature for Window A

Window A is the actual window inside the classroom. The design for window A has a triple-glazed window that has a height of 175 cm and a length of 180 cm.

3.1.1 Experimental Data of Indoor Air Temperature for Window A

Table 4 shows that each sampling point has its own value of indoor air temperature for window A. Point A shows a higher value than all other points because Point A is close to the windows and below the outlet. As a result, the indoor air temperature difference value between sampling points in the classroom is not that different. The experimental value for sample points B through E is roughly the same, which is 299 K because the points are not exposed to heat and the air temperature of the airflow remains constant. As a result, the indoor air temperature rises slightly as the point ratio near the heated area source.

Table 4. Experimental value of indoor air temperature for Window A

Sampling Points	Indoor Air Temperature (K)
A	300.1
B	299.4
C	299.2
D	299.9
E	299.9

3.1.2 Simulation Data of Indoor Air Temperature for Window A

Indoor air temperature was analyzed by plotting the contour air temperature on the four monitoring planes. The air temperature readings were carried out at five selected sampling points, point A until E along the line intersecting between two perpendicular planes, vertical plane y-z and horizontal plane x-z (y = 1.2 m). Higher air temperature values (orange color) are on the plane close to the window and outlet such as Point A refer to Figure 6. The value air temperature for Point A is 300 K as tabulated in Table 5. This is due to the fact that the closer to the window that is exposed to the heat. The middle plane y-z of the class referred to as the center class is found to be green in color because it was close to the four supply units of the air conditioner. Point C is located at the center of the classroom where the air temperature is 296.1 K the coldest among the other points. The temperature of the window, inlet, and outlet air conditioners has the greatest influence on the rate of indoor air temperature response.

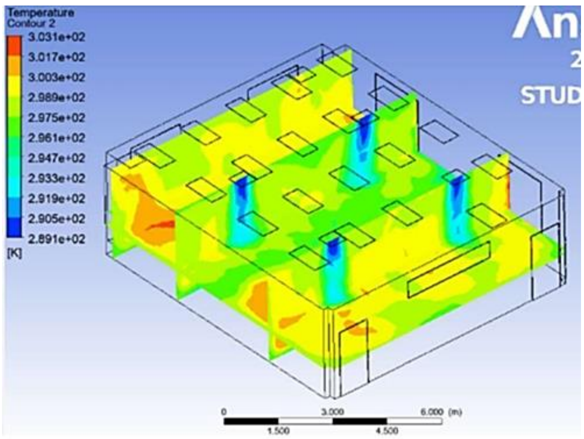


Figure 6. Simulation result of Window A

Table 5. Data of simulation air temperature for Window A

Sampling Points	Indoor Air Temperature (K)
A	300.0
B	299.3
C	296.1
D	299.4
E	298.3

3.1.3 Validation of Simulation Result

Table 6 indicate the percentage difference between the experimental and simulation result of all sampling points for validating the simulation result. The simulation results are generally consistent with the experimental data. As a result for points A and point B the lowest percentage difference is only 0.03 %. This is due to the air temperature for experimental and simulation is similar. The highest percentage difference among the other points is at point C which is 1.04 % but the simulation result still can be accepted because according to the ASHRAE standard, the maximum acceptance percentage difference is less than 25 %. Therefore, the modified CFD model can reasonably predict the real classroom environment.

Table 6. Percentage difference between experimental and simulation results

Sampling Points	Percentage Difference (%)
A	0.03
B	0.03
C	1.04
D	0.17
E	0.53

3.2 Simulation Data of Indoor Air Temperature for Window B

The effects of window area B are considered in the modified CFD model, as shown in Figure 7. The design for window B has double glazed window that has a height is 175 cm and a length is 125 cm. This demonstrates that the length of window B is shorter than the length of window A. The boundary condition at window B is set as 1.09 $W/m^{2} \cdot K$ for heat transfer coefficient, U value. Other boundary conditions are kept the same as those used in Section 2.3.3 Table 7 shows the value of air temperature for all sampling points of window B. According to the result of the air temperature simulation for window B, the temperature in the classroom is colder than the air temperature in window A. This is because the window is smaller than the actual window dimension, exposing less heat in the classroom.

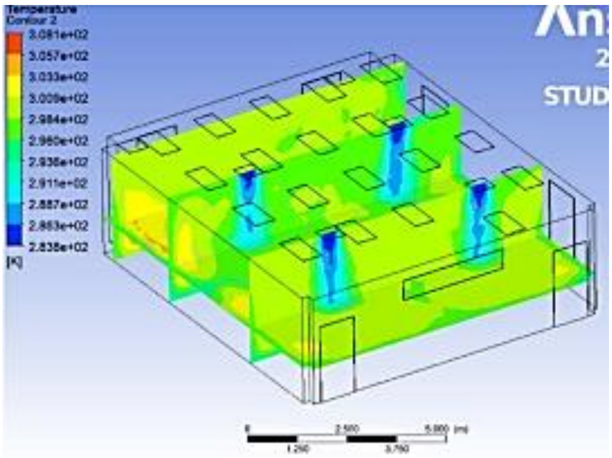


Figure 7. Simulation result of Window B

Table 7. Data of simulation air temperature for Window B

Sampling Points	Indoor Air Temperature (K)
A	299.1
B	299.4
C	296.0
D	293.4
E	292.4

3.3 Simulation Data of Indoor Air Temperature for Window C

The design for window C has a quadral glazed window that has a height is 175 cm and a length is 235 cm. This demonstrates that the length of window C is greater than the length of windows A and B. Table 8 shows the value of air temperature for all sampling points of window C. The result shows air temperature is higher than the temperature in window A. This is because the window looks bigger than it really is, so more of the heat from the window gets into the classroom. The temperature in the classroom increases as the area of the window increases. Figure 8 shows the contours of air temperature for Case 3. The air temperature at the supply unit ventilation system is cold (blue color). However, the value of air temperature increases from supply air unit ventilation (blue color), cold environment to return air unit ventilation and near the windows (red color), warm environment because of airflow distribution. It is found that the air temperature increases obviously and the thermal comfort is dropped as the window area increases leading to a warm environment.

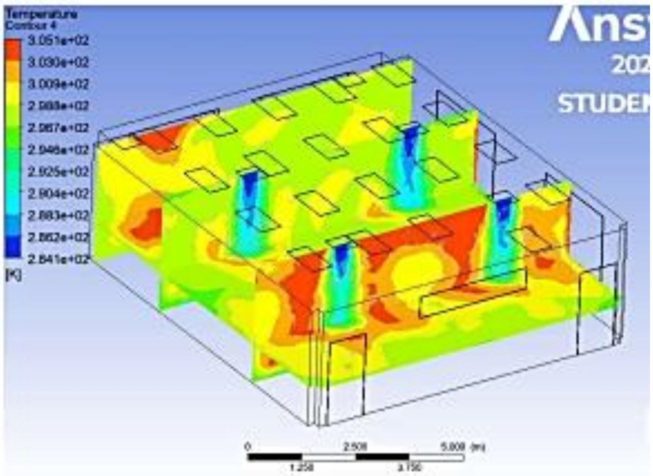


Figure 8. Simulation result of Window C

Table 8. Data of simulation air temperature for Window C

Sampling Points	Indoor Air Temperature (K)
A	303.2
B	302.8
C	299.1
D	301.4
E	299.6

3.4 Comparison of Indoor Air Temperature Between All Window Area

Each of the sampling points of simulations was compared with the ASHRAE Standard 55-2017. According to ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy, indoor air temperatures should range from 19.32 to 27.94 °C for thermal comfort. The standard can be used to establish a more precise range, but it also depends on other variables such as activity levels, clothing worn, season, and relative humidity.

Table 9 shows the comparison of the indoor air temperature for all window areas. The air temperatures are in the range limit except for points A, B, and D for window C. The window area has the biggest impact on the indoor air temperature. The indoor air temperature is low for the double-glazed window due to its small area that allows less heat from entering the space. The temperature in the triple-glazed window is higher than the double-glazed window, while the quadruple-glazed window has the highest air temperature. This is because the classroom absorbs more heat when the area of the window is larger. The study found that the lowest temperature was found in the classroom with a double and triple-glazed window. The quadruple window frame consequently has the warmest air temperature in the classroom. Therefore, double and triple-glazed windows are the most suitable from a thermal technical perspective. A triple-glazed window area is feasible when the room brightness satisfies the criteria for the absence of direct solar radiation. As the window size increases, the temperature inside increases.

In the three simulated cases, the indoor air temperature increased with the window area, demonstrating that solar radiation significantly affects indoor air temperature. Reducing the area of windows is probable to decrease building energy consumption. By adding the window, the classroom will receive more natural light while also increasing the air temperature.

Table 9. Comparison of indoor air temperature between the simulation result

Sampling Points	Indoor Air Temperature (K)			
	ASHRAE standard	Window A	Window B	Window C
A		300.0	299.1	303.2
B		299.3	299.4	302.8
C	292.3 - 300.9	296.1	296.0	299.1
D		299.4	293.4	301.4
E		298.3	292.4	299.6

4.0 CONCLUSION

In this study, a CFD model was established to simulate a classroom condition in terms of indoor air temperature. To validate the reliability of the present CFD method, an experiment was conducted to measure the air temperature in the selected classroom. Based on the experimental data, an improved CFD model was established in terms of validation. With this CFD model, the indoor air temperature of the classroom was studied under different types of window dimensions. The results of the validation CFD model are consistent with the experimental data in terms of percentage difference. The highest percentage difference between experimental and simulation results is 1.04 %. The percentage difference can be accepted because according to the ASHRAE standard must be lower than 25%. Based on the validated CFD model, the effects of window area on indoor air temperature comfort can be evaluated. The conclusion obtained from the present study is air temperature is an important index for identifying thermal comfort. It reflects the heat absorbed through the window of entering the classroom. The lower the value of the air temperature in the limit range stated by ASHRAE Standard 55-2017 the better thermal comfort. This study found a correlation between indoor air temperature and window dimension. The results show that the window dimension has a significant effect on the simulation of the classroom environment. Hence, the effect of the window dimension cannot be ignored. This shows that indoor air temperature increased with the window area. Because larger window areas let in more heat absorbed into the classroom. The indoor air temperature of the classroom directly affects thermal comfort. The result found double and triple-glazed windows show the value of temperature under the range set by ASHRAE Standard 55-2017. The selection of triple-glazed windows is more suitable because the brightness of the classroom meets the criteria for the absence of direct solar radiation. Good thermal comfort on indoor air temperature evaluation is obtained in case 1 with a triple-glazed window. Thus, it can be concluded that the thermal comfort of indoor air temperature is effective with existing windows (actual condition) in the classroom.

ACKNOWLEDGEMENT

This research was not funded by any grant. The authors would like to thank UiTM Permatang Pauh for granting us permission to conduct site measurements inside the classroom and express their appreciation for giving us the opportunity and support to do this research study.

REFERENCES

[1] “Climate Change 2021: The Physical Science Basis,” Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, 2021.

[2] S.M. Bambrook, A.B. Sproul and D.J. Bambrook, “Design optimization for a low energy home in Sydney,” *Energy Build.*, vol. 43, no. 7, pp. 1702–1711, 2011.

[3] F. Bre, A.S. Silva, E. Ghisi and V.D. Fachinotti, “Residential building design optimization using sensitivity analysis and genetic algorithm,” *Energy Build.*, vol. 133, pp. 853–866, 2016.

[4] W. Yang, N.H. Wong and C.Q. Li, "Effect of street design on outdoor thermal comfort in an urban street in Singapore," *Journal of Urban Planning and Development*, vol. 142, no. 1, p. 05015003, 2016.

[5] R Ourghi, A. Al-Anzi and M. Krarti, "A simplified analysis method to predict the impact of shape on annual energy use for office buildings, " *Energy Conversion and Management*, vol. 48, no. 1, pp. 300-305, 2017.

[6] M. Alwetaishi, “Impact of glazing to wall ratio in various climatic regions: a case study,” *Journal of King Saud University-Engineering Sciences*, vol. 31, no. 1, pp. 6-18, 2019.

[7] D. Gomez-Mejia and B. Luis, “Optimisation of building shape and orientation for better energy efficient architecture,” *J. Manag. Dev*, vol. 23, no. 7, pp. 635-648, 2007.

[8] S. Mirrahimi, M.F. Mohamed, L.C. Haw, N.L.N. Ibrahim, W.F.M. Yusoff and A. Aflaki, “The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate,” *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 1508-1519, 2016.

[9] S. Atthajariyakul and T. Leephakpreeda, “Real-time determination of optimal indoor-air condition for thermal comfort, air quality and efficient energy usage,” *Energy and Buildings*, vol. 36, no. 7, pp. 720-733, 2004.

[10] E. Kuchen and M.N. Fisch, “Spot Monitoring: thermal comfort evaluation in 25 office buildings in winter,” *Building and Environment*, vol. 44, no. 4, pp. 839–847, 2009.

[11] L. Chang, X. Zhang and Y. Cai, “Experimental determination of air inleakage to pressurized main control room caused by personnel entering,” *Building and Environment*, vol. 99, pp. 142–148, 2016.

[12] N.A.M. Fohimi, K.M. Hyie, S.S.M. N. Hussin and F. Idrus, “Experimental Study of Indoor Air Temperature in the Laboratory,” *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer*, vol. 9, no. 1, pp. 1-8, 2022.

[13] P.V. Nielsen, A. Restivo and J.H. Whitelaw, “The velocity characteristics of ventilated rooms,” *Journal Fluid Engineering*, vol. 100, no. 3, pp. 291–298, 1978.

[14] Y. Cheng, J. Niu and N. Gao. “Thermal comfort models: A review and numerical investigation,” *Building and environment,* vol. 47, pp. 13-22, 2012.

[15] R.F. Rupp, N.G. Vásquez and R. Lamberts, “A review of human thermal comfort in the built environment,” *Energy and buildings,* vol. 105, pp. 178-205, 2015.

[16] Z. Wang, R. de Dear, M. Luo, B. Lin, Y. He, A. Ghahramani and Y. Zhu, “Individual difference in thermal comfort: A literature review,” *Building and Environment,* vol. 138, pp. 181-193, 2018.

[17] D. Enescu, “A review of thermal comfort models and indicators for indoor environments,” *Renewable and Sustainable Energy Reviews,* vol. 79, pp. 1353-1379, 2017.

[18] L.P. Xiang and H.Q. Wang, “Thermal comfort study based on airflow within a passenger compartment,” *Applied Mechanics and Materials,* vol. 730, pp. 109-112, 2015.

[19] A.H. Poshtiri and S.M. Mohabbati, “Performance analysis of wind catcher integrated with shower cooling system to meet thermal comfort conditions in buildings,” *Journal of Cleaner Production,* vol. 148, pp. 452-466, 2017.

[20] E. Enríquez, V. Fuertes, M. J. Cabrera, J. Seores, D. Muñoz, W. More and J.F. Fernández, “Model to evaluate the thermal comfort factor: Dynamic measurement of heat flow in building materials,” *Journal of Building Engineering,* vol. 20, pp. 344-352, 2018.

[21] ASHRAE Standard 55, “Thermal Environmental Conditions for Human Occupancy,” 2017.