

Original Article

Determination and Standardization of Air Conditioning Requirements for Lecture Rooms: A Computational Fluid Dynamics (CFD) Modeling and Analysis

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Abstract - This study presents the air-conditioning requirements for a typical lecture room at Tarlac State University by integrating cooling load calculations with computational fluid dynamics focused on thermal comfort simulation. Cooling loads for a 9 m × 7 m × 2.8 m classroom accommodating 51 occupants are calculated based on the Carrier E20 method and Department of Energy guidelines, yielding a peak cooling load of 12.12 kW for top-floor classrooms and 10.20 kW for lower floors, corresponding to two 2.5 HP and two 2.0 HP air-conditioning units, respectively. CFD simulations are performed to assess air temperature, velocity distribution, and Predicted Mean Vote at different positions for window-type and wall-mounted split-type ACUs, considering three volume flow rates with a supply air temperature of 14 °C. Results show that increasing airflow improves air mixing and shifts PMV toward the ASHRAE-recommended comfort range of -0.5 to +0.5. Optimal thermal comfort was achieved within the range of 0.25–0.35 m³/s, with 0.25 m³/s providing near-neutral conditions and 0.35 m³/s yielding slightly cool conditions, equivalent to setting the ACU to 23°C and 21 °C, respectively. Also, the results indicate that the upper position is the optimal installation location for the window-type ACU. For a temperature setting of 24 °C, simulation results indicate slightly warm conditions, particularly at lower airflow rates. The findings of this study contribute to practical recommendations for ACU sizing, placement, and operation.

Keywords - Air Conditioning Simulation, Computational Fluid Dynamics (CFD), Cooling Load Calculation, Lecture Room Temperature, Thermal Comfort Simulation.

1. Introduction

Thermal comfort plays an important role in building construction. About 90% of people spend their time indoors, notably of people residing in urban areas [1]. Thus, indoor air quality and conditions are critical aspects to evaluate. The fundamental purpose of ventilation systems, including air conditioning units and fans, is to establish an artificial environment that ensures occupant comfort. Multiple characteristics, including air distribution, temperature, humidity, and mean radiant temperature, regulate the climatic conditions of a room; these factors are crucial for the thermal comfort and well-being of its occupants [2].

ASHRAE (2017) defines thermal comfort as the condition of mind that expresses satisfaction with the thermal environment, influenced by environmental factors such as air velocity, temperature, and humidity, and by personal factors such as clothing insulation and metabolic rate [3]. In the Philippines, the annual average temperature is 26.6°C, with the temperatures ranging from a minimum of 25.5°C in January and climbing to a maximum of 28.3°C in May; while

the annual average relative humidity varies from 71% to 85% [4]. Thus, it is critical to create a comfortable environment for learning. Lamsal et al. (2023) analyzed thermal comfort in offices and concluded that human productivity is directly related to thermal comfort, with adaptive strategies (fans, clothing adjustment, set-point flexibility) central to sustaining satisfaction and performance [5]. Similarly, Bueno et al. (2021) conducted a systematic review of 60 studies to investigate the relation between thermal comfort and occupant productivity [6]. The results showed that peak performance is between 21°C and 22 °C.

Their findings suggest that thermal dissatisfaction acts as a primary stressor, diverting cognitive energy away from work tasks toward physiological regulation. Chen et al. (2018) also support this claim by identifying that differences in air flow speed in a room affect the temperature and comfort levels of people within [7]. This is shown by an air map made by simulating a convenience shop with only one air conditioning unit. In relation to thermal comfort in a learning or educational setting, it is found that thermal comfort from air conditioning



plays a significant role in the design of HVAC systems for buildings [8]. Furthermore, there is a direct relationship between thermal comfort and the performance of students in a well-conditioned lecture room; performance of students increased by 20% when temperatures dropped from 30°C to 20°C [9, 10]. Hotter classrooms create an environment where it is harder for students to learn; for instance, test scores and the motivation of the student fall as the temperature rises in the classroom [11]. Sacobson (2018) examined the test scores of ten million high school students, wherein it was found that rising temperatures reduce the learning of math and reading achievement of students [12]. Park et al. (2020) found that the implementation of air conditioning systems in the schools entirely offsets the effect of rising temperature [13].

Without air conditioning, each 1°F increase in the classroom reduces the amount of learning by 1% of the student. The benefit of installing the appropriate ventilation systems in schools outweighs the costs. Adhvaryu et al. (2018, 2020) supported this by stating that installing the appropriate air conditioning systems in campuses provides significant economic benefit to the students, wherein improvements in the school infrastructures justify more than their cost in terms of the benefits it brings to its students [14].

Also, parameters such as temperatures, humidity and air velocity must be observed and controlled. Lourenço Niza & Broday (2022) stated that humans feel comfortable at 21 to 23°C and a relative humidity of 40 to 60% [15]. Similarly, 70% of students who use the library feel comfortable at a temperature of 22 to 25°C. Another key point to take note of is that students tend to spend a longer time in the library when they feel satisfaction with their thermal comfort [16].

In addition, Mina & Tayactac (2024) conducted Computational Fluid Dynamics (CFD) research to evaluate thermal behavior and energy use in commercial and residential buildings [17]. The researchers stated that in indoor temperatures between 21°C and 23 °C, with relative humidity of 50% to 55%, commercial building occupants feel comfortable.

Furthermore, Tawil (2018) suggested that there is a direct relationship within the air velocity and heat transfer in a room, where in the higher the velocity of the air supplied by air distribution systems is, the higher the heat transfer will be [18]. Sansaniwal et al. (2020) further concurred this claim by conducting a similar study where changes were performed on the velocity of air in a confined office space, and the results show that workers feel the most comfortable with moderately moving air between 0.90 m/s and 1.10 m/s at 23°C [19].

Consequently, the placement of air conditioning units used for air distribution should also be considered. Directly placing the air conditioner in line with the occupants will cause a high air velocity in the work area; this would make

workers feel uncomfortable when working with a draft sensation. It is also recommended to place the air conditioner just slightly angled towards the non-working space of the room to minimize the draft sensation felt by the workers [20]. Subsequently, thermal comfort is associated with the distribution of temperature and airflow within the air-conditioned space [21]. Both air and mean radiant temperature are equally important to thermal comfort to provide a suitable thermal condition [22]. Another factor in this is human activity; it can have a possible effect on the airflow pattern within the indoor environment [23].

Moreover, the Philippines' Department of Energy provides guidelines on designing and constructing buildings, which include building materials and properties, indoor and outdoor design conditions, and cooling load temperature difference for proper sizing of air conditioning units [24, 25]. Carrier, one of the leading air conditioning companies, provides guidelines on cooling load calculation with the aid of the E20 Spreadsheet [26].

However, these guidelines do not specify the type of Air Conditioning Unit (ACU) to be installed or the optimal installation location for optimum thermal comfort. Tarlac State University (TSU), one of the leading state universities in Central Luzon, aims to optimize energy consumption by implementing measures to reduce electricity usage.

One of these measures is properly setting the air conditioning thermostat not less than 24 °C; however, TSU has no local study yet regarding the optimal temperature setting for lecture rooms or classrooms to achieve students' and faculty's thermal comfort, considering optimum energy usage. Additionally, based on some of the University's school building plans, there are different locations for air conditioning installation, which obviously affect temperature and air velocity distributions and occupants' comfort.

Therefore, the present study aims to determine the air conditioning requirements for a standard lecture room accommodating up to 51 occupants (50 students, 1 faculty), considering thermal comfort criteria. Specifically, this study aims to: (a) perform cooling load calculation to determine the appropriate size of ACU's based on DOE guidelines and Carrier system design manual; (b) predict room air temperature, velocity distribution, and Predicted Mean Vote (PMV) in terms of different supply air volume flow rates at different ACU locations using CFD simulation software, (c) recommend the best ACU settings based on thermal comfort parameters resulted from the CFD simulation.

The findings of this study have an important impact on the design of educational classrooms as to the proper or standard size and installation location of air conditioning units. The results can serve as a basis for policy development to conserve energy by optimizing air conditioning unit settings

while maintaining occupants' thermal comfort. This study focused on CFD simulations of ACUs in a lecture room at TSU using free CFD software. The size of the air conditioning units is based on the result of cooling load calculation using the Carrier E20 Spreadsheet described in the Carrier System Design Manual. Cooling load indoor and outdoor design conditions, and equivalent temperature differences are based on the DOE guidelines. Other heat transfer coefficients not available in the guideline were obtained from the Carrier manual, using the highest value to determine the appropriate air conditioning unit size.

Meanwhile, building design and room dimensions, including building orientation, are based on the latest TSU building design and the Philippines Building Code [27]. The number of occupants considered is only fifty-one (51), which includes fifty (50) students and one (1) faculty member.

Volume flow rates and air supply temperature are based on available data from product catalogues and typical values only. Relative humidity was held constant at 55%, and the ceiling fans and the ACU louver swinging effect on thermal comfort were not considered due to software limitations.

Additionally, to speed up the simulation and analysis, air temperature, velocity, and PMV thermal comfort parameters were only considered. CFD simulations were performed in the room with the highest cooling requirement. As for the type of air conditioning unit, only window-type and wall-mounted

split-type units were considered, as these are the cheapest options available. This study uses FloEFD for SolidEdge for the software together with a personal computer having 32GB RAM and 2TB.

2. Methodology

The present study applies a simulation-based, quantitative research design using CFD to evaluate and optimize ACU locations based on indoor thermal comfort criteria (air temperature, air velocity, and PMV). The research methodology is illustrated in Figure 1.

2.1. Data Gathering and CAD Modelling

The data needed for cooling load calculation and CFD simulations are presented in the following tables. Table 1 lists the design conditions from the DOE guideline. Table 2 presents the necessary data for the cooling load calculation based on the Carrier E20 spreadsheet [26]. Meanwhile, Figure 2 shows the CAD model of the academic building and its orientation, drawn in Autodesk Revit.

The building has three storeys, each with multiple lecture rooms or classrooms. The classroom CAD model shown in Figure 3 has dimensions of 9 x 7 x 2.8 m. This complies with the building code requirement for a lecture room [27]. The chair and occupant models were simplified to reduce the number of cells in the CFD simulation. The occupants' heights are based on the average Filipino height, as shown in Figures 3 and 4.

Table 1. Design condition

	Indoor design condition	Outdoor design condition
Design Dry bulb temperature	25 °C	34 °C
Minimum dry bulb temperature	23 °C	27 °C
Maximum dry bulb temperature	27 °C	---
Design Relative Humidity	55 %	58.4 %
Minimum Relative humidity	50 %	---
Maximum Relative Humidity	60 %	---

Meanwhile, Figure 2 shows the CAD model of the academic building and its orientation, drawn in Autodesk Revit. The building has three storeys, each with multiple lecture rooms or classrooms. The classroom CAD model shown in Figure 3 has dimensions of 9 x 7 x 2.8 m. This

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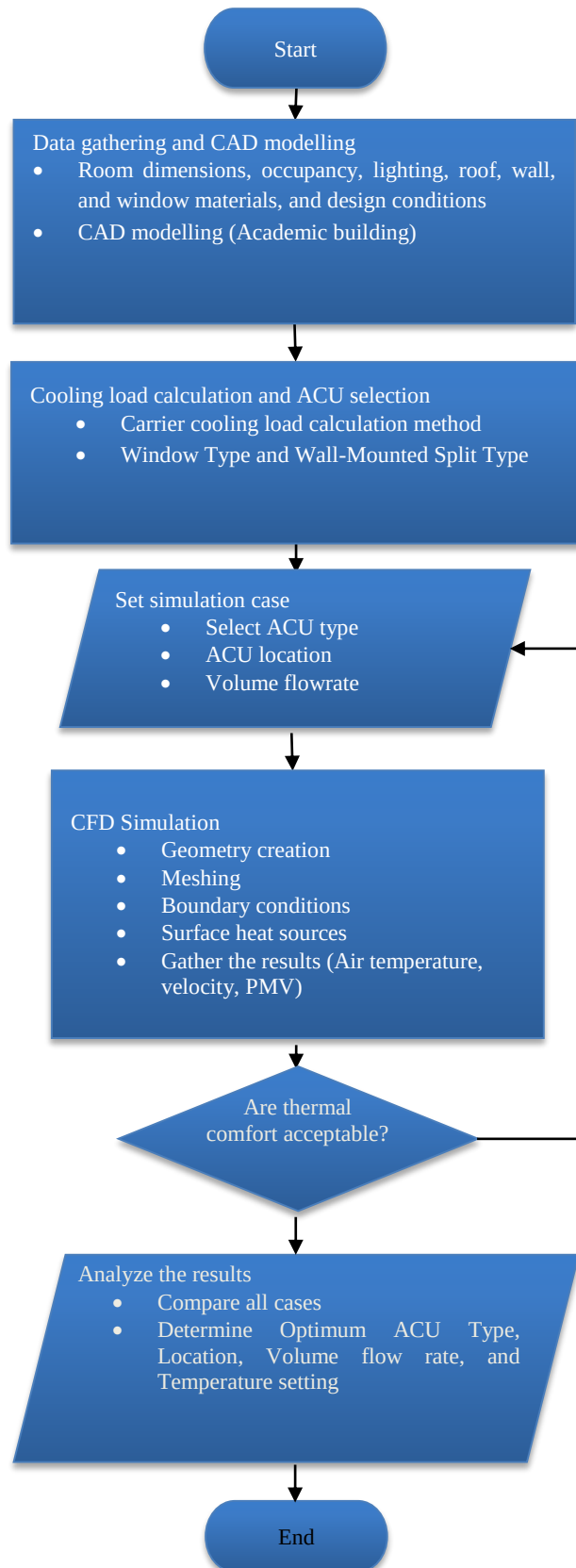


Fig. 1 Research methodology

2.2. Cooling Load Calculation and ACU Selection

To simplify and speed the cooling load calculation, the procedure described in the Carrier E20 spreadsheet was adopted. Fatin Alia Binti Isa & Farid Bin Sies (2023) compared with one of the leading software for cooling load, the results are similar, thus making the E20 spreadsheet reliable for cooling load. The cooling load result was then used to select the appropriate ACU size [28]. This study considers window-type and wall-mounted split-type ACUs, as they are the most affordable options.

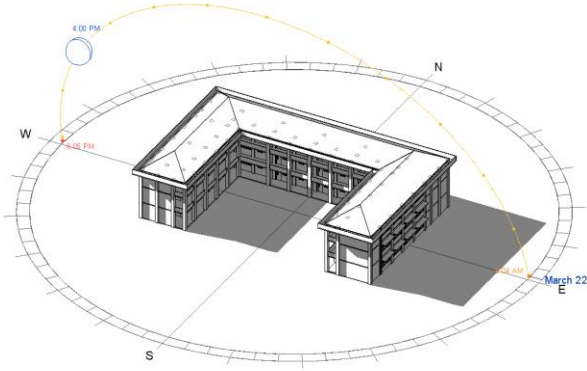


Fig. 2 CAD model orientation of the TSU Academic building

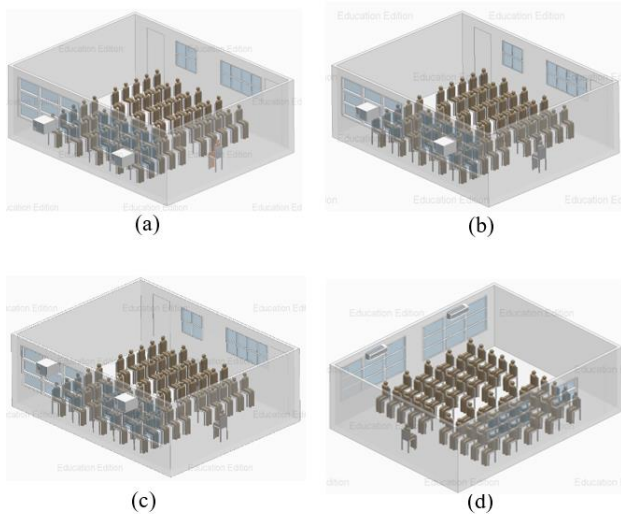


Fig. 3 Classroom, Occupants CAD model, and ACU locations, (a) Lower position, (b) Middle position, (c) Upper position, and (d) Split-type ACU.

The location of the Window-type ACU is determined by the window design (based on the building plan), and the ACU can be installed there. Thus, three positions for the window-type ACU were considered, as shown in Figure 3 (a)-(c). The split-type ACUs were divided equally by classroom length and are at least 7 inches below the ceiling, according to the available split-type installation manual; thus, the split-type ACU location considered for the simulation is shown in Figure 3(d).

For each location in Figure 3, three volume flow rates were simulated based on the available ACU specifications from product catalogues. These are based on the ACU size and are accompanied by measured and typical air-supply temperatures of 14 °C. The volume flow rates are: Low: 0.20 m³/s; Medium: 0.25 m³/s; and High: 0.35 m³/s.

2.3. CFD Simulation of Classroom ACUs

The CFD simulation procedures of this study follow the HVAC module tutorial in SolidWorks [29], as the software used has the same user interface. Using the CAD models shown in Figure 3, CFD simulations were performed to predict thermal comfort for occupants (50 students and 1 faculty member), considering the types and locations of ACUs described in the previous section.

2.3.1. Mesh Refinement Setting

Due to hardware and software limitations, the total number of cells was limited based on the level of initial mesh from 1 to 3 only. The global mesh setting was set to Automatic, and the level of initial mesh can be set using the Global Mesh Settings window shown in Figure 3. Also, mesh refinement was delimited based on the refinement level for the fluid cells, solid cells, and solid-fluid boundary. Additionally, an equal local mesh refinement level of up to 6, as shown in Figure 4, was only applied due to these limitations and for simplicity.

The mesh refinement level was applied to the ACU supply grills and to the occupants. The personal computer used in the study can only run up to 10M total cells, which was reached when the initial mesh level is 3, and the mesh refinement level is 6, as shown in Figure 5. The comparison of global mesh and refinement-level settings is summarized in Table 2. The global goals of operative temperature, average fluid temperature, and air velocity were observed in the solver display of the goal plot, considering a single setting and configuration of ACU only. It can be observed that there are no significant differences between the values, thus the level 1 global mesh setting was used for all configurations discussed in the previous sections.

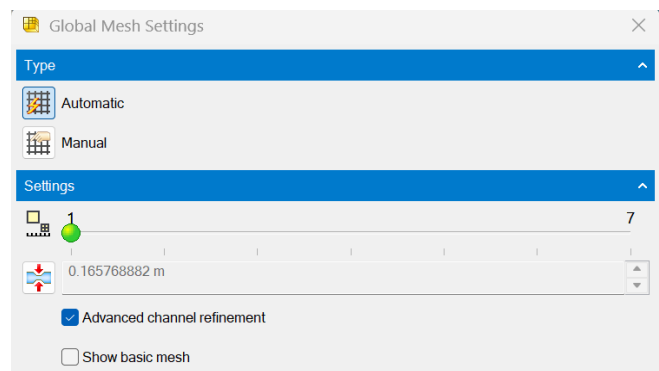


Fig. 4 Level 1 Global mesh setting

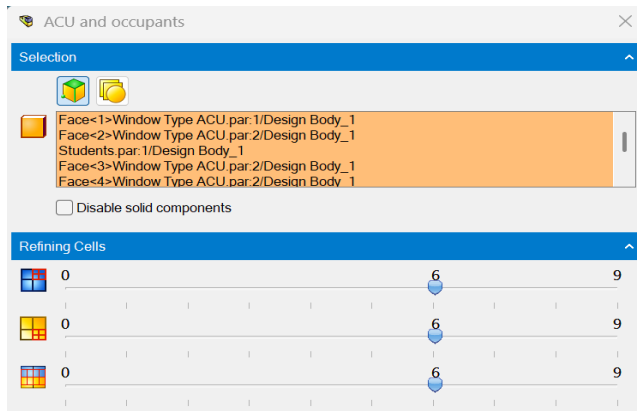


Fig. 5 Refinement level setting

Table 2. Mesh setting comparison at Level 1 initial mesh

Parameter	Level 1	Level 2	Level 3
Total number of cells	2.6M	3.89M	10.28M
Operative Temperature	27.52 °C	27.46 °C	27.40°C
Average Temperature	23.59 °C	23.39°C	23.28°C
Average Velocity	0.2727 m/s	0.2644 m/s	0.2511 m/s

2.3.2. Boundary Condition Setting

The boundary conditions are based on the ACU volume flow rate, while the surface heat sources are based on the cooling load of Table 3. The present study applies four boundary conditions to the supply and return grilles of the two air-conditioning units. The locations of these boundary conditions are shown in Figures 6 and 7.

The thermal comfort parameters gathered during simulations are air temperature, velocity, and PMV, only to simplify and speed the simulation.

A simulation for a minimum number of students of 30 was also performed, considering the two ACU types and

different configurations. The results of the simulation are presented in the following section.

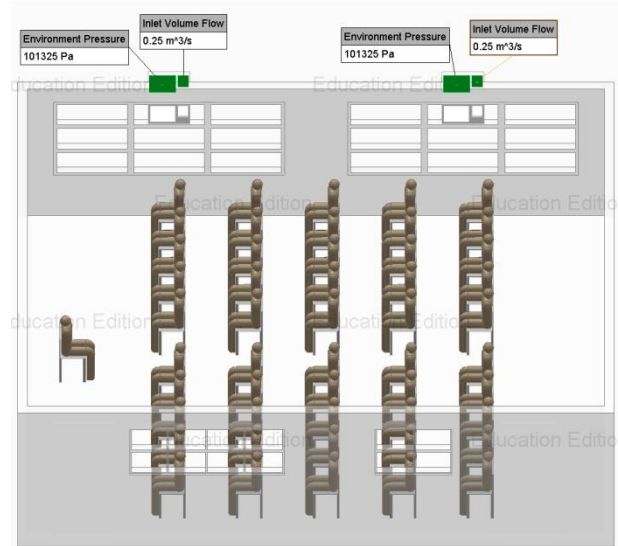


Fig. 6 Boundary condition location for Window type ACU

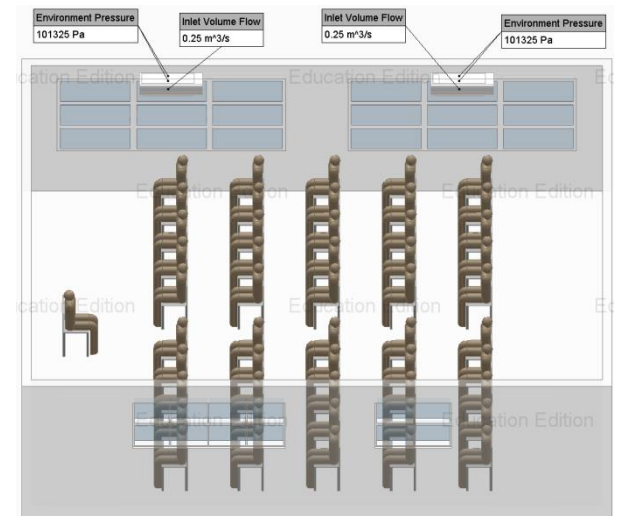


Fig. 7 Boundary condition location for Split-type ACU

Table 3. Cooling load input data

Cooling load source	Value	Source/Reference
Roof	Heat transfer coefficient, $U = 1.21 \text{ W}/(\text{m}^2 \cdot \text{K})$	DOE guideline
	Equivalent temperature difference, $T_{\text{Deq}} = 24.0 \text{ K}$	DOE guideline
	Area, $A = 63 \text{ m}^2$	TSU building plan
Wall (East)	Heat transfer coefficient, $U = 2.92 \text{ W}/(\text{m}^2 \cdot \text{K})$	DOE guideline
	Equivalent temperature difference, $T_{\text{Deq}} = 9.0 \text{ K}$	Outdoor and indoor temperature difference
	Area, $A = 17.09 \text{ m}^2$	TSU building plan
Wall (West)	Heat transfer coefficient, $U = 2.92 \text{ W}/(\text{m}^2 \cdot \text{K})$	DOE guideline
	Equivalent temperature difference, $T_{\text{Deq}} = 15.0 \text{ K}$	DOE guideline
	Area, $A = 15.24 \text{ m}^2$	TSU building plan

Wall (South)	Heat transfer coefficient, $U = 0.514 \text{ } 2.92 \text{ W}/(\text{m}^2 \cdot \text{K})$	DOE guideline
	Temperature difference, $TD = 9.0 \text{ K}$	Outdoor and indoor temperature difference
	Area, $A = 19.6 \text{ m}^2$	TSU building plan
Glass window (East)	Heat transfer coefficient, $U = 6.42 \text{ W}/(\text{m}^2 \cdot \text{K})$	Carrier System Design Manual, Table 33
	Temperature difference, $TD = 9.0 \text{ K}$	Outdoor and indoor temperature difference
	Area, $A = 2.97 \text{ m}^2$	TSU building plan
Glass window (West)	Sensible Heat Gain, $SHG = 517.35 \text{ W}/\text{m}^2$	Carrier System Design Manual, Table 15
	Factor = 0.52	Carrier System Design Manual, Table 16
	Temperature difference, $TD = 164 \text{ }^\circ\text{F}$	DOE guideline
	Area, $A = 17.09 \text{ m}^2$	TSU building plan
Lighting	Power rating = 40 W	TSU installed lighting
Students	Sensible heat = 63.60 W	Carrier System Design Manual, Table 48
	Latent heat = 38.98 W	Carrier System Design Manual, Table 48
Faculty	Sensible heat = 65.94 W	Carrier System Design Manual, Table 48
	Latent heat = 65.94 W	Carrier System Design Manual, Table 48

Note: Tables 15, 16, 33, and 48 refer to the data obtained from Carrier System Design Manual [26] and are not from the manuscript.

PMV is a common thermal comfort index that estimates how most people will feel in a certain environment. It uses the ASHRAE seven-point thermal sensation scale to measure how people perceive temperature. The scale goes from +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), to -3 (cold).

Within this scale, ASHRAE standard recommends PMV values between -0.5 and +0.5 as the thermal comfort zone [3]. PMV combines both environmental and personal factors to give a clear measure of how comfortable people feel [3, 30]. Details of these and the governing equations of PMV can be found in SolidWorks Technical Reference [29, 31].

The measurement levels of these parameters are in accordance with section 7.3 of ANSI/ASHRAE 55-2017 [3]. Thus, air temperatures and air velocities were gathered at 0.1, 0.6, and 1.1 m levels above the floor. While the PMVs were measured at 0.6 m above the floor.

Since the standard specifies that measurement shall be made where the occupants are expected to spend their time, the measurement locations were set between the occupants on each level, as shown in the seventy-four (74) points of Figure 8. The CFD software's Probe tool was used to gather data at each point on each level. The average velocity, temperature, and PMV were then computed.

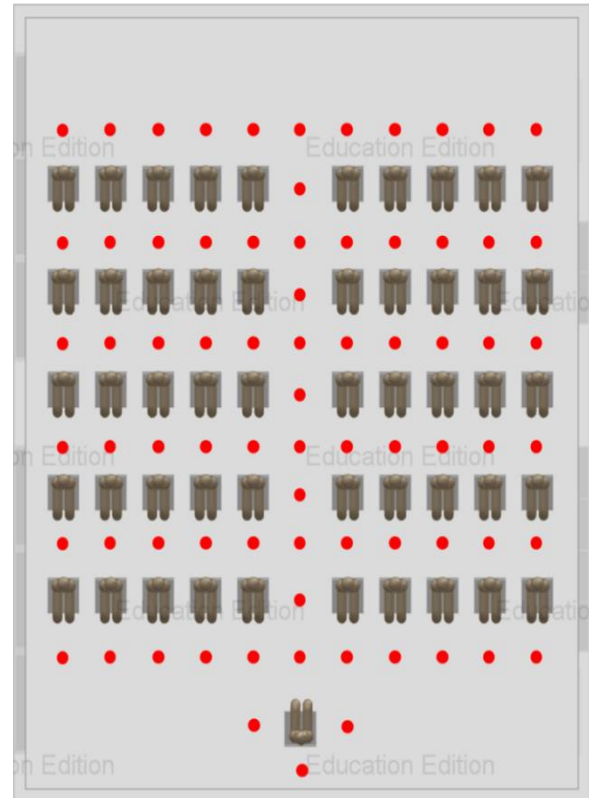


Fig. 8 Measurement points

2.4. Analysis of CFD Simulation Results

Data on average air temperature, air velocity, and PMV obtained from CFD simulations were compared for each setting of volume flow rate, ACU type, and ACU location. The recommended ACU configuration was selected not only based on average PMV values within or near the ASHRAE comfort range, but also on the consistency of the temperature distribution and airflow conditions throughout the lecture room.

3. Results and Discussion

Cooling load calculation was performed, and the appropriate ACU size was selected thereafter. CFD simulations were initiated considering the different scenarios described in the previous sections. The CFD simulation results are presented in the following sections.

3.1. Cooling Load Calculation Result and ACU Selection

After gathering necessary data, the cooling load method based on the Carrier E20 spreadsheet described in the Carrier System Design manual was carried out. The calculation results show that the highest cooling load is on the left side of the highest floor.

Meanwhile, rooms located on the lower floor level have lower cooling loads. The highest cooling load is 12,119 W on the highest floor (see Table 4) and 10,196W on the lower floor. Rooms on lower floors have lower cooling loads since there is no heat transmission from the ceiling. Thus, two 2.5 HP air conditioning units are recommended for each of the highest-floor classrooms, while two 2.0 HP units are recommended for each of the classrooms located at lower floor levels.

Table 4. Highest cooling result

Cooling load source	Watts
Roof	1,922
Wall (East)	471
Wall (West)	700
Wall (South)	541
Glass window (East)	180
Glass window (West)	2,362
Lighting	418
Students (sensible heat)	3,339
Students (latent heat)	2,046
Faculty (sensible heat)	69
Faculty (latent heat)	69
Total	12,117

3.2. CFD Simulation Results

CFD simulations were performed for the three window-type positions shown in Figure 3(a)-(c) and for the split-type configuration shown in Figure 3(d).

For each position, three volume flow rates (Low, Medium, High) were simulated. Table 5 summarizes the average temperatures, velocities, and PMVs simulation results for all ACU configurations.

3.2.1. Window-Type ACU Simulation Results

Figure 9(a)-(c) presents the results of the CFD simulation for the lower-position window-type ACUs. These results indicate that thermal comfort improves with increased airflow. Meanwhile, Table 5 shows that the average PMV decreases from +0.80 at 0.20 m³/s to +0.24 at 0.25 m³/s, then to -0.71 at 0.35 m³/s. At the same time, the average temperature decreases from 24.3 °C to 21.34 °C. The temperature contour in Figure 9 shows that the room remained quite warm at 0.20 m³/s (Figure 9(a)), became more comfortable at 0.25 m³/s (Figure 9(b)), and approached overcooling at 0.35 m³/s (Figure 9(c)). Figure 10 depicts the same trend in the PMV contours. Figure 10a shows warmer areas (red and yellow

regions), Figure 10b shows areas that are close to neutral (yellow-green), and Figure 10c shows areas that are too cool with more negative PMV regions with blue colors. The middle-position window-type ACU in Figure 3(b) had a similar overall pattern, but was less comfortable at low and medium airflow rates.

Table 5 shows that the average PMV values are +1.06 at 0.20 m³/s, +0.52 at 0.25 m³/s, and -0.46 at 0.35 m³/s. These results show that the middle position only reaches the recommended comfort zone when the airflow rate is high, or the temperature setting is 21°C. This means that the middle position is less comfortable than the lower position at medium airflow levels. The window-type ACU at the upper position simulation result showed the most even performance among the similar configurations. Table 5 shows that the PMV values ranged from +1.06 at 0.20 m³/s to +0.47 at 0.25 m³/s, then to -0.52 at 0.35 m³/s. The temperature fell from 24.63 °C to 21.93 °C. Figure 11 shows that the average temperatures at 0.1 m, 0.6 m, and 1.1 m levels were quite close to each other. This means the vertical temperature uniformity has improved. The temperature contours in Figure 12, notably at 0.25 m³/s (Figure 12(b)), support this by showing a more stable

temperature field. This means that the air is mixed more effectively before reaching the lecture room. Figure 13 also shows the airflow pattern, which includes velocity trajectories and ISO surfaces. In addition, the PMV contours in Figure 14 support this, with Figure 14(b) showing the most balanced near-neutral state among the window-type positions.

Although the CFD simulation result for the lower position showed an average PMV value closer to neutral at $0.25 \text{ m}^3/\text{s}$, the upper position was preferred since it exhibits better vertical temperature uniformity and a more balanced thermal environment across the lecture room.

Table 5. Thermal comfort parameters for all ACU configurations

ACU Type / Position	Flow Rate (m^3/s)	Temperature ($^{\circ}\text{C}$)	Velocity (m/s)	PMV	Recommended Comfort Zone ($-0.5 \leq \text{PMV} \leq +0.5$)	Thermal Sensation
Window Type/Lower	0.20	24.3	0.2	0.80	No	Slightly Warm
	0.25	23.2	0.26	0.24	Yes	Neutral
	0.35	21.34	0.35	-0.71	No	Slightly Cool
Window Type/Middle	0.20	24.87	0.21	1.06	No	Warm
	0.25	23.45	0.23	0.52	No	Slightly Warm
	0.35	21.79	0.31	-0.46	Yes	Slightly Cool
Window Type/Upper	0.20	24.63	0.2	1.06	No	Warm
	0.25	23.51	0.22	0.47	Yes	Neutral
	0.35	21.93	0.32	-0.52	No	Slightly Cool
Split-Type	0.20	24.89	0.19	1.13	No	Warm
	0.25	23.47	0.21	0.55	No	Slightly Warm
	0.35	21.71	0.28	-0.46	Yes	Slightly Cool

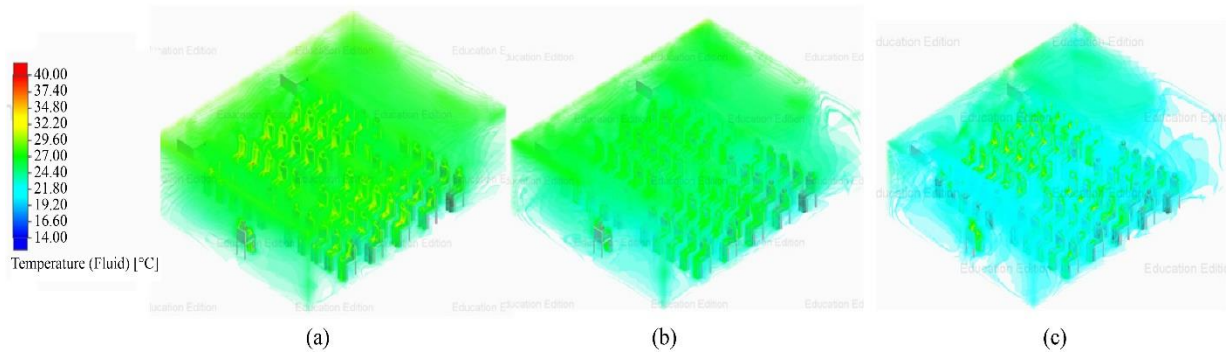


Fig. 9 Lower position temperature distribution for (a) $0.20 \text{ m}^3/\text{s}$, (b) $0.25 \text{ m}^3/\text{s}$, and (c) $0.35 \text{ m}^3/\text{s}$ volume flow rates.

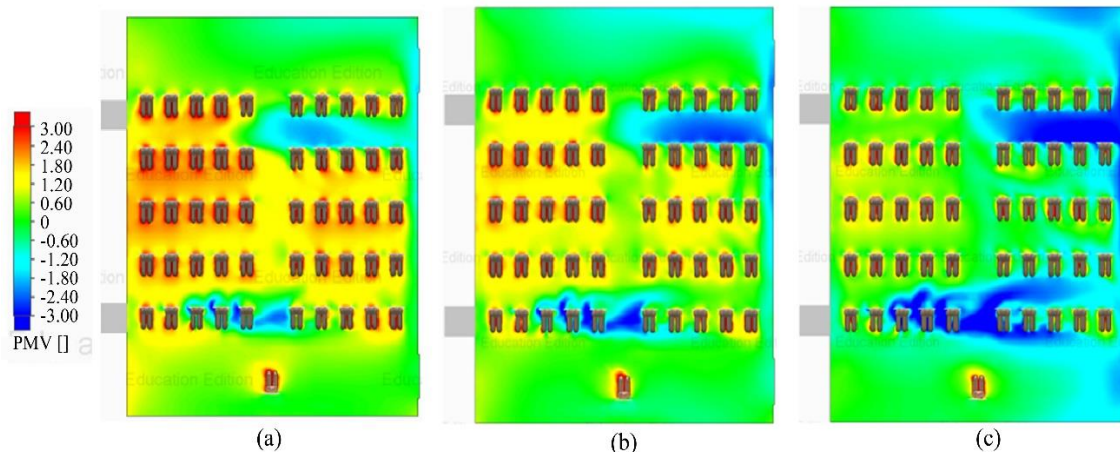


Fig. 10 Lower position PMV contour maps for (a) $0.20 \text{ m}^3/\text{s}$, (b) $0.25 \text{ m}^3/\text{s}$, and (c) $0.35 \text{ m}^3/\text{s}$ volume flow rates.

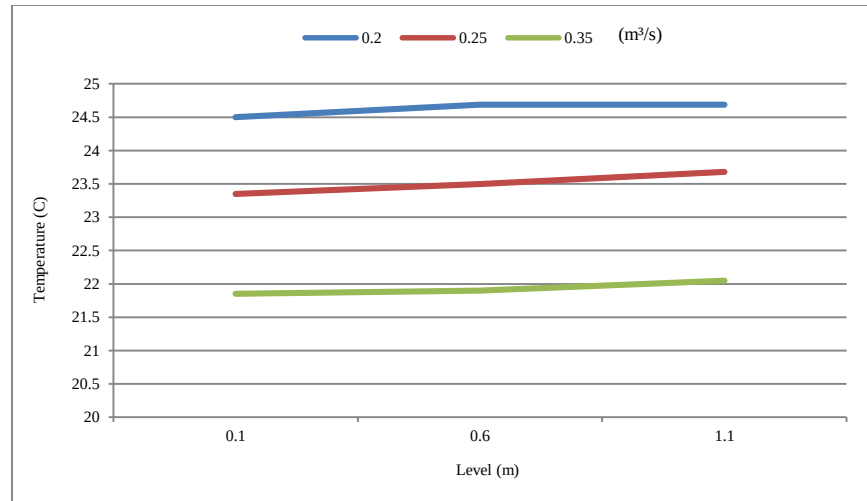


Fig. 11 Upper position average temperature at three levels and three volume flow rates

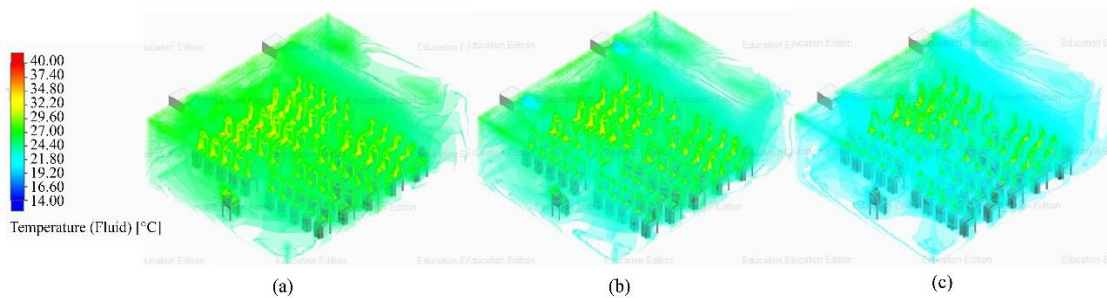


Fig. 12 Upper position temperature distribution for (a) 0.20 m³/s, (b) 0.25 m³/s, and (c) 0.35 m³/s volume flow rates.

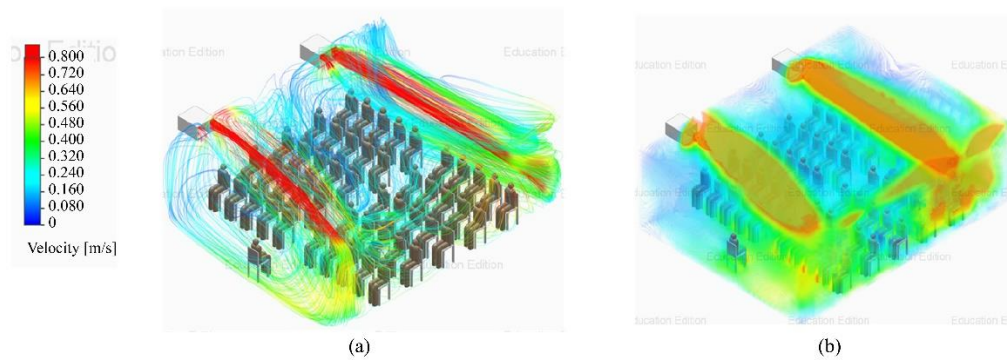


Fig. 13 Upper position (a) Velocity trajectory, and (b) ISO surface at 0.25 m³/s.

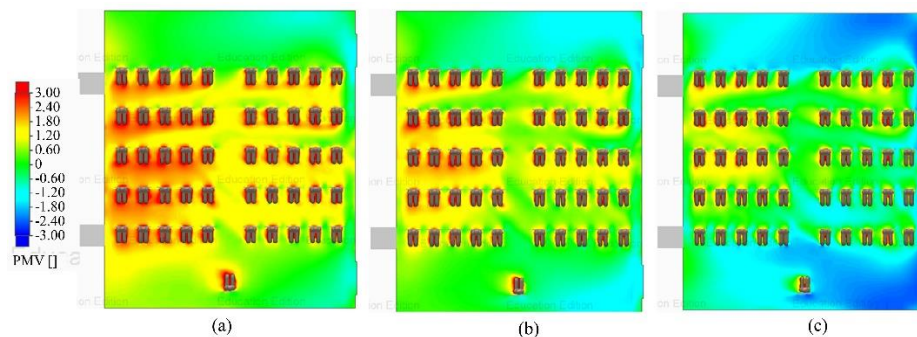


Fig. 14 Upper position PMV contour maps for (a) 0.20 m³/s, (b) 0.25 m³/s, and (c) 0.35 m³/s flow rates.

3.2.2. Split-Type ACU Simulation Results

The split-type ACU position shown in Figure 3(d) provided better comfort as airflow increased, similar to the pattern or trend of the window-type positions. Table 5 shows that the average air temperature dropped from 24.89 °C at 0.20 m³/s to 23.47 °C at 0.25 m³/s, and then to 21.71 °C at 0.35 m³/s. The average PMV values also changed from +1.13 (warm) to +0.55 (slightly warm), and then to -0.46 (slightly cool). These results indicate that the split-type ACU provided clear comfort only at the highest airflow or the lower ACU temperature setting equivalent to 21 °C. Figure 15 shows this change: at 0.20 m³/s in Figure 15(a), the classroom remained mostly warm, indicating that airflow was insufficient for effective cooling. Additionally, Figure 15(b) shows that the distribution improved at 0.25 m³/s, but some areas remained slightly warm, corresponding to a PMV of +0.55. Lastly, Figure 15(c) shows that the high flow rate at 0.35 m³/s lowered the room temperature enough to reach a comfortable range.

The PMV contour maps in Figure 16 confirm that thermal comfort improves with increasing volume flow rate. Figure 16(a) shows high PMV values in the red and yellow regions, indicating inadequate cooling at the minimal flow rate. In

Figure 16(b), PMV values next to the comfort zone indicate a marginally warm sensation in certain regions. In Figure 16(c), a more favorable PMV distribution is observed as airflow increases to 0.35 m³/s, but the room begins to cool, as indicated by the blue regions. Consequently, although the split-type air conditioning unit can deliver satisfactory comfort, it appears to require a higher airflow rate than the upper-position window-type configuration to achieve comparable results. Table 5 and Figures 9 through 16 indicate that the optimal airflow rate is between 0.25 and 0.35 m³/s. The window-type ACU simulation set up at the upper position resulted in better thermal comfort than the other positions or configurations. CFD simulation results showed a more even temperature distribution and PMV values that were quite close to the ASHRAE comfort zone, even with moderate airflow. Conversely, the lower-position window-type air conditioning unit resulted in localized overcooling at high volume flow rate. Meanwhile, the window-type middle position required high airflow to attain comfort level, and the split-type ACU achieved satisfactory conditions just at the high flow rate. Overall, the upper-position window-type ACU configuration is recommended, as the CFD results show the best overall acceptable PMV, uniform temperature distribution, and air-mixing performance.

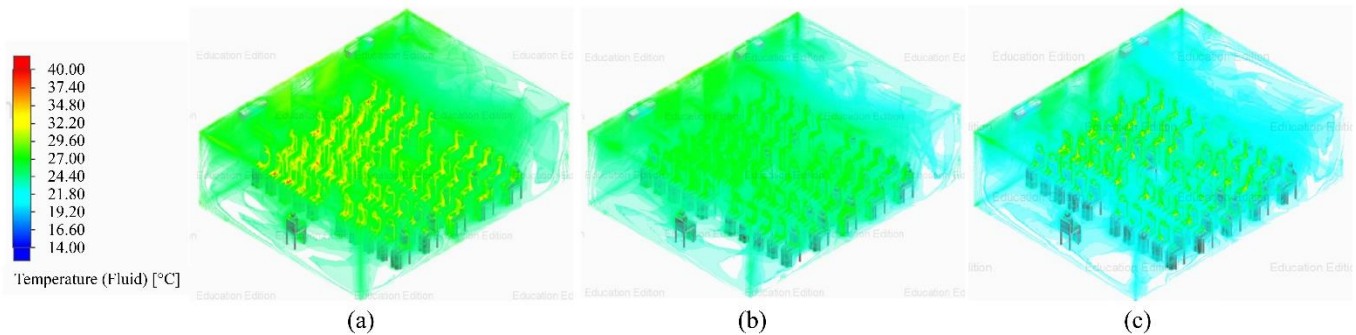


Figure 15 Temperature distribution for the split-type ACU configuration at (a) 0.20 m³/s, (b) 0.25 m³/s, and (c) 0.35 m³/s volume flow rates.

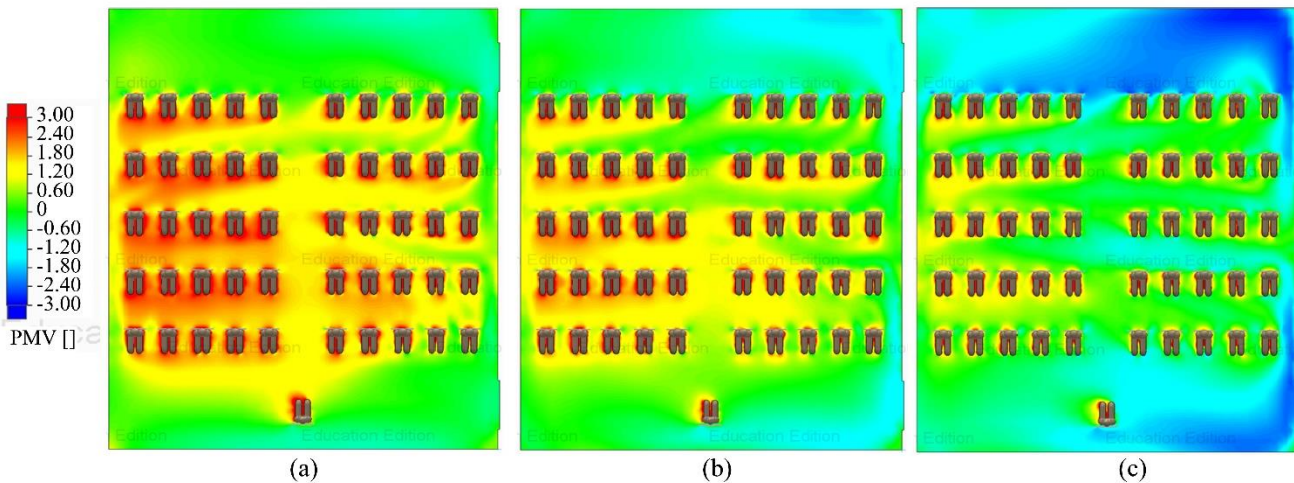


Fig. 16 Split-type ACU PMV contour maps for (a) 0.20 m³/s, (b) 0.25 m³/s, and (c) 0.35 m³/s flow rates.

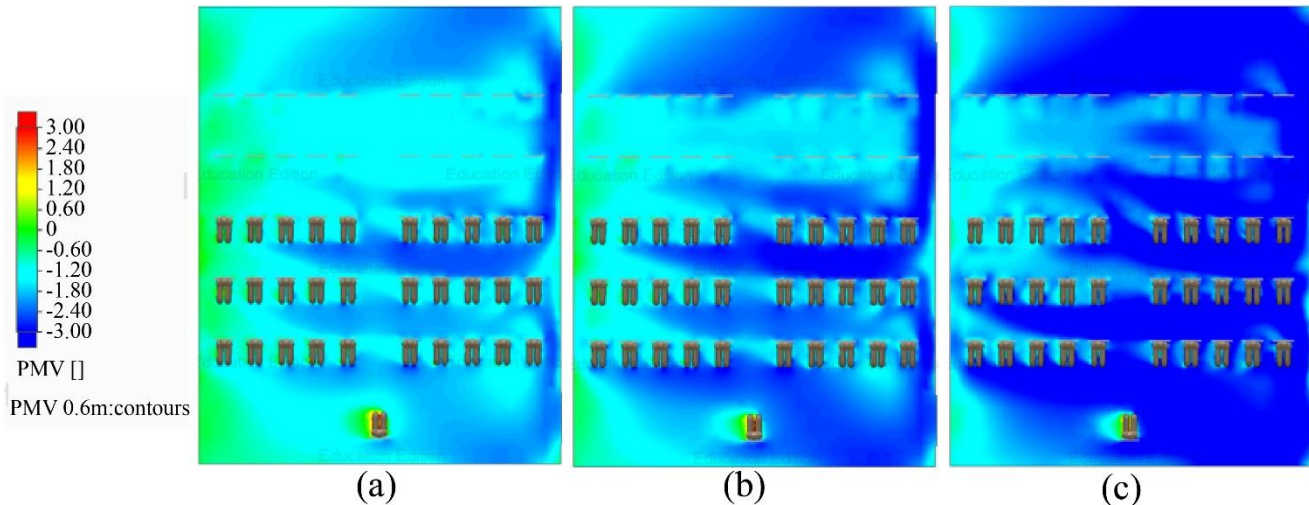


Fig. 17 Window-type ACU PMV contour maps for (a) 0.20 m³/s, (b) 0.25 m³/s, and (c) 0.35 m³/s flow rates.

3.2.3. ACU Simulation Results for Different Numbers of Occupants

In Tarlac State University, the minimum number of students is 30; a simulation was also performed considering the optimum setting and configuration discussed in the previous section. Figure 17 shows that the PMV distribution at 0.6m elevation, -3 (blue), is widely distributed at different volume flow rates, which means the occupants will feel cold when the number of students is at a minimum. The average room temperature at Figure 17(a) is 20.25 °C, which means that the ACU can easily cool the room even if the temperature is set to 20 °C.

4. Conclusion

This study determined the optimal air-conditioning requirements for a lecture room by applying cooling load calculation following the Carrier cooling load method, together with CFD-based thermal comfort simulations. Actual ACU dimensions and physical size, including the actual temperature of the supply air from the available ACU, were used in the study to achieve better results. The peak cooling load of approximately 12.12 kW is addressed by two 2.5 HP air conditioning units for the top-floor classrooms, but the lower levels require only two 2.0 HP units since there is no heat load from the ceiling.

CFD simulation results consistently showed that increased volume flow rates improve air dispersion, reduce temperature gradients, and shift PMV values towards the neutral target. For the window-type ACU, the 0.25 m³/s flow rate resulted in near-neutral conditions, while the split-type ACU remained slightly warm at the same flow rate and reached more acceptable comfort at 0.35 m³/s with improved uniformity in terms of PMV. These two flow rates correspond to average room temperatures of approximately 23 °C at 0.25 m³/s and 21 °C at 0.35 m³/s. Therefore, an ideal ACU setting

of 21°C to 23°C is recommended for a lecture room with 51 occupants. Furthermore, among the simulated installation positions, the window-type ACU in the upper position showed the best overall performance, providing a more uniform temperature distribution and more balanced comfort conditions inside the lecture room. Although the lower-position CFD results showed an average PMV closer to neutral at 0.25 m³/s, the upper position is considered optimal because it reduced vertical temperature variation and minimized the risk of localized overcooling.

Overall, when the ACU thermostat is set to 24 °C, simulations suggest that occupants may feel slightly warm, especially at lower airflow rates, with PMV values near +0.5 or higher. Hence, if the TSU lecture room ACUs are set to 24 °C and 51 occupants are uncomfortable at 24 °C, using the four ceiling fans is recommended to boost air movement and lower the PMV, thereby improving the thermal sensation of the occupants. This approach aligns with ASHRAE Standard 55, that higher air speeds can offset higher indoor temperatures and maintain comfort within acceptable limits. The optimal ACU installation location, along with the best ACU temperature setting and ceiling fan utilization, provides an effective, energy-efficient strategy for maintaining comfortable conditions in lecture rooms. To further improve this study, ACU louver swing movement and ceiling fan rotations simulation are recommended.

Acknowledgments

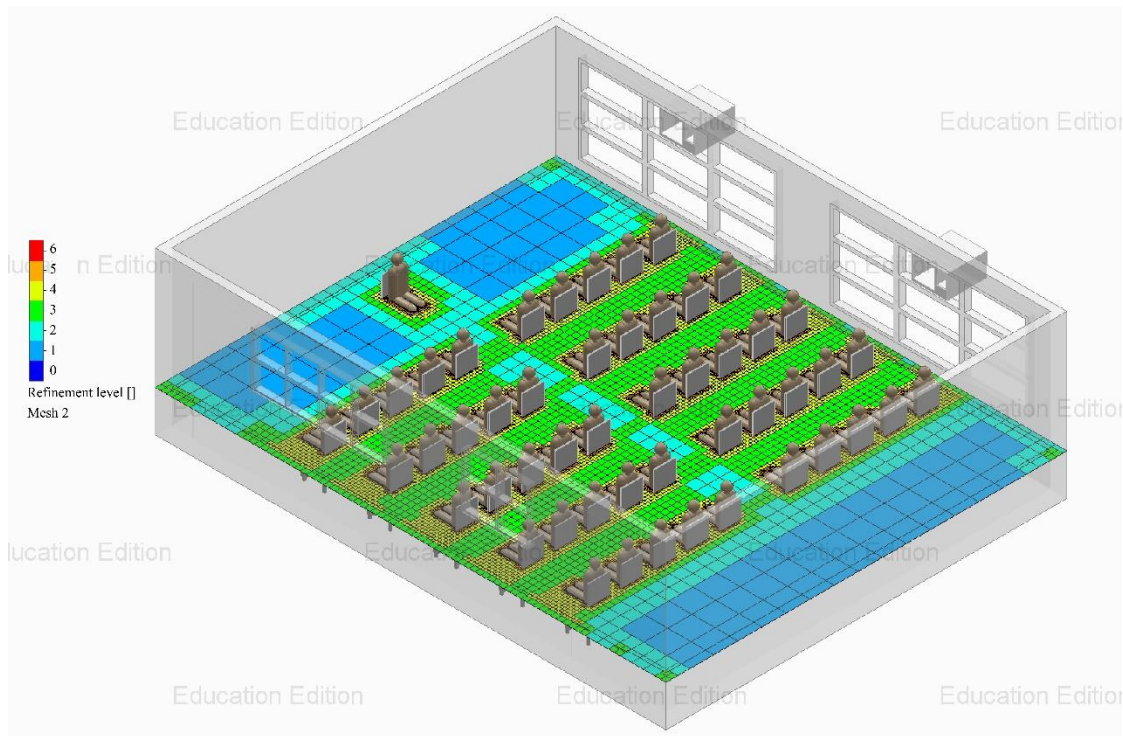
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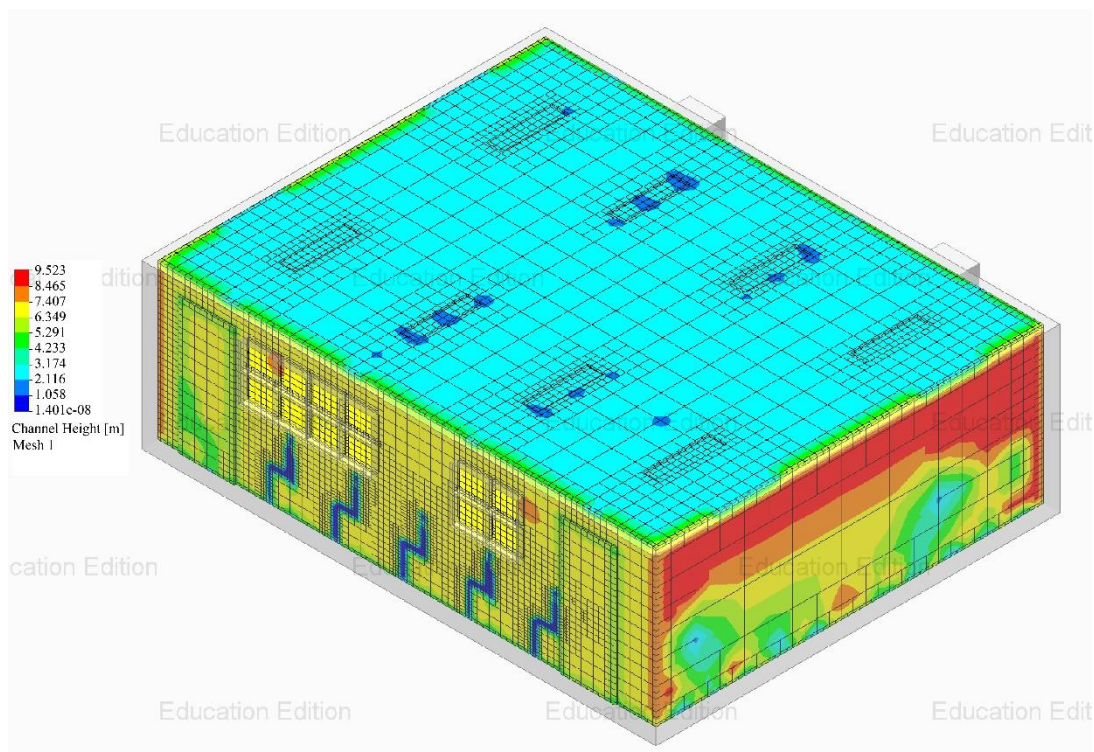
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Appendix 1



Mesh refinement sample Figure 1

Appendix 2



Mesh refinement sample Figure 2

Appendix 3

CAD model link: <https://drive.google.com/drive/folders/1CdXOtkBfHcJ6WS7nIMcBVfMZIetLhaM?usp=sharing>

