RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 5 No. 2 (2024) 303-313
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Energy Utilization Analysis and Flow Simulation for the Projected Al-Faizin Mosque's Air Conditioning System

Muhammad Nizam khamis[1], Mohd Azwir Azlan[1]*

[1] *Faculty of Mechanical and Manufacturing Engineering,*
Universiti Tun Hussein Onn (UTHM), 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author: azwir@uthm.edu.my

DOI: https://doi.org/10.30880/rpmme.2024.05.02.034

Article Info

Received: 01 June 2024
Accepted: 20 October 2024
Available online: 31 December 2024

Keywords

Thermal Comfort, Mosque air conditioning, Energy efficiency, Flow simulation, HVAC energy consumption

Abstract

The project emphasizes the significance of ensuring thermal comfort in mosques, focusing on Al-Faizin mosque. It addresses how inadequate thermal conditions can impact worship and emotional factors. The project analyzes air conditioning energy use by studying other mosques' internal factors, structure, and existing systems. It aims to optimize the mosque's air conditioning system to provide suitable conditions while minimizing energy consumption. Methodologically, the project assesses Al-Faizin mosque's layout and structure, determining a requirement of 45 horsepower across 13 air conditioning units with specific configurations for optimal cooling. Flow simulations indicate that units placed at 3 meters height achieve peak efficiency, maintaining temperatures between 22°C to 25°C during critical times like Friday prayers, aligning with comfort standards of 22.5°C to 26°C. However, the study notes a 150% increase in electricity consumption post-installation, highlighting the need for energy-efficient models, regular maintenance, and moderate temperature settings (24-26°C). Recommendations include enhancing building insulation and utilizing HVLS fans for additional cooling. In conclusion, the project underscores that strategic use of energy-efficient technologies can effectively balance thermal comfort with energy conservation goals in mosque settings like Al-Faizin mosque.

1. Introduction

People always strive to live in comfortable surroundings, seeking warmth in cold weather and coolness in hot weather, a concept known as thermal comfort. *Thermal comfort* is defined as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." Studies have shown that occupants can accept a thermal range beyond the ASHRAE Standard and Malaysia Standard (ICOP-2010), with neutral temperatures for air-conditioned and non-air-conditioned buildings being 24.4°C and 28.4°C, respectively. Regression analysis of Thermal Sensation Vote (TSV) on operative temperature found acceptable temperature ranges of 23.1°C to 25.6°C for air-conditioned buildings and 26.0°C to 30.7°C for non-air-conditioned buildings. Thus, air conditioning systems are vital for achieving thermal comfort in buildings. The project aims to optimize the Al-Faizin Mosque's air conditioning system by analyzing energy utilization, evaluating design strategies, and determining passive design criteria to minimize energy consumption while maintaining acceptable thermal comfort levels. Scenarios of mosques were compared in terms of thermal comfort and energy consumption in temperate, humid climate conditions.

With the rapid growth of mosque construction in Malaysia, the congregation's comfort is a significant concern. Inadequate thermal comfort in mosque buildings leads to uncomfortable thermal environments. However, a lack of research on air conditioning usage in mosques makes it difficult for mosque management to make informed decisions. This project aims to study the condition of the Al-Faizin Mosque and assist in analyzing air conditioner energy usage, allowing management to make better decisions about installing the system. Al-Faizin mosques are medium-sized buildings with diverse user types, densities, and usage schedules, making it challenging to establish homogeneous thermal comfort. Despite the decrease in conventional energy sources, energy consumption in these buildings should be minimal. The problem statement outlines the primary issues and objectives to be addressed in the energy utilization analysis and flow simulation project for the projected Al-Faizin Mosque's air conditioning system. Currently, the Al-Faizin Mosque uses High Volume Low Speed (HVLS) fans and ventilation systems. This project aims to investigate whether installing air conditioners at the Al-Faizin Mosque is affordable in terms of monthly installation and maintenance costs. The study examines whether the funds available justify the monthly electricity bill post-installation. The energy-intensive nature of air conditioning systems leads to high operating costs and a significant carbon footprint, affecting the mosque's financial resources and contributing to broader environmental challenges. The objectives are to conduct an energy consumption and cost-effective analysis of the planned air conditioning system in the Al-Faizin Mosque and to simulate flow analysis based on the positioning and number of proposed air conditioning units, focusing on comfort and congregation capacity. The scope of the project includes conducting five benchmark studies on energy consumption and operating costs for mosques with existing air conditioning systems, proposing the appropriate type, location, and quantity of air conditioning units to balance comfort with energy consumption, promoting the use of alternative energy for cost and energy savings, and using SolidWorks software to simulate air conditioner flow to ensure optimal comfort temperature is achieved quickly.

2. Material and method

This study examines the airflow within the Al-Faizin mosque building to determine the efficiency of air conditioner installation. Different building types require different air conditioning systems, such as centralized or decentralized systems. The equipment needed for these systems varies due to building size and specifications. Figure 1 below depicts the 8 stages of the flowchart and methodology used in this project.

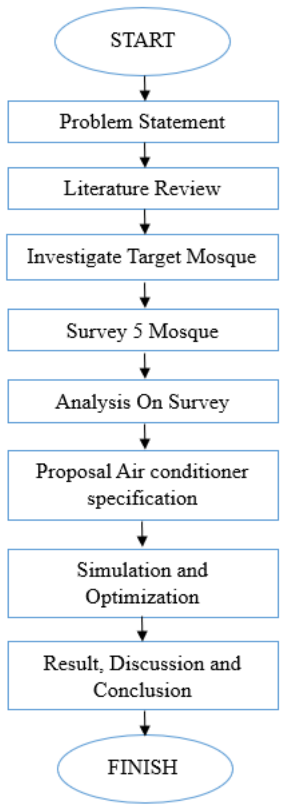

Fig. 1: Methodology flow chart

The study also considers the building's function, as the building's function influences decentralized system design. The other vital part that will be focused on in this study is the airflow requirement for the building. The authority requirements that will follow are the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard [2] and the Malaysia Standard (ICOP-2010) [3]. The standards can be achieved by referring to the guidelines in the handbook developed by the ASHRAE standard and Malaysia Standard (ICOP-2010). With a complete understanding of the standards, the objective of this study can be satisfied. Table 1 shows the requirement for the physical parameters of the ACMV system in Malaysia Standard (ICOP-2010) and ASHRAE standard 55-2013.

Table 1: Physical requirement from the authorities

	Malaysia Standard (ICOP-2010)	ASHRAE Standard 55-2013
Comfort Temperature	24 °C - 26 °C	22.5 °C - 26 °C
Air velocity	0.15 m/s - 0.50 m/s	15 m/s - 0.50 m/s
Relative Humidity	40 % - 70 %	30 % - 60 %

2.1 Study on a targeted mosque

The first method is to find out the specifications of Al-Faizin mosque reviewed to determine the dimensions and area of structures in Al-Faizin mosque. All the data taken is used to determine cooling capacity in the building. There is some data taken in the mosque building in this study to achieve the target of air conditioner installation in the Al-Faizin mosque. Table 2 depicts the taken parameter.

Table 2: Parameters taken in mosque building

No.	Parameter	Data
1.	Length	24.8 m
2.	Width	17.58 m
3.	Height	6.77 m
4.	Dome height	9.68 m
5.	Maximum occupancy	800 persons

The parameter will be analyzed by calculating the required Horsepower (HP) using the rule-of-thumb cooling capacity formula. [5] Figure 2 below shows the governing equation to calculate cooling capacity in buildings.

$$cooling\ capacity = \frac{(A \times H_f) + h + H_p}{(\text{BTU/hour heat removed by 1HP}}$$

Were,

A= area, m^2

H_f= Heat factor

h= height, m

H_p= heat generated by person, BTU/hour

1HP = 9000 BTU/hour

Fig. 2: Formula cooling capacity

This governing equation is implemented to figure out the horsepower required in building, and this calculation is used to evaluate the required horsepower for Al-Faizin mosque based on the parameters taken. Some additional fundamental data listed in Table 3 below were used to solve the calculation:

Table 3: Fundamental Data for calculation

Data fundamental	
Heat generates by a person	$1\ MET = 18.4\ BTU/hr\ ft^2$
The average body per person	$19\ ft^2$
Activity level measured in a mosque	$1.4\ MET$

Heat generates by 1 person,

$$= 18.4\ BTU/hrft^2 \times 1.4$$
$$= 25.76\ BTU/hrft^2 \times 19\ ft^2$$
$$= 489.44\ BTU/hr \approx 140\ \ watt$$

Heat is generated by maximum occupancy in the building, H_p

$$= 489.44\ BTU/hr \times 800$$
$$= 391{,}552\ BTU/hr$$

Area building,

$$24.8m \times 17.85m = 435.98m^2$$

Heat factor, H_f((depends on room location) if the room is located on the main floor, the factor used is 50. If the room is located on the second floor, the factor is 40 [5]

High building, h for each foot above 8ft ceiling need to increase about 1,000 BTU/hr [5]

For mosque height, $6.77\ m \approx 22.21\ ft$

The additional BTU increases were; $22.21\ ft \times 1{,}000\frac{BTU}{hr} = 22{,}210\frac{BTU}{hr}ft$

BTU/hr heat removed by 1 $HP = 9{,}500\ BTU/hr$

Cooling capacity, HP

$$= \frac{(A \times H_f) + h + H_p}{\text{(BTU/hour heat removed by 1HP)}}$$

$$= \frac{(435.98 \times 50) + 22{,}210 + 391{,}552}{(9{,}500)}$$

$$= 44.9\ HP \approx 45.0\ HP$$

Let's say 12 units of air conditioner unit were needed to be installed; by dividing the HP required by 12,

$$45\ HP \div 12\ units = 3.75\ HP/unit$$

So, the suitable air conditioner capacity for this building is around 4 HP.

After determining the required cooling capacity, Figure 3 illustrates the recommended layout for positioning air conditioners with the necessary horsepower distributed to cover up to 45 HP. This positioning was then validated through SolidWorks flow analysis to ensure efficiency.

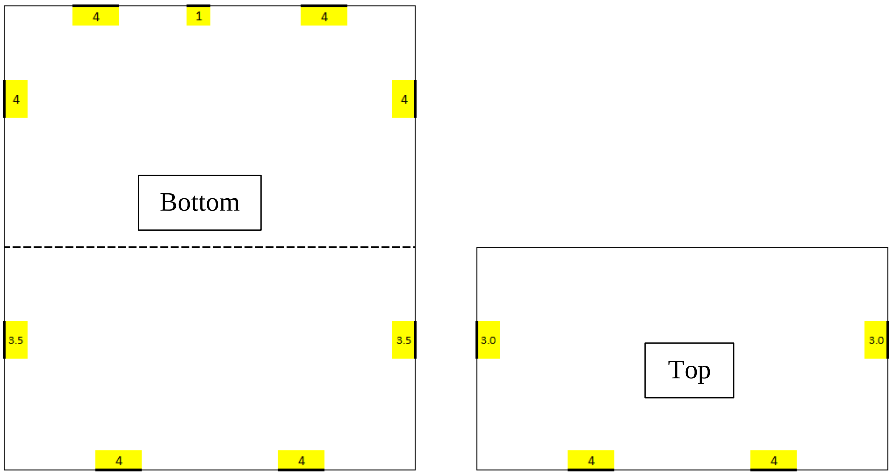

Fig. 3: Layout the mosque building with the suggested air condition position and specification

The model uses SolidWorks, a desktop CAD solution supporting 3D mechanical design. The software is used to analyze airflow in a mosque, which is based on the actual parameters of the mosque. The model is created using the Al-Faizin mosque, which has 24.8 m length x 17.58 m width x 6.77 m height, as shown in Figure 4. The model's design is similar to the Al-Faizin mosque but has a much more simplified layout for analysis purposes.

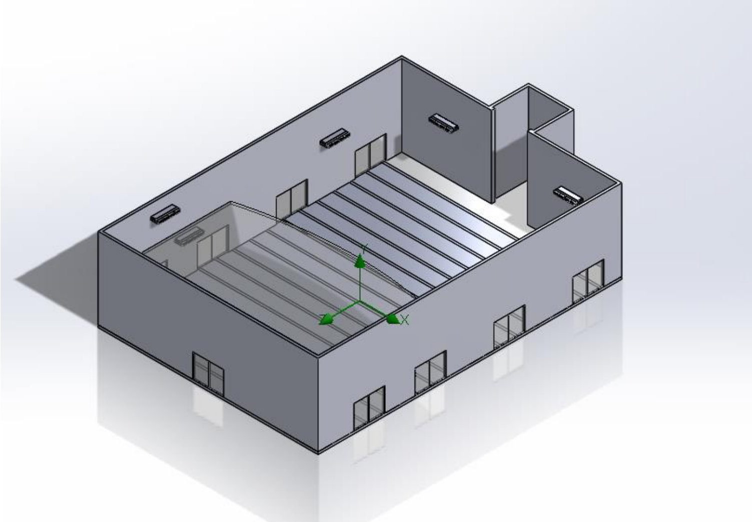

Fig. 4: The model of Al-Faizin mosque

SolidWorks software simulations were chosen to model airflow and gather necessary airflow data aligned with specified requirements. This study also emphasizes compliance with airflow standards set by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [2] and Malaysia's ICOP-2010 standards [3].

2.2 Analysis of Survey

The project aims to implement air conditioning in targeted mosques by surveying five selected mosques. The survey collected data on building area, horsepower used, electricity bill costs, and congregation size, which are included in the appendix for reference. The study analyzed data from five selected mosques using questionnaires. Most attendees were generally satisfied with the temperature comfort during prayer times. The data was analyzed using Excel software, comparing air conditioning power (HP) use based on calculation and survey, area and capacity congregations, monthly electric bill, and total power consumption. The results were graphically analyzed, as shown in Figures 5, 6, and 7. The study aimed to understand attendees' satisfaction with their air conditioning system during prayer times.

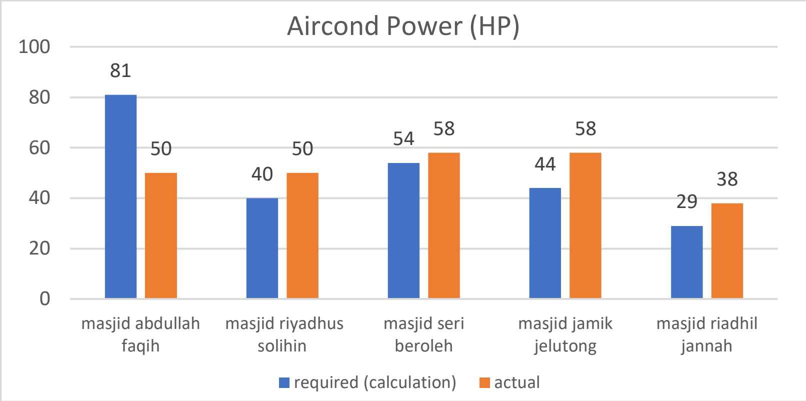

Fig. 5: Comparison of calculation and actual

Based on the graph above, most mosques have installed total air conditioners that exceed the calculated requirement, except for Abdullah Faqih Mosque. Notably, all mosques using air conditioners exceeding the required horsepower report comfort, except for Abdullah Faqih Mosque, which reported discomfort in surveys. This indicates that installing air conditioners with a horsepower exceeding the calculated requirement by 5 HP or more contributes significantly to achieving comfort in mosques.

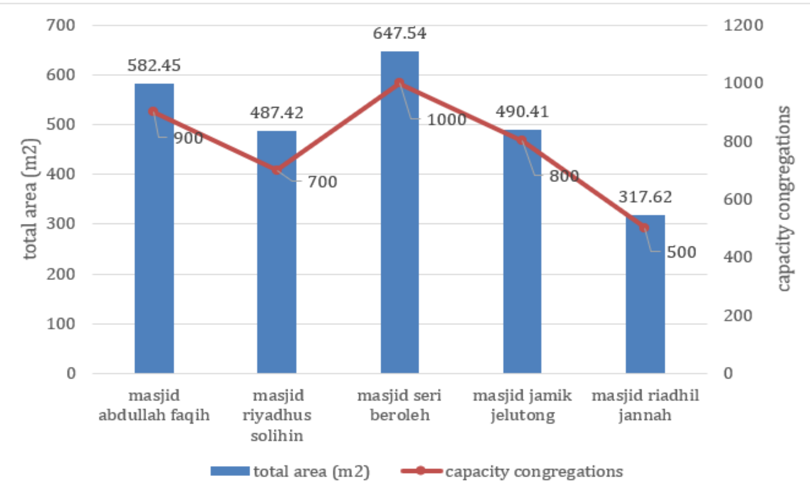

Fig. 6: Total area and capacity of congregations

Figure 6 above displays the prayer hall area and maximum occupancy capacity. Using this graph, the area allocated per person in the mosque can be calculated by dividing the prayer hall area by the capacity of congregants, resulting in an average of 0.650 m^2 per person. This figure corresponds sensibly to the space required for one person during prayer.

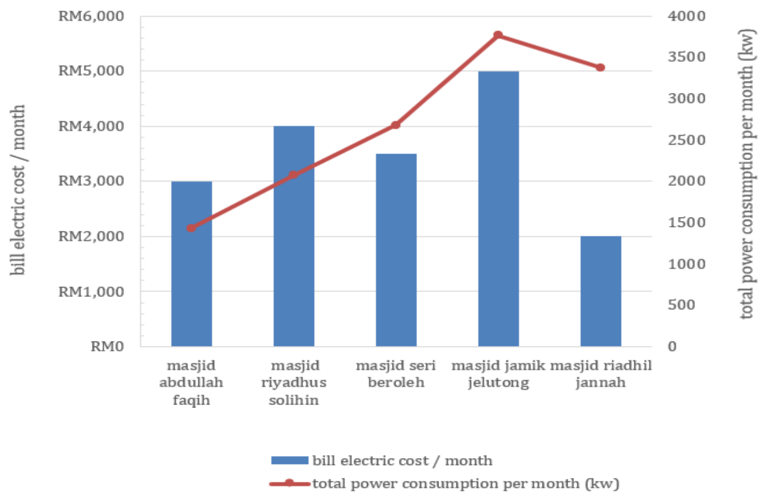

Fig. 7: Usage of electric bill and total power consumption per month

Figure 7 above shows Masjid Jamik Jelutong has the highest electric bill despite moderate power consumption, possibly due to higher electricity rates, less efficient energy use, or higher tariffs. The graph suggests a correlation between power consumption and electric bill cost, with variations attributed to energy efficiency, pricing structures, or usage patterns. Further investigation is needed to understand the reasons behind this high bill.

3. Result and Discussion

This next study uses SolidWorks Flow Simulation software to assess temperature and airflow dynamics within the Al-Faizin mosque. The data reveals four distinct air conditioner flow geometries: high flow rates during peak times and reduced flow rates during regular congregations. The diffuser efficiently disperses air across various angles and directions, ensuring comprehensive coverage of the entire building area. Each simulation step spans 10 minutes, with an overall duration of 1 hour. The results underscore the diffuser's effectiveness in evenly distributing air throughout the mosque, supported by detailed discussions on flow behavior, velocity contours, and temperature distribution across each simulation step. Setup parameters for the SolidWorks Flow Simulation software are outlined in Table 4 below, adhering to the critical temperature specifications defined by ASHRAE Standard 55-2013.

Table 4: Parameter setup

Parameter	Value
Temperature in building	35°C
Heat generates by a wall	25°C
Heat generates by 1 person	140 $Watt$
Inlet volume flow, Q	2.5 m^3/s
Inlet velocity, V	2 m/s
Inlet temperature by aircon	17°C
Relative humidity	50%

3.1 Flow simulation with the best outcome

Result of 3 meters high aircon with regular congregations

Figure 8 demonstrates the result of a 3-meter aircon of flow trajectories and contours during regular prayer. Geometries 3 meters high of aircon and regular congregation, which is 2 rows of congregations with 5-unit aircon, show the good flow coverage area and temperature distribution still in range thermal comfort. Furthermore, this figure also demonstrates the time travel within one hour.

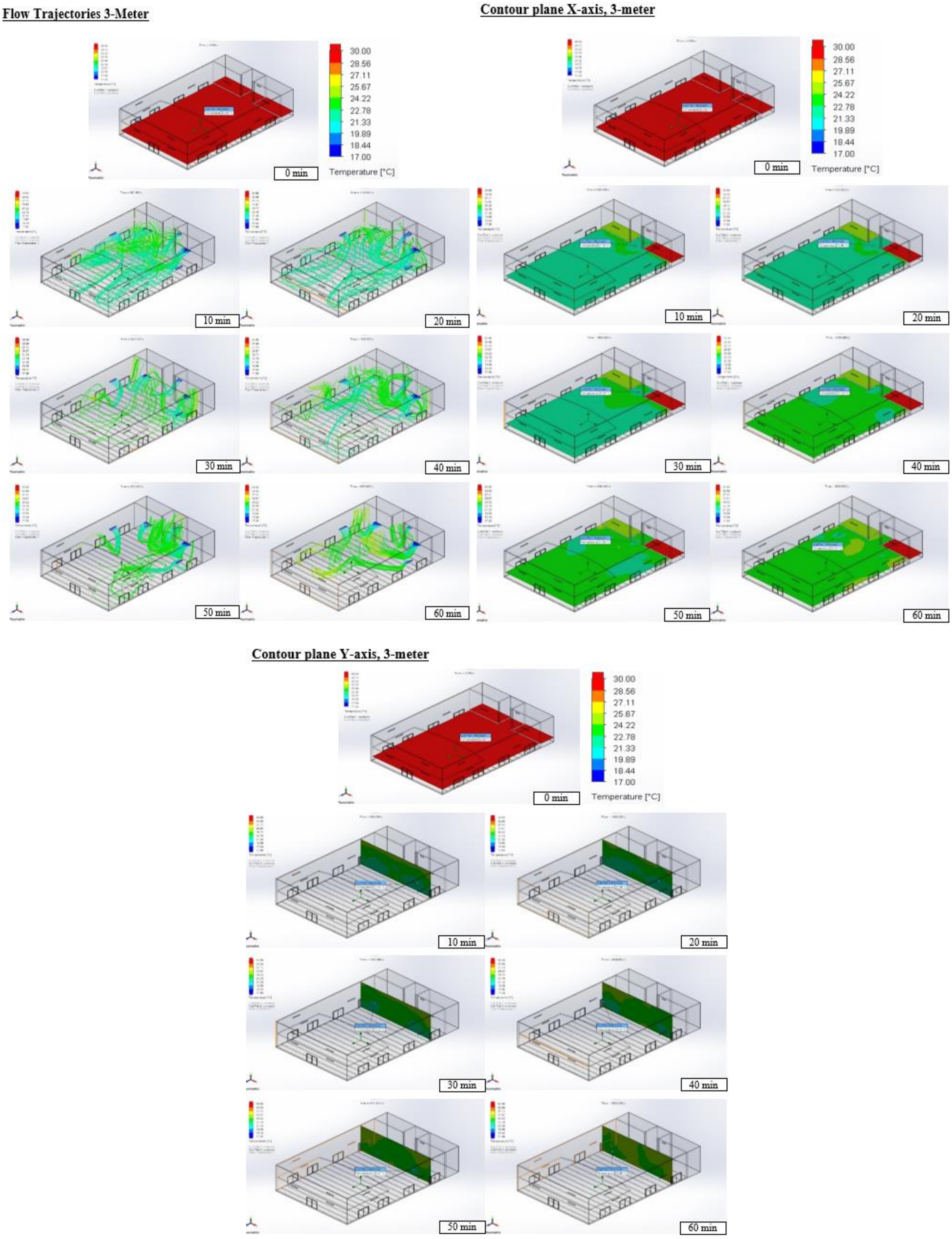

Fig. 8: Flow Trajectories and Contour Plane with Aircons Position 3-Meter Height (2-Row Congregation)

Result of 3 meters high aircon with max congregations (Friday prayer)

Figure 9 simply shows the result from a 3-meter high aircon of flow trajectories and contours plane during Friday prayer. Geometries 3 meters height of aircon and maximum congregation, which is full rows of congregations with all unit aircon activated, provide a strong flow coverage area and temperature dispersion while remaining within the thermal comfort zone. Furthermore, this figure shows the time travel within one hour.

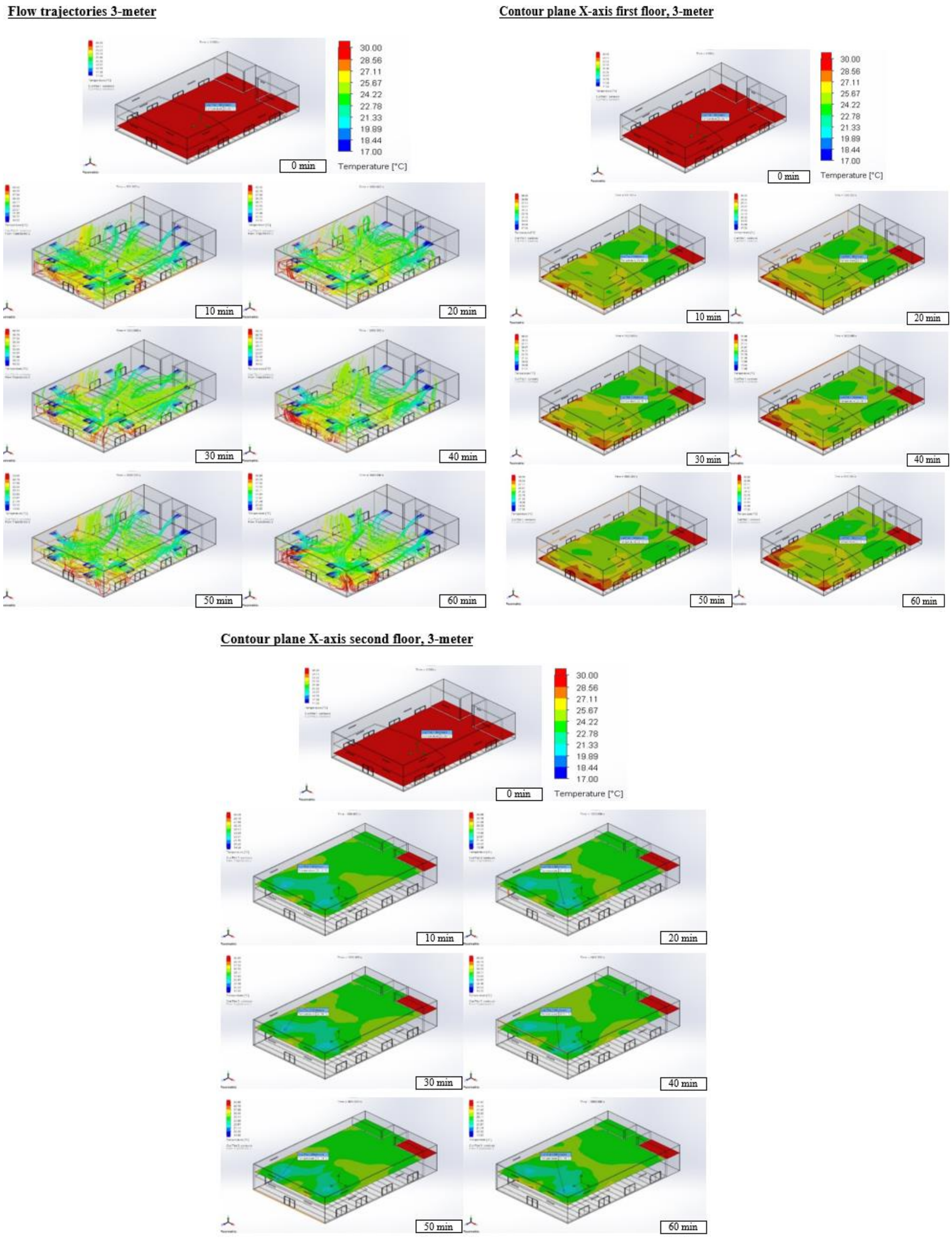

Fig. 9: Flow Trajectories and Contour Plane with Aircons Position 3-Meter Height (Full Row Congregation)

This result only indicates a simulation 3 meter high of aircons. The temperature range is set in between 17°C and 35°C. In the duration of the simulation, a height of aircon 3 meters shows the best choice because the flow due to the large coverage area and the contours plane demonstrates the temperature comfort during the time travel within 1 hour which is the temperature is in thermal comfort range that is 22°C -25°C when setup 17°C temperature outlet of aircons in peak situations for example Friday Prayers.

3.2 Cost-effective analysis

Based on the Al-Faizin mosque's recent bills, the average over three months totals RM 1,037 when air conditioning is unused. Calculations were conducted based on the total input power of each air conditioner installed according to specifications. The bill analysis is outlined below:

Table 5: Air conditioner specification usage

Aircons specification	Normal total input power (Watt)	Quantity Normal usage	Total (Watt)	Quantity Friday usage	Total (Watt)
4 HP	3,860 Watt	4	15,440	4	15,440
3.5 HP	3,250 Watt	0	0	2	6,500
3 HP	2,860 Watt	0	0	2	5,720
1 HP	905 Watt	1	905	0	0
	Total		16,345	Total	27,660

Power daily usage in 1 month,

$$16{,}345\ Watt \times 6\ h\ (assume\ daily\ usage) \times 30\ days = 2{,}942{,}100\ Wh$$

Power Friday usage in 1 month,

$$27{,}660\ Watt \times 1.5\ h\ (Friday\ usage) \times 4\ days\ (1\ months) = 165{,}960\ Wh$$

Summation of power in 1 month,

$$2{,}942{,}100\ Wh + 165{,}960\ Wh = 3{,}108{,}060\ Wh \approx 3{,}108.06\ kWh$$

The power consumption is calculated by multiplying the daily usage, including peak conditions during Friday prayers, by 30 days, reflecting the mosque's daily operational status as a commercial building. This total is then multiplied by TNB Malaysia's tariff rate of RM 0.509 for usage exceeding 200kWh.

$$3{,}108.06\ kWh \times RM\ 0.509 = RM\ 1{,}582.00$$

Average bill Al-Faizin mosque in 3 months = RM 1,036.85

Total billing price after made installation of aircon For Al Faizin mosque =

$$RM\ 1{,}582.00 + RM\ 1{,}036.85 = RM2{,}618.85$$

Figure 10 displays the current electricity billing cost before air conditioners and estimates the cost after installation. This highlights the huge increase in estimated monthly costs of 150% associated with AC usage.

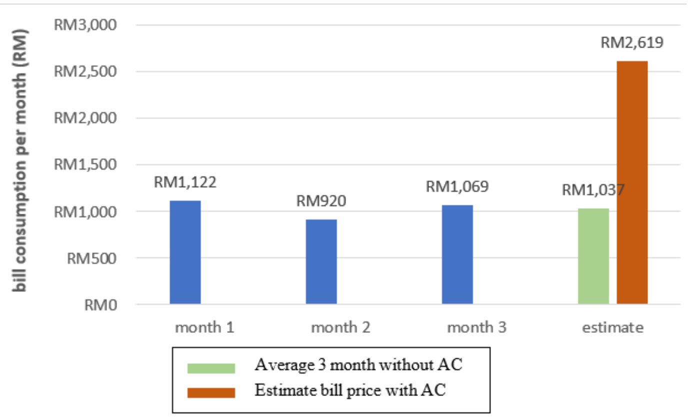

Fig. 10: Comparison of Current Electric Bill Price without AC and Estimate Electric Bill Price with AC

4. Conclusion

In conclusion, this study successfully achieves both objectives. Temperature analysis shows a range of 22°C to 25°C over six one-hour time steps inside the mosque hall, meeting authority requirements of 22.5°C to 26°C. The simulation validates the optimal positioning, number, and horsepower of air conditioner units for installation in Al-Faizin mosque. These findings serve as valuable reference data for mosque designers considering air conditioner installations. Based on visual surveys and monitoring, recommendations include installing air conditioning units with slightly higher horsepower than calculated for increased comfort. Additionally, setting the temperature to 24°C or higher helps conserve electricity by allowing the compressor to stop when the desired temperature is reached inside the building.

References

[1] S. C. Turner et al., "American Society of Heating, refrigerating and Air-conditioning Engineers," International Journal of Refrigeration, vol. 2, no. 1, pp. 56–57, 1979, doi: 10.1016/0140-7007(79)90114-2.

[2] ASHRAE, "ASHRAE Standard 62.1 Ventilation and Acceptable Indoor Air Quality in Commercial Buildings," Energy Efficiency & Renewable Energy, 2014

[3] J. Keselamatan Dan Kesihatan Pekerjaan, "Industry Code of Practice on Indoor Air Quality 2010 Department of Occupational Safety and Health Ministry of Human Resources, Malaysia JKKP DP(S) 127/379/4-39 a."

[4] I. Hussein, M. H. A. Rahman, and T. Maria, "Field studies on thermal comfort of air-conditioned and non-air-conditioned buildings in Malaysia," ICEE 2009 - Proceeding 2009 3rd International Conference on Energy and Environment: Advancement Towards Global Sustainability, no. December, pp. 360–368, 2009, doi: 10.1109/ICEENVIRON.2009.5398622.

[5] Junaedi Irwan, Wan Abdul Halim. 2021. "UMP News." Estimate the Air ConditionerCapacity. September 22. https://news.ump.edu.my/print/pdf/node/5882.