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# A case study on cooling load performance of a large multi-storey house through simulation

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ABSTRACT

Air conditioning system consumes the most energy in a residential building; therefore, it is necessary to understand the elements that contribute to its design and operation. One of the important factors is the cooling load of the building, which is the result of multiple heat gains from internal and external sources. The research aims to comprehend the distribution and behaviour of cooling load in a house with the help of a case study. The target building is a simulation model of a three-storey bungalow in tropical climate. DS-HL2 modelling is utilised with building specification and measurement as the input. Simulation finding shows that the rooms located at the rear end of the house experienced peak heat gain as early as 11 a.m., compared to 4 p.m. for the room located in the middle. Also, three passive measures were introduced to the premise. Outperforming roof insulation and overhang shade, tinted glass was observed to be the most effective at 11.4 % cooling load reduction. When the combination of all passive measures was implemented, each room in the house had a unique percentage of cooling load reduction per area. The room with highest benefit was Master Bedroom at 28.1 % cooling load reduction per area.

***Abbreviations***

| | |
|---|---|
| CL | cooling load (W) |
| DS-HL2 | Daikin Software Heat Load Calculation Program Ver 1.1.0 |
| SH | sensible heat (W) |
| LH | latent heat (W) |
| CL | cooling load (W) |

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## 1. INTRODUCTION

Air conditioning has become a necessary equipment for residential building in providing comfortable environment in the house. In tropical region where the weather is naturally hot and humid like Malaysia, a high amount of energy has to be consumed to provide thermal comfort. The use of air-conditioners and electric fans was found to account for at least 20% of the total electricity consumption worldwide in the building sector [1]. The trend is expected to increase when factoring in the standard of living, declining process of the air-conditioner unit and extreme heat wave due to climate change. Residential buildings consume the largest amount of energy most of which consumed by air-conditioning systems in tropical countries and in Malaysia, nearly 70% of the electricity in buildings is consumed by air-conditioning and refrigerator. Energy efficiency is a key factor that should be considered as an effective solution to some environmental effects like global warming.

Cooling load (CL) is one of the most important parameters in air conditioning performance analysis. It is basically the rate of heat to be removed from a conditioned room in order to keep the targeted thermal comfort in terms of temperature and humidity. Having an efficient air conditioning system is always the goal for any cases, but on the other hand, the existence of passive design of the building is in fact beneficial as well. Research that helps to increase awareness towards green building is an effective way to promote passive measures.

A good example of research was carried out by Mushtaha et al. who investigated three passive measures namely shading equipment, natural ventilation and insulation [2]. The outcome showed that such implementation would reduce the energy by 9.89 kW which represents 59 % of the building energy. Meanwhile, Shukla et al. did a comprehensive work in proposing alternative building envelopes with lower U-value [3]. As a result, the total cooling load of the hostel building was cut by 34.7 % compared to base case. The benefit of passive measures was also confirmed by Liu et al. who conducted research on the use of solar protection, windows airtightness and ventilation utilisation [4]. With the combination of all measures, the annual cooling load can be saved up to 56.7 %, which is an impressive achievement. In similar spirit, Sun et al. analysed 11 passive measures for the home of local communities [5]. In their findings, the two most effective measures were the installation of window films and roof insulation which helped to save up to 51 % of power.

An interesting study was done by Malla et al. who evaluated passive measures potential in Europe [6]. It was observed that shading and glazing upgrades are the most effective, well above other options and should be considered for future building directives. A unique approach was taken by Piselli et al. who looked into the possibility of phase change materials integration in building envelope [7]. It was a successful attempt as the results showed that the inclusion could lower the energy consumption of up to 300 kWh per year. Another research was carried out by Bas in the city of Dubai [8]. In his study, a special glazing to reduce solar transmittance was tested, resulting to a cut in annual energy by 38 %. Also, he found that better airtightness would lessen energy consumption by 8 %.

The feasibility of using insulated ceilings and reduced window-to-wall ratios as passive measures was examined by Rodrigues et al. [9]. The output was a success as the combination of both strategies achieved 68 % of savings in cooling energy. In the tropical climate of Indonesia, Chen et al. did a thorough analysis of improving thermal insulation, natural ventilation, and solar shading as passive measures [10]. It was confirmed that the cooling load reduction was 7.4 % for insulation, 8.4 % for ventilation and 5.4 % for

the shading. In the meantime, Khalid et al. went to the extreme by comparing 16 scenarios of passive options [11]. According to their findings, the combination of wall insulation, external shading, double pane glass windows with air in-between, roof insulation, cross ventilation and LED lighting had the best performance. The setup managed to bring down the cooling load by 39.3 %.

Bughio et al. contributed the findings of using double-glazed window for a building in Karachi [12]. By doing so, the cooling energy was lessened by 8.6 %. Lastly, Elnabawi et al. modelled a polystyrene insulation into the outside wall. In arid climate, the initiative was able to reduce annual cooling energy by 25 % [13]. From the review of past research, the specific techniques of passive measures were observed to be influenced by the material technology, existing building envelope and local climate. For the current study, cooling load characteristics of a residential premise was examined. The target building is a simulation model of a relatively large house, therefore the investigation is extended to spatial analysis of internal locations as well. In addition, tinted window, roof insulation and overhang shade are three passive measures being proposed to be tested by means of simulation.

## 2. METHODOLOGY

Air-conditioning design is using Daikin Software Heat Load Calculation Program (DS-HL2) Ver 1.1.0. It is based on ASHRAE's Radiant Time Series calculation method to compute the design heating and cooling load. There are three sections of the software that require user input which are General, Components and Other. The General section consists of room design criteria, specification and infiltration. Internal load such as lighting, internal equipment operation heat, occupancy and operating time, with ratio and airflow calculation setting from outdoor air intake and fresh air requirement is also specified under this section. On the other hand, the Components section consists of building envelop such as roof, wall, window, floor and underground room. Lastly, the Other section consists of personnel heat gain, radiant time factor consideration, room condition such as glass surface ratio and next room conditions, internal heat gain in heating and safety factor. Figure 1 shows the screenshot of the DS-HL2 simulation program.

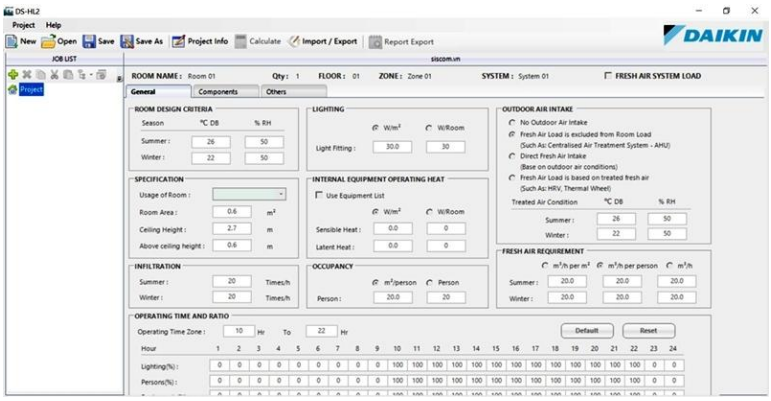



Figure 1. Screenshot of Daikin DS-HL2

In the simulation, the heat gained by the building was determined. Therefore, the most important parameter is the cooling load. It is calculated using Equation (1),

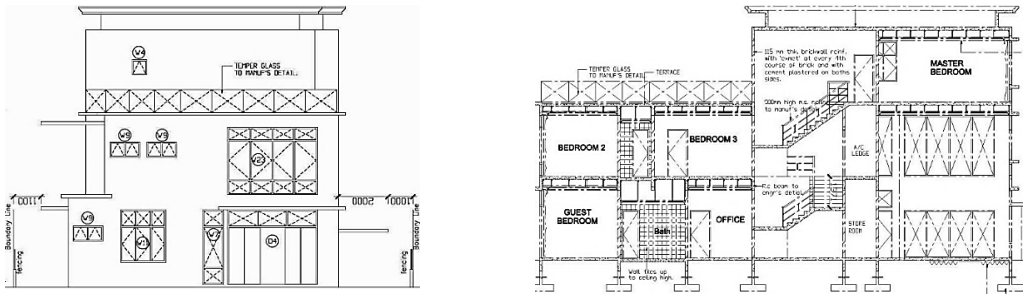
$$Q = UA\Delta T \quad \text{(W)} \quad (1)$$

where U is the thermal transmittance, A is the total surface area and Delta T is the total equivalent temperature difference in which the values are referred to as cooling load temperature difference.

The current study was based on the target building of a 2½ storey detached bungalow house at Kuching, Malaysia. The research is purely based on simulation and the setup of software input is shown in Table 1. Figure 2 shows the front and side view of the building, which is rectangular in shape and facing south. With such orientation, the house receives the most heat gain from either side, in the morning and afternoon. From the look of the side, it is obvious that the second floor of the house consists of Master bedroom only, hence the house is designed to be higher in the front half compared to the rear half. According to the architectual drawing, ground floor height is 3.6 m, while the height for first and second floor is 3.3 m. Figure 3 shows the plan of the first and second floor. There is a void area on the first floor in front of the house. It indicates that the height of Living and Dining room is extended until the second floor. In terms of bathrooms, there are 2 units on the ground floor, and 3 units on the first floor. The wall is made of 115 mm brick and plastering on both side and reinforcement concrete slab. The roof and floor is a flat concrete with similar specification, with a thickness of 150 mm.

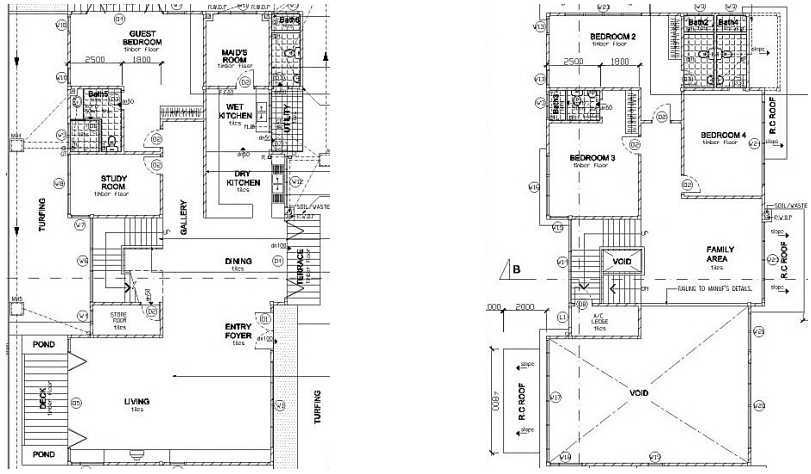
Table 1. Simulation setup

| **Input** | **Floor** |
|---|---|
| Location | Kuching |
| Latitude | 1.55 °N |
| Longitude | 110.36 °E |
| Max. temp – Summer | 35.4 °C |
| Safety factor (cooling) | 1.05 |
| Design – Summer, Dry Bulb | 24 °C |
| Design – Summer, Relative Humidity | 60 % |
| Infiltration – Summer | 0.4/hour |
| Wall thickness | 115 mm |
| Wall U-value | 2.84 W/m$^2$K |
| Ceiling thickness | 150 mm |
| Ceiling U-value | 2.32 W/m$^2$K |
| Window thickness | 10 mm |
| Window U-value | 5.20 W/m$^2$K |

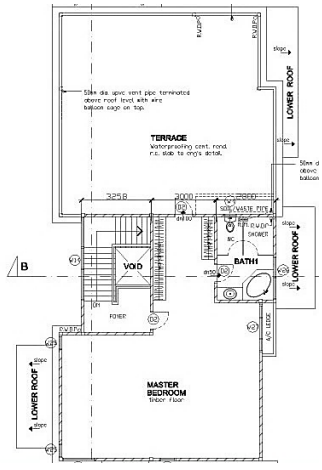



(a) (b)

Figure 2. View of the (a) front and (b) side of the house




(a) (b)




(c)

Figure 3. Plan view of the house: (a) ground floor, (b) 1st floor, and (c) 2nd floor.

Table 2 shows the area of the specific locations in the building. There are nine rooms or locations that are intended to be air-conditioned, with the largest area being the Living and Dining, while the smallest area is the Maid room. The staircase area is not intended to be air-conditioned, as well as the bathrooms. Figure 4 shows the pie chart for the percentage of floor area for each location. The total area is 326.3 $m^2$.

At a glance, the specification of building envelope for the house is common for a residential premise in the country. Since the research is analysing the effect of passive design on a typical residential building, several features are being suggested to be investigated using the simulation. The list is shown in Table 3 and it is specifically chosen based on the DS-HL2 modelling capabilities and limitations. The Base case is for the existing house and its specifications. Case studies 1, 2 and 3 are for the particular feature being intoduced to the house while Case 4 is the combination of all three proposals combined. The overhang shade is an opaque type, extruded 350 mm from the wall and placed on top of the window.

Table 2: Internal location in the house

| **Location** | **Floor** | **Area ($m^2$)** |
|---|---|---|
| Guest Bedroom | Ground | 29.4 |
| Maid Room | Ground | 10.0 |
| Study Room | Ground | 13.0 |
| Living and Dining | Ground | 104.4 |
| Bedroom 2 | 1st | 22.8 |
| Bedroom 3 | 1st | 20.6 |
| Bedroom 4 | 1st | 19.6 |
| Family Area | 1st | 35.9 |
| Master Bedroom | 2nd | 71.8 |

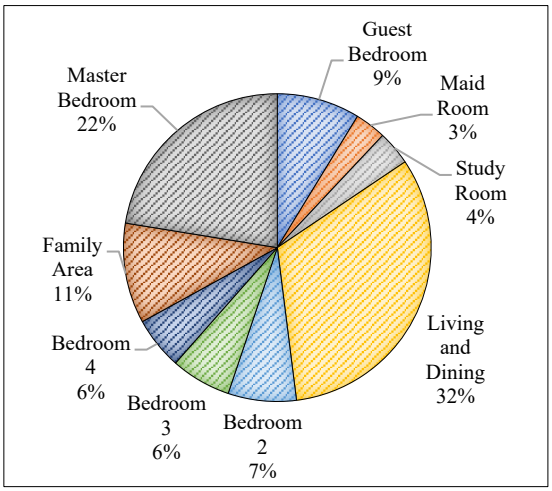



Figure 4. Percentage of area by location

Table 3. Passive design measures case studies

| Feature | Base case | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|---|
| Tinted window | - | Yes | - | - | Yes |
| Roof insulation | - | - | Yes | - | Yes |
| Overhang shade | - | - | - | Yes | Yes |

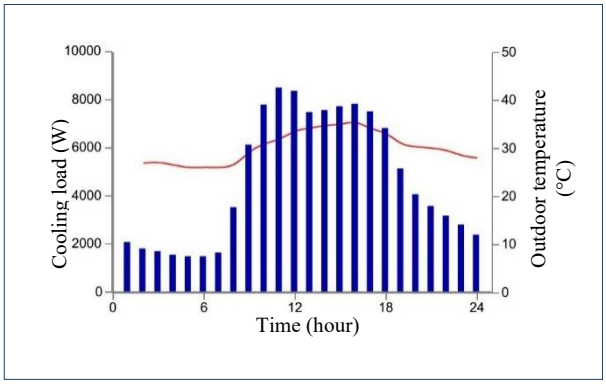
## 3. RESULTS AND DISCUSSION

After all building data have been inserted as the input to DS-HL2, the simulation was run in order to get the results. Aligned to the objective of the research, the output focuses on the cooling load generation of the premise. For the sake of argument, Figure 5 shows the distribution of hourly cooling load of the Guest Bedroom for the whole day. In the early morning, the house is in a relatively lower temperature due to the lack of main source of heat from the sun. As a result, the cooling load stays below 2000 W for a few hours. After sunrise, the presence of heat starts to increase the temperature inside the house. The heat gain of the house continues to rise steadily until noon. The heat penetrates the building through window, wall, door and roof, causing the cooling load to reach its peak at about 8000 W.

The hourly output for another location in the house, namely Bedroom 2, is shown in Figure 6. It has the profile of almost similar to that of Guest Bedroom. Cooling load proportionates to the outdoor temperature, which is represented by the red curve. In a typical day, the maximum temperature reaches around 33 - 34 °C, causing the cooling load to peak as early as 11 a.m. consistently until the afternoon. The behaviour is common for a tropical climate, where a lesser temperature could only be achieved during a cloudy environment or perhaps when raining occur.

The third instance of location under scrutiny is Bedroom 3. The floor area is documented to be 20.6 m2 and the profile of its cooling load is shown in Figure 7. As a rule of thumb, apart from the external source, there is also heat gain from the internal such as human perspiration, which contributes to the latent heat (LH). Meanwhile, lighting and electrical equipment supply the sensible heat (SH) in the conditioned room. At a glance, the cooling load profile for Bedroom 3 is somewhat differ from that of Guest Bedroom and Bedroom 2. It is observed that after sunrise at 7 a.m., the cooling load rises rapidly for Bedroom 2 and Guest Bedroom. On the other hand, the load increase for Bedroom 3 is more gradual from an hour to another hour as shown in Figure 5. As a result, the peak load does not reach before noon, but it is way later at about 4 p.m. in the late afternoon. However, peak value is almost similar at around 8000 W.

The explanation for the difference in cooling load profile among these locations lies on the positioning in the house. As shown in Figure 3, Guest Bedroom and Bedroom 2 are located at the back of the house. The location is similar but at different level, as Guest Bedroom is at the ground floor and Bedroom 2 is at the first floor. Due to the far end location, both rooms have windows at the north and west side. The extra exposure to sunlight causes additional heat to penetrate the room, hence the increase in cooling load. Occupants in both rooms feel the warm for an extended period. In contrast, Bedroom 3 is located in the middle section of the house. Only the west side of the room is facing the outside, therefore it has a relatively lower window area. The other three sides that face north, east and south are adjacent to the internal portion of the house. The condition has a significant impact on the cooling load profile of the room, as shown in Figure 5. It is safe to assume that the occupant in Bedroom 3 would have a better thermal comfort compared to that of Guest Bedroom and Bedroom 2.



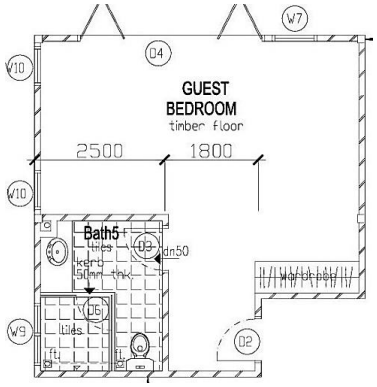
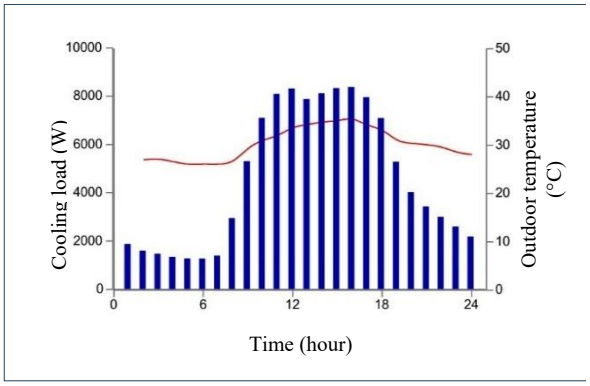




Figure 5. Cooling load profile for Guest Bedroom



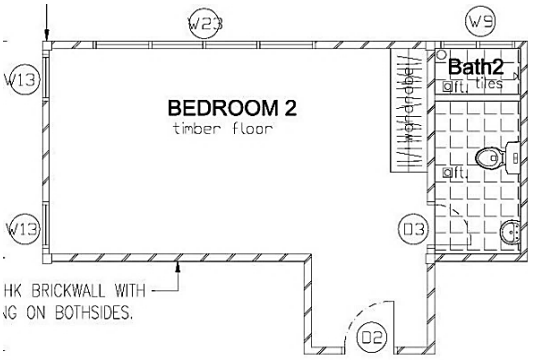
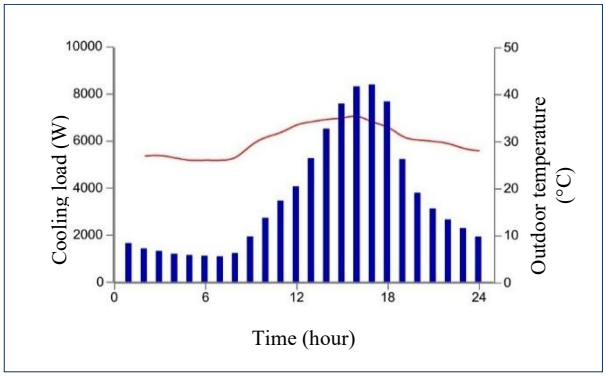




Figure 6. Cooling load profile for Bedroom 2



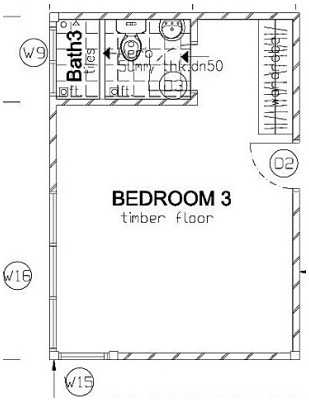




Figure 7. Cooling load profile for Bedroom 3

As there are many locations within the house, it is necessary to break down the cooling load accordingly as shown in Figure 8. Not surprisingly, Living and Dining section contributes the most since the area is the largest at 104.4 $m^2$. Master Bedroom recorded the second highest load, proportionate to having the second largest area. However, the third largest location, namely Family Area, is observed to register only 6.92 kW of cooling load. It is less than that of Guess Bedroom at 8.51 kW. The results show that the value of cooling load is not based on magnitude of area only. It is a combination of factors and one of the most important considerations is the spatial design of the location within the house.

For the comparison between Family Area and Guest Bedroom, spatial factor has a direct influence on the windows of both locations. As shown in the plan view of Figure 3(b), Family Area is located in the middle section of the 1st floor. Its front end is adjacent to the Living room, while the rear end is next to Bedroom 4. The west side of Family Area is the internal stairs and Bedroom 3. Only its east wall and windows are exposed to the outdoor. By and large, the main source of heat gain is from the sun and as a result, the cooling load of Family Area is relatively minimised. On the other hand, as explained before, the Guest Bedroom is located at the rear end of the house. By having two sides of walls and windows adjacent to the outdoor, the heat gain of Guest Bedroom is relatively high due to the solar radiation and heat conduction from the sun.

The observation of room positioning in the house and its effect are further revealed in Figure 9. The bar chart shows that Study Room has the lowest value of cooling load per unit area. Referring to Figure 3(a), Study Room is located in the middle of the building at ground level. Except for the west side, Study Room is surrounded by internal rooms. Again, the spatial argument is self-explanatory for the reasoning of minimum cooling load.

Figure 10 shows the results of cooling load comparison for all Case studies as detailed in Table 2. The simulation for Base Case shows that the cooling load is 81.9 kW. Case 1, representing the measures of using tinted glass for windows, has the highest cooling load reduction at 72.6 kW, or 11.4 %. Since glass is a transparent material, heat can easily penetrate through it, hence the use of a dark film really helps to filter. There is not so much difference between Case 2 and 3 though, in which cooling load is shown to be 78.0 kW and 77.8 kW respectively. The roof insulation initiative in Case 2 has a relatively minor influence due to the fact that the house is a three-storey, and the roof is only for the 3rd floor. A single-storey house is believed to benefit more from roof insulation measure. The third proposal in Case 3, which installs an overhang shade, was also observed to have a limited induction to cooling load. The reduction is just 5.0 % of the Base Case. Analysing the case study in a standalone manner seems to produce little, therefore it is important to combine passive measures in order to have a significant result. Case 4 is the collective output of all three case studies, which produce a cooling load of 68.8 kW, or 16.0 % in reduction.

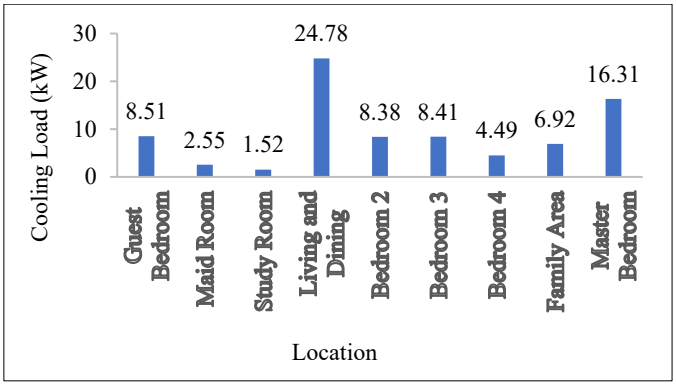



Figure 8. Cooling load for Base Case

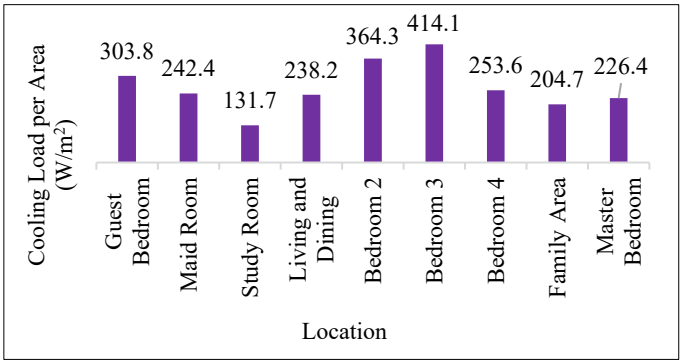



Figure 9. Cooling load per area (kW/m$^2$) for Base Case

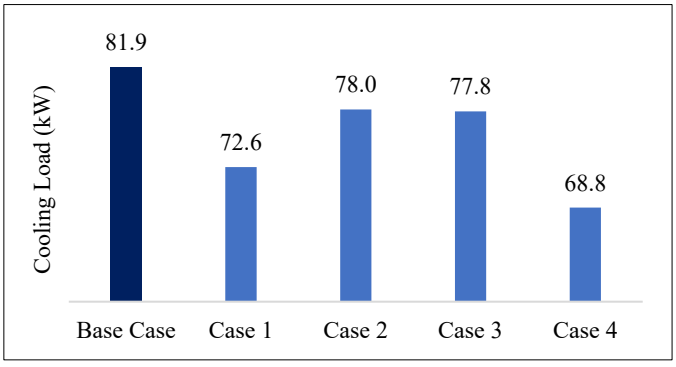



Figure 10. Cooling load for case studies

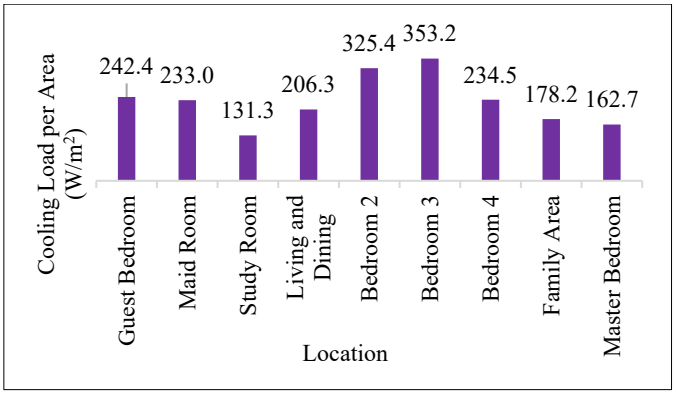



Figure 11. Cooling load per area (kW/m$^2$) for Case 4

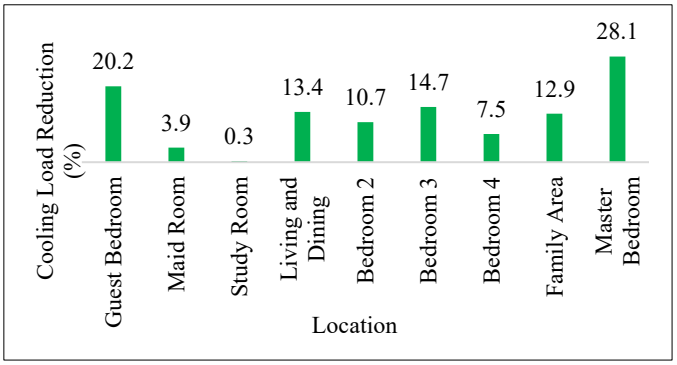



Figure 12. Percentage of cooling load reduction per area (%) for Case 4

Further investigation was carried out to look into the effect of the combined passive measures on the profile of cooling load per area. Figure 11 shows the cooling load per unit area for Case 4, which provides a straight comparison with the Base Case in Figure 7. At a glance, it was observed that there are some changes in the load profile of both figures, indicating that all nine locations in the house behave differently to the passive measures. In other words, the reduction in cooling load is not uniform to all locations.

Hence, it is necessary to explore the effect of cooling load reduction per area for all locations in the premise. Figure 12 offers such details in terms of percentage. From the chart, it is obvious that Master Bedroom reaps the highest advantage should all passive measures be implemented. Based on the building plan in Figure 3(c), Master Bedroom is the only room located on the 3rd floor. Thus, the room is exposed to the outdoors on each side of the wall. It has the most windows area, meaning that the installation of tinted glass is welcome in terms of heat gain prevention. Also, the room is in direct contact with the roof, therefore any insulation on top of the room would reduce the cooling load significantly. The same can be mentioned regarding the use of overhang shade, as Master Bedroom has the most windows. On the other hand, Study Room has the least impact on passive measures with only 0.3 % cooling load reduction. The spatial position of Study Room, which is in the middle of the house provides its protection from external heat gain.

## 4. CONCLUSIONS

A simulation model of a relatively large house is chosen as a case study to investigate the cooling load behaviour of a residental in a hot and humid environment. The target building is basically a three-storey bungalow with the orientation of facing the south. The premises are divided into 9 locations, enabling a thorough investigation amongst the spots. The research is carried out with the use of DS-HL2 as the modelling tool. Three rooms are picked to be scrutinized for the spatial effect of cooling load. Guest Room and Bedroom 2, positioned at the rear end of their respective floor, are observed to experience earlier cooling load increment, peaking just above 8000 kW at 11 a.m. The peak load for Bedroom 3 only occurs at 4 p.m. as the room is located in the middle of the house. Guest Room and Bedroom 2 have more walls and windows area facing outdoor; thus, the higher heat gain. Passive measures are also being applied to the building envelope in order to examine the cooling load response. It is observed that the tinted window provides the highest cooling load reduction at 11.4 %, followed by the insulated roof. The overhang shade has the least effect. When the combination of all passive measures are implemented, the results show that each location has a unique percentage of cooling load reduction per area. The location that benefited the most is Master Bedroom at 28.1 % per area, as it is the sole room at the 3rd floor and has all walls and windows facing outdoor. In addition, the roof is directly on top of the room and contributes a significant amount of heat gain. In contrast, Study Room has the minimum effect at 0.3 %, due to its spatial position, which is in the middle of the house.

## 5. ACKNOWLEDGEMENTS/FUNDING

The work was not funded by any research grant.

## 6. CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 7. AUTHORS' CONTRIBUTIONS

**Nik Izzati Atheerah Nik Razali:** Data curation

**Azizuddin Abd Aziz**: Supervision, Original Draft

**Ahmad Basirul Subha Alias:** Methodology, Validation

**Mohd Yusof Taib:** Review, Validation

## 8. DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS

During the preparation of this work, the author(s) did not use any AI-assisted technologies.

## 9. DATA AVAILABILITY/SUPPLEMENTARY MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## 10. ETHICS STATEMENT

The authors declare that this research did not involve human or animal subjects.

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