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An Investigation on Indoor Temperature of Modern Double Storey House with Adapted Common Passive Design Strategies of Malay Traditional House

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ABSTRACT

Past years have witnessed the popularity of traditional Malay house as a common housing type in Malaysia. However, double-storey house has become one of the common types of low-rise housing in Malaysia. Several passive cooling strategies have been adopted to cope with the hot-humid climate of Malaysia. In this study, the thermal comfort of a double-storey house was examined when different passive cooling strategies that were adopted from traditional Malay houses were applied using IES-VE 2019 building simulation software. The simulation was conducted for various design strategies such as changing concrete roof tiles to clay roof tiles, adding two small openings to the attic, removing the ceiling between the upper floor and the attic, and extending the overhang by 50% of its length for all the four facades. All these strategies were tested and compared between full-day natural ventilation and without any ventilation. The thermal comfort of these strategies was graphically defined based on the operative temperature. These analyses revealed that protecting the building envelope by extending the overhang by 50% of its length for all the four facades could ensure the best thermal comfort is achieved compared to other selected strategies. Recommendations for further studies are also outlined in this paper.

Keywords: Double storey house, IES-VE software, indoor temperature, simulation, thermal comfort, traditional Malay house

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INTRODUCTION

Traditional Malay House

For hundreds of years, the traditional Malay house concept has been developed and modified by locals to suit their immediate environmental and cultural needs. Various design strategies can be observed from traditional Malay houses from different states in Malaysia. Although the form and architectural design of traditional Malay houses in all states in Penisular Malaysia may look different, their response to the local environment and culture does not differ much due to similar local climatic condition. According to the Malaysian Meteorological Department (MMD), Malaysia is an equatorial country characterized by uniform temperature (21-35°C), high humidity (42 - 100%), high solar radiation, and profuse precipitation (1000 mm per year) (MMD, 2017). This tropical climate is designated by the Köppen climate classification (Yau & Hasbi, 2017).

The design strategies of the traditional Malay house are seen as sustainable solutions to the current modern housing development in Malaysia. Two important strategies are the optimization of natural lighting and ventilation through many openings that lead to good indoor environmental quality as well as reduced energy consumption of the house. However, the recent housing development in Malaysia such as double-storey terrace house does not adopt these green strategies and leads to a poor indoor environment (Al-Obaidi & Woods, 2006; Ibrahim et al., 2014; Nugroho et al., 2007; Sadafi et al., 2012; Tinker et al., 2004) . Thus, this can lead to possible dependence on air conditioning system or other mechanical systems to ensure indoor thermal comfort which subsequently leads to high energy consumption. Hence, it is crucial for the community, especially designers or developers, to understand and adopt the green design approach that exists in the traditional Malay house design and appropriately applied into modern house design to ensure sustainable development in Malaysia.

Figure 1 and 2 show two traditional Malay houses from two different states, Terengganu and Kelantan, respectively. Both states are located in the Northeast of Malaysia. Both houses share common green strategies such as a raised floor system, use of timber as the main material, ventilation through walls including just below the roof, and many more. The houses demonstrated similarities with the common double-storey terrace or detached houses which is around two-storey height.

The Green/Sustainable Strategies of the Traditional Malay House

Numerous green design approaches can be studied from the traditional Malay house. A review of the literature and fieldwork were completed to list the common green or sustainable design strategies that were used for traditional Malay houses.

Fieldwork visits were completed to at least one traditional house from each state in Peninsular Malaysia to understand the basis of their designs. These include traditional

Figure 1. Original condition of Traditional Malay House of Terengganu at Terengganu Museum, Kuala Terengganu, Terengganu, Malaysia.

Figure 2. Renovated and extended (including building rooms with brick walls under the original on stilts traditional house) Traditional Malay House of Kelantan at Kota Bharu, Kelantan, Malaysia.

houses in Universiti Putra Malaysia (4 units from Perak, Negeri Sembilan, Terengganu, and Pahang), Universiti Kebangsaan Malaysia (1 unit from Kelantan), Politeknik Port Dickson (1 unit of Negeri Sembilan Traditional houses), Lembaga Muzium Negeri Sembilan (2 units from Negeri Sembilan), Terengganu State Museum (5 units of Terengganu's Traditional houses), Kedah State Museum (2 units Kedah's House), and many more. This fieldwork is completed within 3 years. Literature review was also completed from relevant publications (Lim, 1987; Mohamed, 2018a, Mohamed, 2018b; Nasir, 1985; Nasir & Teh, 2011; Nasir & Teh, 1997; Surat, 2018, Surat, 2016; Surat et al., 2012; Yusoff & Mohamed, 2017). Authors' observation during the fieldwork and literature review revealed 23 significant green or sustainable approaches (Table 1) that commonly existed in various types of traditional Malay houses. However, the list is not limited to this.

Table 1

Selected significant green or sustainable approaches that commonly exist in various traditional Malay houses.

No	Green or sustainable approaches
1	Large window opening to allow for natural lighting and ventilation. Some of the openings are designed to be full height.
2	Wide roof overhang for shading and protection from heavy rain and direct sunlight.
3	Built on stilt with concrete or stone base to allow for working space, livestock, as well as to protect from wet ground, flood, and dangerous animals/insects.
4	Steep roof to allow an uninterrupted flow of rainwater and to clean the roof. Also, it is common to have a two-tier roof to allow natural ventilation through gaps between the two roofs.
5	The area with open space such as verandah for activities including entertaining visitors.
6	Opening at roof attic to cool the space under the roof.
7	Roof made of leaves or clay (Singgora) for better heat protection from sunlight.
8	Opening on walls (Examples: wooden craft and timber louver) to allow for natural lighting and ventilation, as well as for security reasons.
9	Natural construction materials such as timber and bamboo that are readily available from the site.
10	Open floor plan for uninterrupted airflow and daylight to penetrate into the house.
11	House plan with a small width for greater efficiency of natural ventilation and lighting.
12	A modular house plan that allows easy construction, future extension, and relocation.
13	Rain harvesting is an alternative water source to water well for domestic water usage.
14	Different floor levels to differentiate between various purposes of spaces, to suit timber joint construction, and to allow ventilation between the floor gap.
15	Seating area below the house for resting, meeting visitors, storage, or large event or gathering.
16	Construction using a wood joint for stronger construction as well as easy assemble and disassemble.

Table 1 *(Continued)*

No	Green or sustainable approaches
17	More than one entrance to allow for access or exit for various purposes, such as in the event of a large gathering, normally, a woman will use the entrance at the kitchen.
18	Connecting space between two indoor space for natural lighting and ventilation, as well as various activities such as drying clothes and other family activities.
19	Flooring with gaps to allow for natural ventilation as well for cleaning & draining.
20	High indoor spaces that allow better natural ventilation airflow.
21	Attic space with ladder for various purposes such as protection (hiding), room for women (daughter), and storage
22	Orientation towards Qibla due to religious factors and subsequently lead to the housing to face west sunlight (the house protected from the direct sunlight by building elements such as long overhang and verandah), and some respond to site context such as road.
23	Reuse of materials especially hardwood such as Cengal wood that can last for hundreds of years and the reuse purpose is supported by the jointing system (without nail) that allow the house to be easily disassembled and relocated to other locations.

The approaches listed in Table 1 are common design approaches in traditional Malay house design and are influenced by many social, economic, and environmental factors. This study observed that the cultural differences among many states contributed to the varying architectural aesthetic of traditional Malay houses according to the states in Malaysia. Despite the differences, the basic design approaches are generally similar.

Thermal Comfort

Thermal comfort occurs in a narrow range of body temperatures and the skin moisture is kept low with minimum physiological effort (ASHRAE, 1992). Occupants in naturally ventilated buildings have a wide range of comfort temperatures which may exceed the limitations of ASHRAE Standard 55, and also a response to local outdoor climate changes. On the contrary, occupants who stay in air-conditioned buildings have a very narrow range of comfort temperature as they develop a high expectation for cool temperature, and as a result, they become critical to any changes (Brager & de Dear, 2000).

The objective of this study is to investigate the effect of the application of selected green passive cooling strategies of typical traditional Malay houses on a double-storey modern detached home on the aspects of indoor temperature and thermal environment.

METHODOLOGY

In this study, several design strategies that traditional Malay house used were selected and applied to the tested house (Case 1) to investigate the effect of these strategies on internal thermal environment. The investigation was conducted and compared under two conditions which were fully ventilated and totally without ventilation. The selected approaches are as follows:

a. Clay roof tiles: to investigate the roof materials with different thermal transmittance (U-value).

b. Ventilated attic space: to allow ventilation within the attic for heat removal.

c. No ceiling underneath the roof: to allow higher clear vertical height but without protection from the heat originated from the roof tile.

d. Extended overhang for all the four facades: to further protect façade from direct sunlight.

The tested house was located at the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), Bangi, 27 km from Kuala Lumpur, the capital city of Malaysia. Figure 3 shows the double-storey house that was built using common modern construction building materials (sand brick and cement for the walls and concrete roof tiles for the roof). This house was built purposely for research activities. Therefore, easy access of the house enabled the researcher to enter the house easily for site investigation.

The house includes a living room, kitchen, and a bathroom on the ground floor, and three bedrooms and two toilets on the first floor. In this study, Room 1 refers to the living room, Room 2 refers to the second bedroom, and Room 3 refers to the master bedroom. The windows of the house faced the four directions. Figure 4 shows the ground and first floors' plans of the tested house.

Figure 3. The tested house

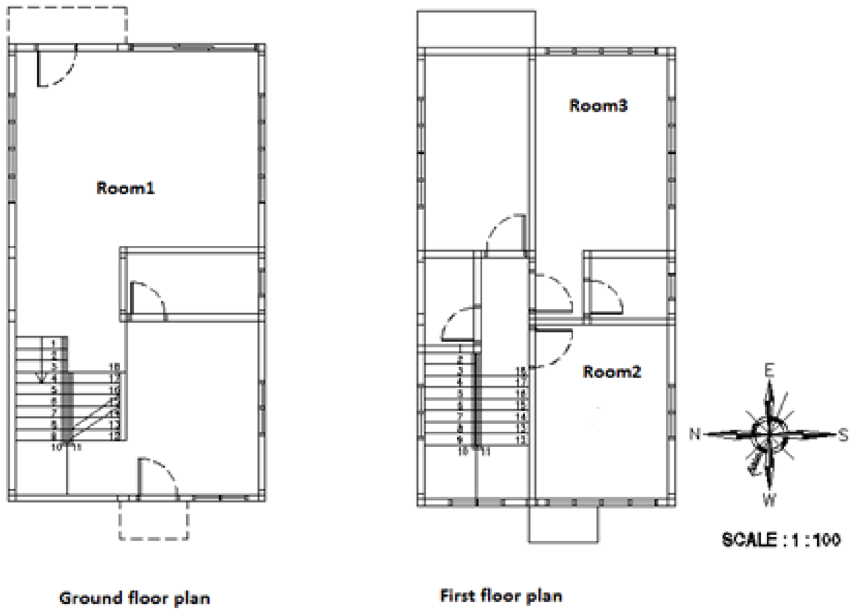


Figure 4. The plans of the tested house

The geometry of the computational model for the tested house was created using the IES-VE (2019) software. The building' geometry, dimensions, and areas of solid and transparent surfaces were defined using [ModelIT]. The location of the house was defined by [APlocate], which was set as Kuala Lumpur suburbs as it was the nearest to the site. Windows and doors openings profile and windows' types were set using [MacroFlo]. Then, fabric materials and their thermal properties and simulation time were defined using [Apache]. Table 2 shows the details of construction materials used in the simulation of the tested house.

The simulation was done in April which falls in the hottest period in the year in Malaysia as reported by the MMD (2017) and Sulaiman (2017). The weather data of this study were provided by IES-VE which can be determined according to the nearest location that was defined earlier.

The main simulation output obtained from IES-VE wast the indoor and outdoor air temperature (T_a) and the mean radiant temperature (T_{mrt}) for each case. The results were converted into Excel sheets to facilitate data analysis. IES-VE was selected as it is a software that has a simple input interface that creates the prototype and modifies its layout. The output can be easily interpreted and represented in tabular data or graphs. Finally, IES-VE is user-friendly, which makes this software useful for this study. A three-dimensional view of the building modelled in IES-VE is illustrated in Figure 5.

Table 2

Details of construction materials for the tested house. The values are the standard values in the software.

Element	Construction	U-Value (W/m^2 k)
External walls	Cement plaster (19 mm), sand brick with cement (114 mm), cement plaster (19 mm)	3.4
Internal walls	Cement plaster (19 mm), sand brick with cement (114 mm), cement plaster (19 mm)	3.4
Roof (concrete tiles)	Concrete tiles (5 mm), aluminium sisalation (1 mm), UCO Superflex ceiling board (3.2 mm)	6.9
Roof (clay tiles)	Clay tiles (5 mm), aluminium sisalation (1 mm), UCO Superflex ceiling board (3.2 mm)	6.85
Floor	Cast concrete (220 mm)	3.6
Doors	Plywood	2.2
Windows	Glass (one-layer clear float 5 mm)	5.2

IES-VE permits the user to change the types of construction materials, dimensions, thicknesses for all house components (roof, ground, and walls), and windows opening profile.

Firstly, the concrete roof tiles that were used in the tested house were changed to clay roof tiles (Case 2), while other original conditions of Case 1 remained. In Case 3, two small openings were added to the attic, while other original conditions of Case 1 remained. In Case 4, the ceiling between the upper floor and the attic was removed to determine any difference, while other original conditions of Case 1 remained. In Case 5, the overhang of the house was extended by 50% of its length for all four facades (from 1.2 to 1.8 meter) to increase its shading on the walls and windows, while other original conditions of Case 1 remained. All the previous strategies were done with full-day natural ventilation (all windows and internal doors were open for 24 hours) and no ventilation (all windows and

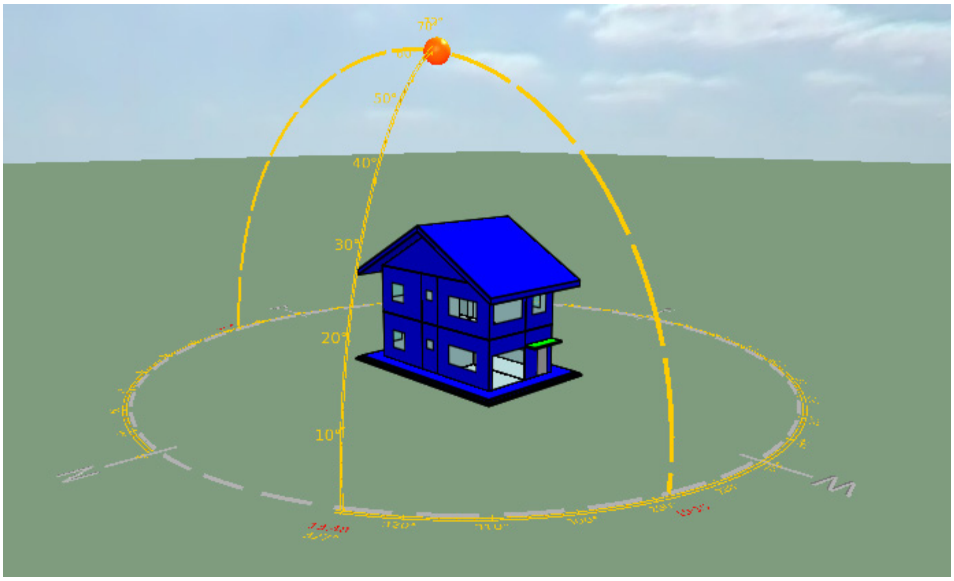


Figure 5. The tested house in IES-VE software

doors were closed for 24 hours) separately. All five cases were simulated on the same date of the year using the validated model of the tested house at IES-VE software. The validation process of IES-VE software was previously performed by Oleiwi et al. (2019).

The main simulation output obtained from IES-VE was the indoor air temperature (T_a) and the mean radiant temperature (T_{mrt}) for the three rooms. The results were converted into Excel sheets to facilitate data analysis.

Operative temperature (T_o) was calculated based on the Equation 1 that was proposed by ASHRAE Standards (ASHRAE, 2010):

$$T_o = \frac{(T_a + T_{mrt})}{2} \qquad (1) \quad (3.1)$$

Where T_o is the operative temperature in °C, T_a is the air temperature in °C, and T_{mrt} is the mean radiant temperature in °C.

RESULTS AND DISCUSSION

A comparison of the operative temperature of the five cases was conducted by applying full-day ventilation (all windows and internal doors were opened for 24 hours) and no ventilation (all windows and doors were closed for 24 hours) to identify the best strategy to achieve thermal comfort for the tested house. Thereafter, strategies that could potentially achieve the best thermal comfort were combined to test if the combination can increase thermal comfort inside the tested house.

The effect of different strategies on indoor thermal environment using the validated model (with ventilation)

Table 3 shows the average operative temperature of April of the simulated five cases with full natural ventilation. Figure 6 shows the average hourly operative temperature of April to demonstrate the patterns of the five cases with full-day ventilation.

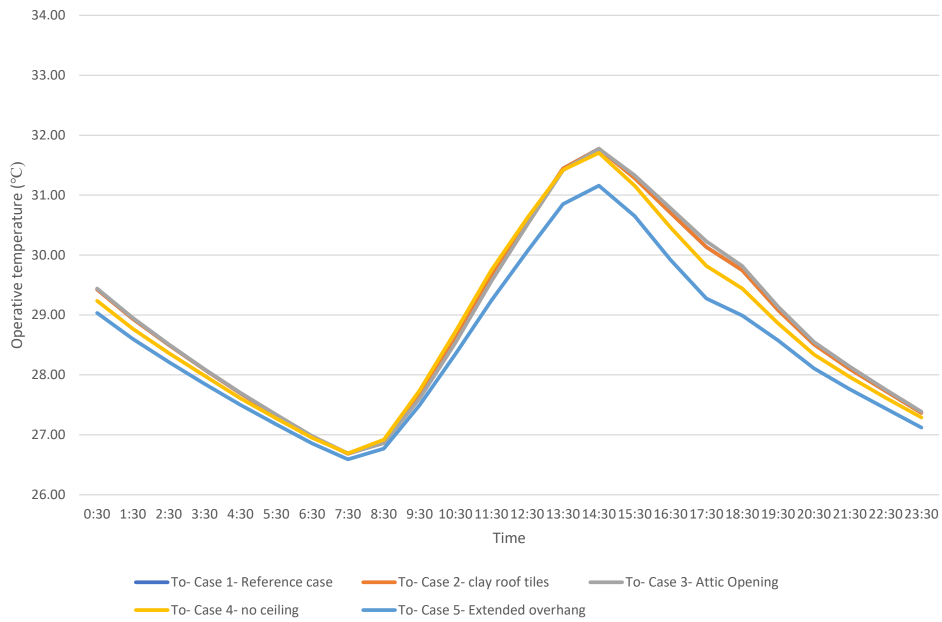
Table 3

Operative temperature of the simulated five cases with full natural ventilation.

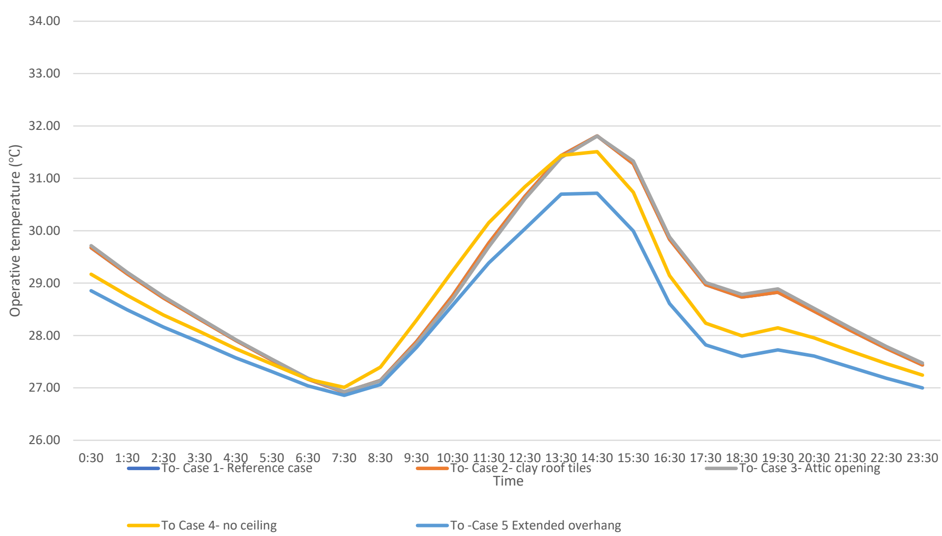
Thermal variables	Statistics	Case 1	Case 2	Case 3	Case 4	Case 5
Room 1						
Operative temperature (°C)	Mean	28.87	28.87	28.88	28.78	28.48
	Maximum	31.78	31.78	31.78	31.71	31.16
	Minimum	26.69	26.69	26.69	26.69	26.59
Room 2						
Operative temperature (°C)	Mean	28.84	28.84	28.86	28.64	28.22
	Maximum	31.81	31.81	31.81	31.51	30.72
	Minimum	26.92	26.92	26.93	27.01	26.86
Room 3						
Operative temperature (°C)	Mean	28.88	28.88	28.89	28.69	28.24
	Maximum	31.76	31.76	31.75	31.53	30.73
	Minimum	27.00	27.00	27.01	27.05	26.87

Table 2 and Figure 6 depict that no changes happened in the mean, maximum, and minimum operative temperature when the concrete roof tiles were changed to clay roof tiles (Case 2). This could be attributed to the small difference between the u-value of clay roof tiles for 5mm thickness (6.85 W/m^2K) and the u-value of concrete roof tiles (6.85 W/ m2K) with the same thickness.

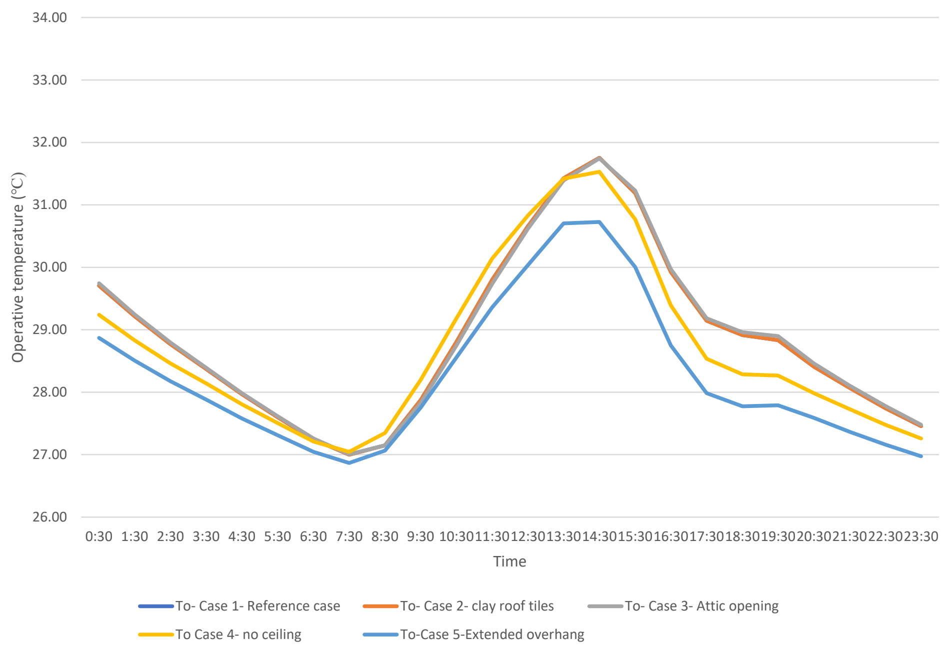
It was observed that the addition of two small windows to the attic in Case 3 was an ineffective strategy when full-day ventilation was applied for all the three rooms. The highest maximum operative temperatures for Room 1, Room 2 and Room 3 were 28.88, 28.86, and 28.89°C during the afternoon hours, respectively.



(a) Room 1



(b) Room 2



(c) Room 3

Figure 6. The hourly operative temperature patterns of the five cases with full-day ventilation strategy

In Case 4, the removal of the ceiling between the rooms in the upper floor and the attic contributed to a slight decrement from the reference case (Case 1) in the mean, maximum, and minimum operative temperature of Room 1, and the mean and maximum operative temperature of Room 2 and Room 3.

The best decrement was obtained when the overhang was extended by 50% of its length for all the four facades (Case 5) in the mean, maximum, and minimum operative temperature of Room 1, Room 2, and Room 3.

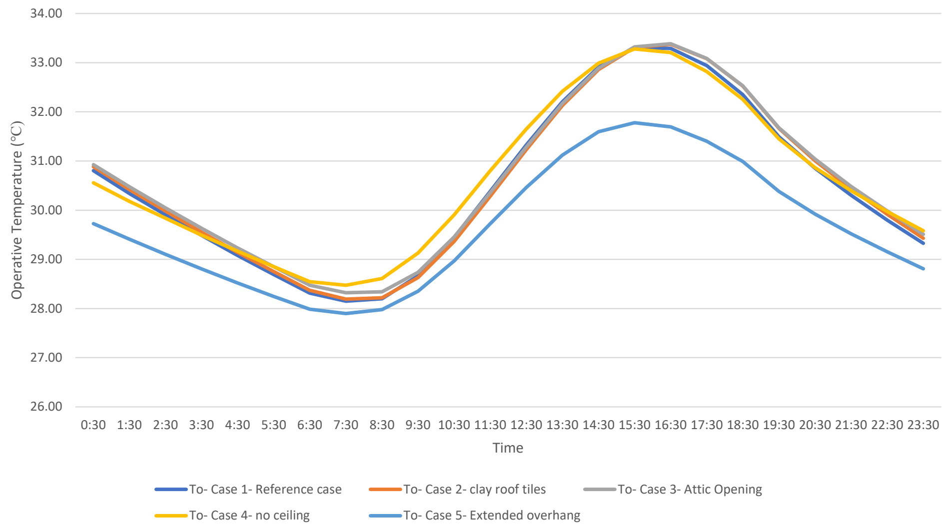
The previous cases were tested with 24 hours of natural ventilation when outdoor air can enter the rooms and affect the indoor environment. Subsequently, no ventilation strategy was applied by closing all the windows and doors for the same five cases to remove the effect of outdoor air.

The effect of different strategies on the indoor thermal environment using the validated model (without ventilation)

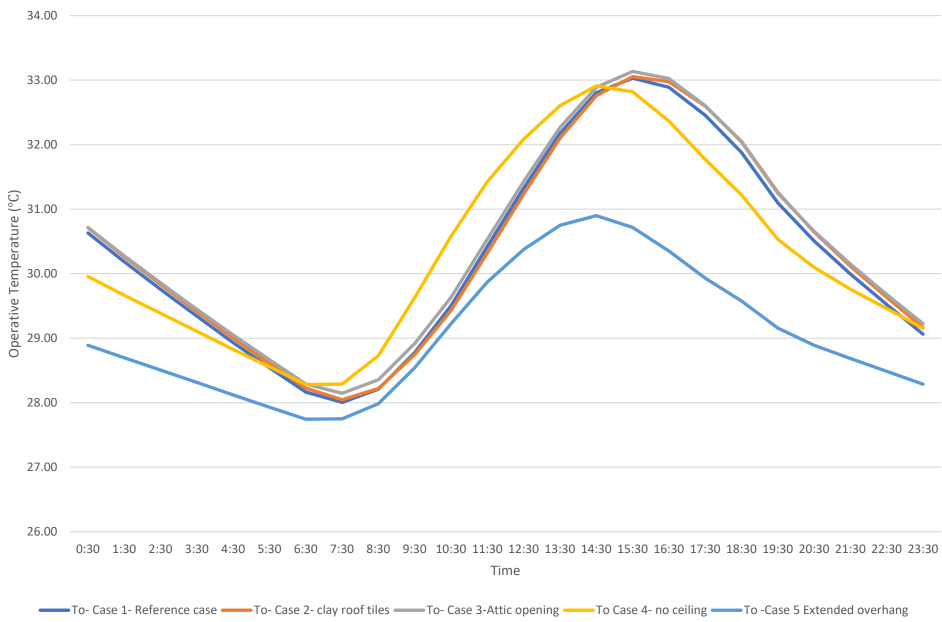
Table 4 shows the average operative temperature of April of the simulated five cases with no ventilation. Figure 7 depicts the average hourly operative temperature of April and demonstrates the patterns of the five cases with no ventilation.

Table 4
Operative temperature of the simulated five cases without ventilation.

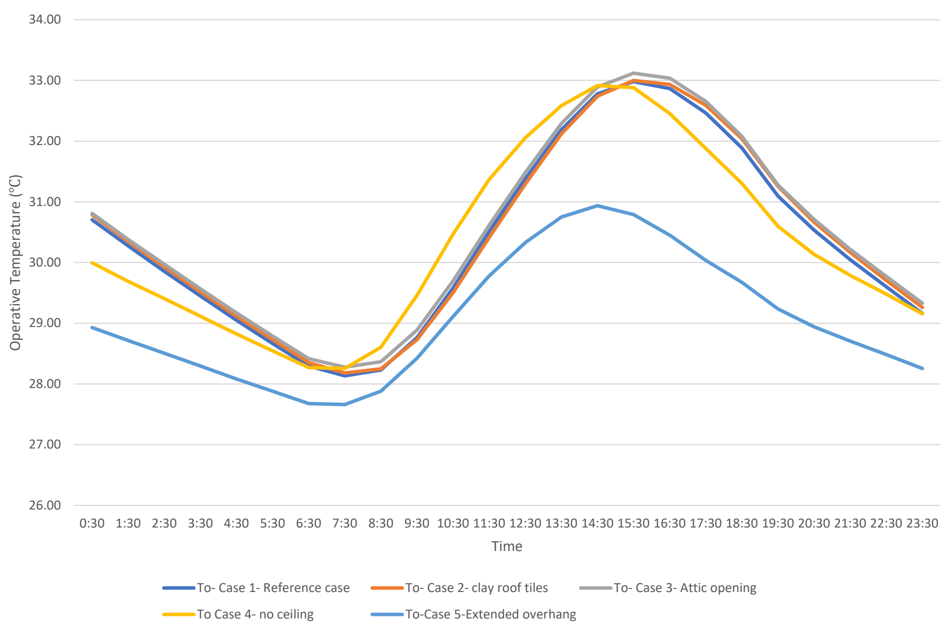
Thermal variables	Statistics	Case 1	Case 2	Case 3	Case 4	Case 5
Room 1						
Operative temperature (°C)	Mean	30.48	30.53	30.59	30.60	29.65
	Maximum	33.30	33.38	33.39	33.28	31.78
	Minimum	28.15	28.19	28.32	28.48	27.90
Room 2						
Operative temperature (°C)	Mean	30.30	30.35	30.43	30.32	29.07
	Maximum	33.03	33.06	33.14	32.91	30.90
	Minimum	28.01	28.05	28.15	28.28	27.75
Room 3						
Operative temperature (°C)	Mean	30.35	30.40	30.49	30.30	29.06
	Maximum	32.98	33.00	33.12	32.92	30.94
	Minimum	28.14	28.18	28.28	28.26	27.66



(a) Room 1



(b) Room 2



(c) Room 3

Figure 7. The hourly operative temperature patterns of the five cases without ventilation.

Table 3 and Figure 7 highlighted that there was a slight difference in the operative temperature of the three rooms for all the other cases when compared with the reference case (Case 1).

The mean, maximum, and minimum operative temperature of all the three rooms was slightly higher when the concrete roof tiles were changed to clay roof tiles (Case 2). Moreover, the maximum operative temperature of Room 1, the mean and maximum operative temperature of Room 2, and the mean, maximum and minimum operative temperature of Room 3 registered the highest value when two small windows were added to the attic (Case 3).

In addition, the mean and minimum operative temperature of Room 1 and the minimum operative temperature of Room 2 registered the highest operative temperature when the ceiling between the upper floor and the attic was removed (Case 4). However, the maximum operative temperature of Room 1 and Room 2 and the mean and maximum operative temperature of Room 3 was slightly less than the reference case (Case 1).

The best thermal comfort was achieved when the overhang of the house was extended by 50% of its length for all the four facades of the house (Case 5). The mean, maximum, and minimum operative temperature of Room 1, Room 2, and Room 3 registered the lowest operative temperature values.

The previous results concluded that there is no thermal comfort improvement when clay roof tiles were used (Case 2) or two small windows were added to the attic (Case 3) for both full-day ventilation and no ventilation. However, the removal of the ceiling between the rooms of the upper floor and the attic contributed to a slight decrement in the operative temperature inside the house for the two ventilation strategies. Additionally, extending the overhang to increase shading and protect the wall and windows from direct solar radiation for all the four facades of the house was identified as the best-tested strategy in this study to decrease the operative temperature inside the tested house in both full-day ventilation and no ventilation. Therefore, Case 4 and Case 5 were combined to examine their effect on thermal comfort inside the tested house for both full-day ventilation and no ventilation.

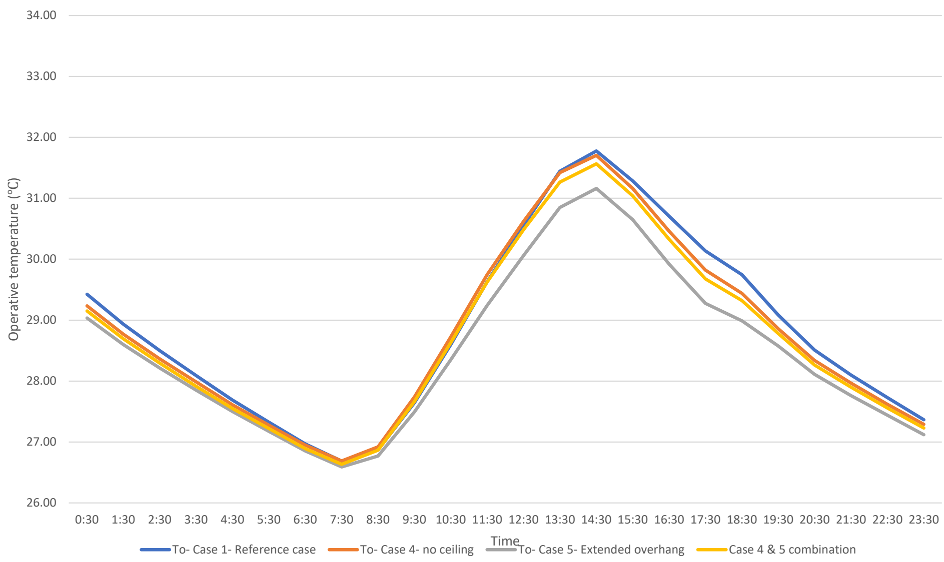
The effect of combined strategies on the indoor thermal environment (with ventilation)

Case 4 and Case 5 were reported to have achieved the best thermal comfort for all three rooms for ventilation and no ventilation strategies. Therefore, a simulation for a combination of the two cases was performed (Case 6) using the same validated model. Table 5 compares the average operative temperature of April of Case 6 and other related cases. Figure 8 shows the average hourly operative temperature of April and demonstrates the patterns of the selected cases with ventilation.

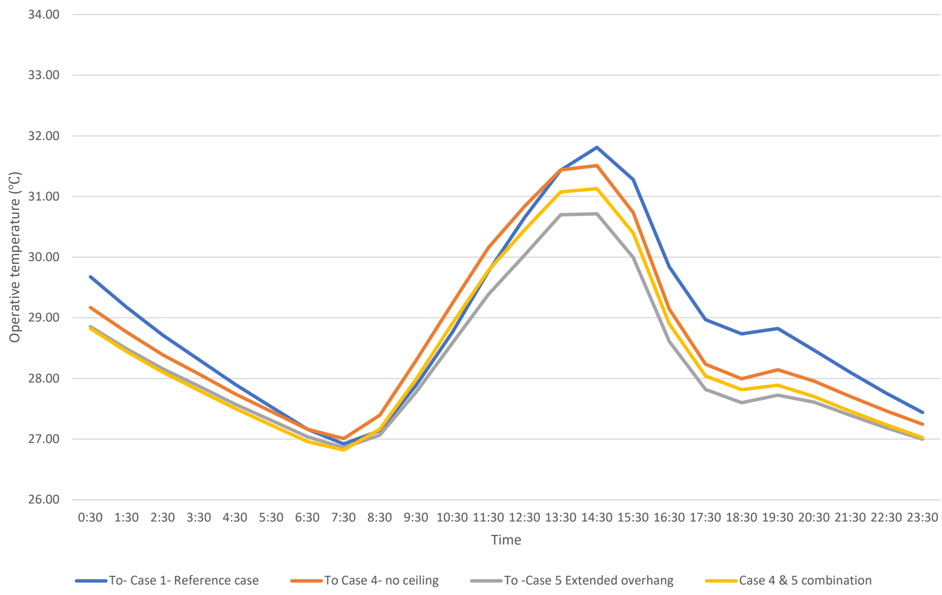
Table 5

Operative temperature of the simulated selected strategies with ventilation.

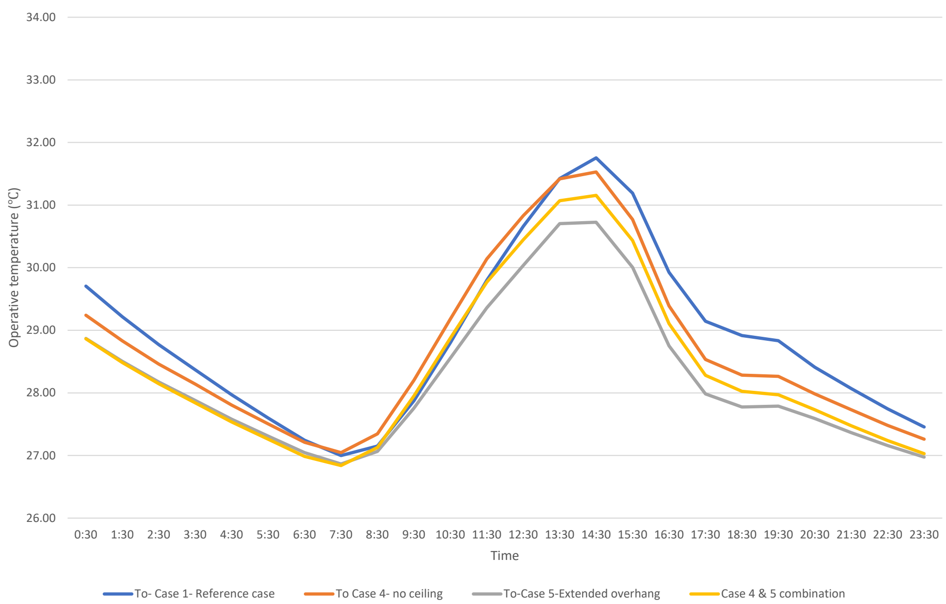
Thermal variables	Statistics	Case 1	Case 4	Case 5	Case 6 (combination of case 4 and case 5)
Room 1					
Operative temperature (°C)	Mean	30.48	28.78	28.48	28.69
	Maximum	33.30	31.71	31.16	31.57
	Minimum	28.15	26.69	26.59	26.64
Room 2					
Operative temperature (°C)	Mean	30.30	28.64	28.22	28.36
	Maximum	33.03	31.51	30.72	31.13
	Minimum	28.01	27.01	26.86	26.82
Room 3					
Operative temperature (°C)	Mean	30.35	28.69	28.24	28.36
	Maximum	32.98	31.53	30.73	31.13
	Minimum	28.14	27.05	26.87	26.82



(a) Room 1



(b) Room 2



(c) Room 3

Figure 8. The hourly operative temperature patterns of the selected cases with ventilation.

Table 4 and Figure 8 established that the mean, maximum, and minimum operative temperature of Room 1 and the mean and maximum operative temperature of Room 2 and Room 3 when the overhang was extended (Case 5) was less than Case 6 (the combination of removing the internal ceiling and extending the overhang). The best thermal comfort was not achieved in Case 6 and this is attributable to the effect of the roof that receives a high amount of solar radiation during the daytime and there is no barrier or insulation to protect the rooms. Moreover, when full-day ventilation was applied, the windows and internal doors were open, which may increase the operative temperature by spreading the hot air inside the house. For the same reason, the minimum operative temperature of Room 2 and Room 3 in Case 6 was less as the cool outdoor air could enter the house easily and spread inside the rooms.

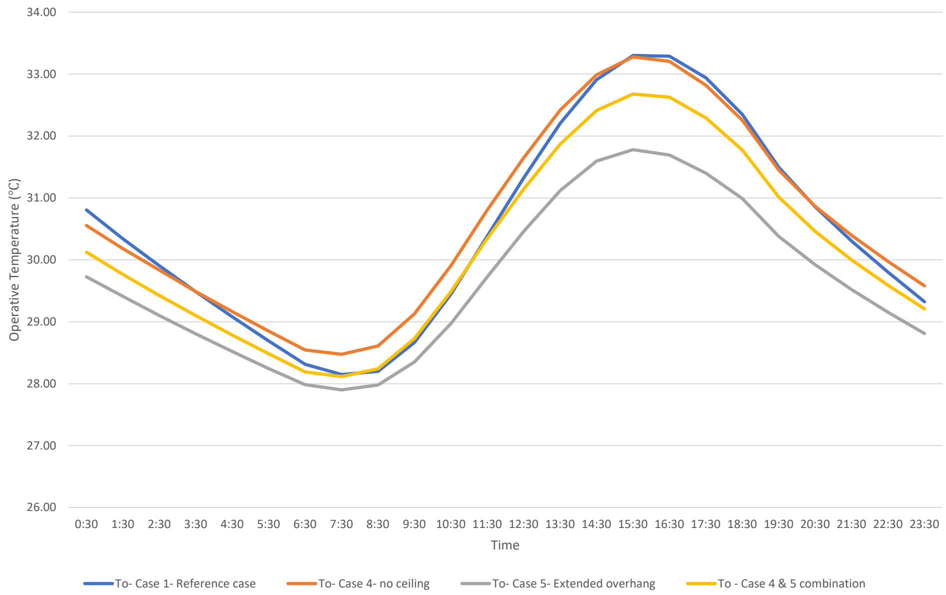
The Effect of Combined Strategies on the Indoor Thermal Environment (Without Ventilation)

Table 6 shows the average operative temperature of April for Case 6 and other related cases. Figure 9 shows the average hourly operative temperature of April and also the patterns of the selected cases without ventilation.

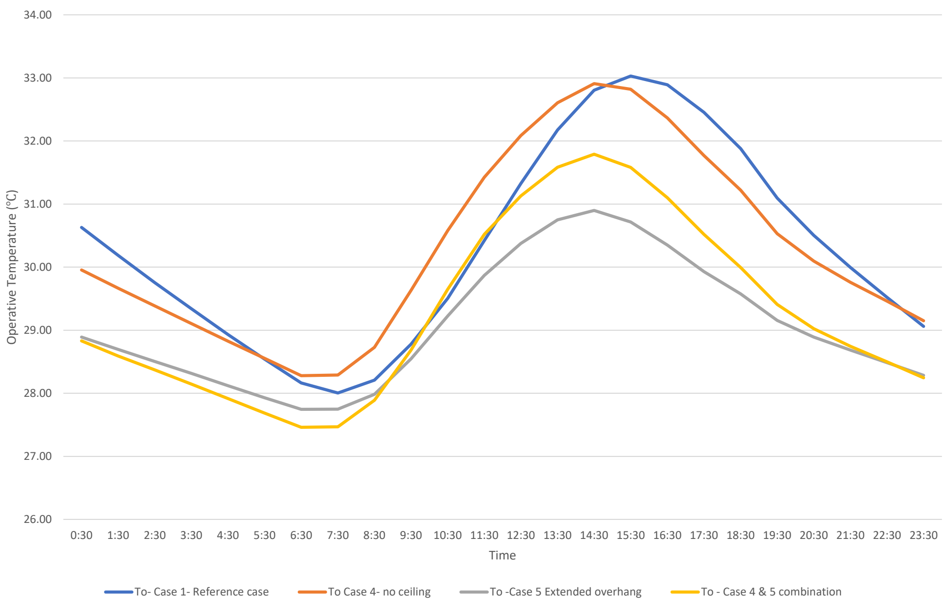
Table 6

Operative temperature of the simulated selected strategies without ventilation.

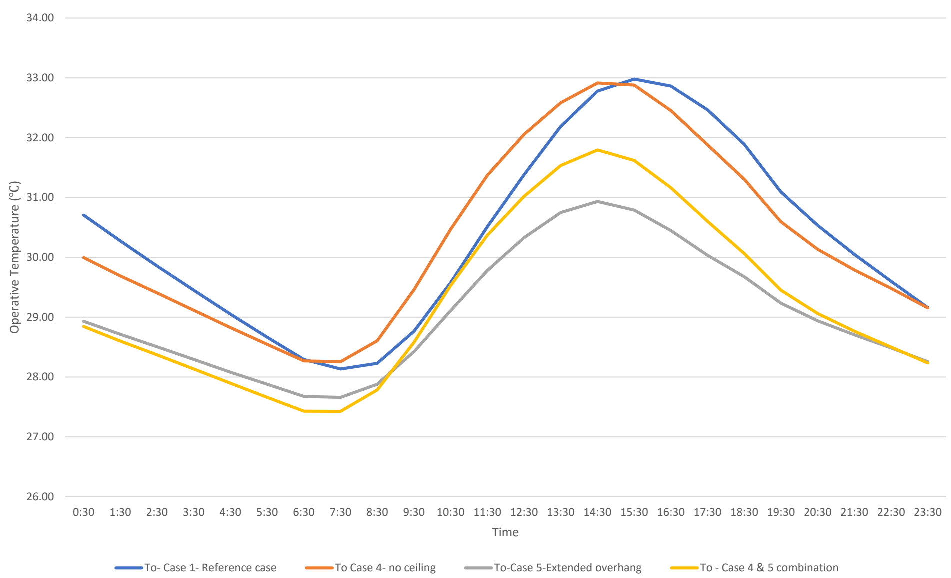
Thermal variables	Statistics	Case 1	Case 4	Case 5	Case 6
	Room 1				
Operative temperature (°C)	Mean	30.48	30.60	29.65	30.16
	Maximum	33.30	33.28	31.78	32.68
	Minimum	28.15	28.48	27.90	28.12
	Room 2				
Operative temperature (°C)	Mean	30.30	30.32	29.07	29.28
	Maximum	33.03	32.91	30.90	31.79
	Minimum	28.01	28.28	27.75	27.46
	Room 3				
Operative temperature (°C)	Mean	30.35	30.30	29.06	29.27
	Maximum	32.98	32.92	30.94	31.80
	Minimum	28.14	28.26	27.66	27.43



(a) Room 1



(b) Room 2



(c) Room 3

Figure 9. The hourly operative temperature patterns of the combination of case 4 and case 5 without ventilation.

Table 5 and Figure 9 reported that the mean, maximum, and minimum operative temperature of Room 1 and the mean and maximum operative temperature of Room 2 and Room 3 for Case 5 (when the overhang was extended) was less than Case 6 (the combination of removing the internal ceiling and extending the overhang). Meanwhile, the minimum operative temperature of Room 2 and Room 3 in Case 6 was less.

A possible reason for this situation is the effect of the high amount of solar radiation that the roof received during daytime. The removal of the ceiling creates no barrier to protect the rooms. However, the minimum operative temperature of Room 2 and Room 3 in Case 6 was less as the effect of solar radiation had disappeared during night-time and the effect of natural ventilation appeared.

Despite the best minimum operative temperature was received in Room 2 and Room 3 in Case 6 with and without ventilation, the improvement is minimal when compared with Case 5 for the same rooms. Therefore, this study identified that extending the overhang of the tested house by 50% of its length for all the four facades of the house (case 5) can reduce the operative temperature of the three rooms and enhance indoor thermal comfort. It must also be highlighted that low wind speed could be the main reason behind low-temperature changes when natural ventilation was applied due to low heat flushing through the openings.

CONCLUSION

The outcomes of this study showed that many sustainable strategies can be acquired from traditional Malay houses. These include strategies that were examined in this study. Strategies that were tested were clay roof tiles instead of concrete tiles, naturally ventilating the roof by adding several openings to the attic, changing the design of the roof by removing the ceiling, and extending the roof overhang to provide shade to the walls and windows and decrease the effect of solar radiation. These selected strategies were investigated and compared in this paper with full-day ventilation and without ventilation. The IES- VE simulation software was used to simulate the tested house and apply all the mentioned strategies.

The results proved that the use of clay roof tiles instead of concrete roof tiles or adding small openings to the attic would not enhance thermal comfort inside the tested house when using full-day ventilation and no ventilation. In addition, the removal of the ceiling between the attic and the upper floor contributed to a small amount of decrement in the operative temperature inside the house when full-day ventilation was applied. However, this strategy brought a negative effect when there was no ventilation. An interesting finding in this study is that the indoor operative temperature of test house reduced by extending the overhang with 50% of its length for all the four facades of the house which is ideal to protect the building's envelope from direct solar radiation. This can subsequently improve indoor thermal environment and reduce energy consumption of the modern house.

It is recommended for future research to examine other cooling strategies such as adding shading devices to the windows and using different materials for the walls and the glass of the windows to determine other effective trategies that can enhance thermal comfort inside modern houses.

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