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The Effect of Cool Roof System on Surface and Indoor Temperature for Residential House in Malaysia: Field Measurement on Small Scale Model

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Abstract: High indoor thermal environment causes passive and cooling method used in residential building is getting more attention in hot climate countries such as Malaysia. One of the strategies to reduce the heat gain in a building is limiting the heat transfer through the roof. This study investigates existing cooling strategies for the roof then compares its effectiveness to reduce heat gain through the roof in low rises building in Malaysia. A field measurement has been conducted on a small-scale model house located in open spaces University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia. The study cases included the application of a control model, ventilated roof (case 1), two types of insulation (roof (case 2) & ceiling (case 4)), reflective roof (case 3), and roof with double skin roof (case 5). The air temperature and the ceiling surface temperature reduction of the control and case study model were calculated based on the surface and air temperature data of the models. The finding shows that the ventilated roof (case 5) performed the best, with an attic temperature reduction of around reduced (-1)°C to risen (2)°C at most, and inside temperature reduced (-4)°C to risen (3)°C at most. This shows double roof able to perform better compared to other cases when compared to outdoor.
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Keywords: Cool Roof System, Thermal comfort, Residential House, Small-scale Model

1. Introduction

Malaysia, which has a hot, humid environment, receives more than 10 hours of sunlight every day throughout the year. Through the building exterior, the heat was transferred from the sun to the inner rooms; as a result, thermal comfort in the house is deranged, especially in the home's attic space. Attics are the space between the roof and the ceiling of the house's highest floor. An air conditioning system is installed to compensate for the residence discomfort because of the heat since mechanical fans cannot

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cool the house. The application of a cool roof system is essential to enable natural ventilation in buildings to decrease thermal discomfort and energy consumption [1]. A good roof promotes natural ventilation and mostly high thermal admittance, reducing thermal radiation from the sun on sunny days. By doing so, the occupant benefit because less mechanical cooling usage due to the roof itself is adequate. Then by lowering the temperature of the roof, which may help extend the life of the roof and save the cost of roof maintenance [2]. Cool roofs and green roofs might be a long-term endeavour that attracts energy scientists, architects, and urban planners to increase thermal comfort while also conserving energy and improving urban quality [3]. To get the best result in terms of energy savings for buildings in the present environment, an ideal combination of surface reflectivity and roof insulation is advocated. According to research, in a hot, dry climate, a cool roof with enough insulation is recommended, and this approach may be used in different nations and temperature conditions to satisfy their needs [4].

Insulation and reflecting materials in roof designs have been the subject of several research programmes. Based on his field testing of numerous passive roof designs, Ong determined that insulation beneath the tile is preferable than insulation above the ceiling [5]. Akasaka and Takeda have spent a lot of time studying a feasible heat transfer calculation method for the construction of roofs with vented air layers in order to quantify the shading and insulating effects of different combinations of approaches [6]. The flowing air stream in the air gap was explored by Chong et al. According to his research into the multilayered green roof system's heat transfer mechanism, moving the surrounding air into the air gap area prevents hot air aggregation and quickly takes out the inside hot air to prevent attic heating [7]. One of the most effective ways to minimise roof temperature is to utilise reflective materials on the building exterior, according to Synnefa et al [8]. Natural ventilation and double layer roof are one of the best strategies for cool roof.

The goal of this study is to look at the present roof cooling system in order to minimise heat and energy usage when cooling residential homes. The objective of this study is to conduct a field measurement of different types of roof systems based on developed study cases. To identify an effective roof system in order to improve the indoor thermal environment for low-rise buildings in Malaysia's climate.

2. Thermal Comfort

According to [9], thermal comfort is a state in which there are no strong desires to alter the surroundings through activities. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines it as a mental condition in which one is at ease with one's thermal environment. Due to differences in metabolic heat produced and emitted by the human body, not every human has the same level of thermal comfort. Human thermal comfort is influenced by environmental factors such as air temperature, mean radiant temperature, relative air velocity, and relative humidity. As a result, these elements are considered while selecting an effective cool roof system.

2.1 Natural ventilation

Natural ventilation is a well-known energy-saving approach in buildings that provides occupant thermal comfort while using no energy and having no influence on global warming. Natural ventilation may be categorised into wind-driven natural ventilation and buoyant effect (stack ventilation). No mechanical forces are necessary to replace room air with fresh outdoor air through thermal comfort and indoor air quality openings due to various phenomena impacted by wind velocity, wind direction, temperature difference, opening design (size, shape, and location), building form, and neighboring building [10].

2.2 Cool Roof

Cool roof materials and components can stay cool even when exposed to direct sunlight. They have high solar reflectance values, which reduce the quantity of solar radiation received by typical building materials and limit surface temperature increase when solar loads are high. High infrared emittance values identify these materials, allowing them to emit to the sky at night and release absorbed heat without transferring it within. To keep temperatures down, cool roofs must have brilliant solar-reflective surfaces compared to a darker colour roof can gained higher temperature. These qualities allow the material to elevate its surface temperature a few degrees above ambient, reducing the heat transferred from the roof to the external air via convection and therefore lowering the urban heat island (UHI) effect [11]

2.3 Ventilated Roof

A roof ventilation system helps remove overheated air and moisture from the attic and roof system and decreases the effects of fluctuating temperatures and moisture levels both within and outside the property by delivering a continuous flow of air through the attic area. According to Lee et al, Significantly increased solar heat absorption through the roof; heat transfer from the exterior to the interior via the roof accounts for a considerable portion of the cooling load. This heat may be absorbed by adding a ventilation layer to the roof [12]. The thermal performance of a pitched ventilated roof was also investigated theoretically, and it was shown that a slanted ventilated roof might save 30% more energy than a non-ventilated structure. Ventilated roof has a similar build to a traditional pitched roof, but it is more 20° tilted than the conventional pitched roof. Temperature differences allow for ventilated roofs (buoyancy effect), whereas mechanical equipment creates forced convection (i.e., fan). Solar radiation heats the outer air within the air gap, causing it to become lighter and move upward. This air movement is advantageous because it reduces heat accumulation in the structure and heat flux transmitted via the roof [13]. According to Ibrahim et al, pitched ventilated roofs may save more than 30% of energy in the summer compared to a standard roof [14]. For this experiment, 30-degree angle ventilated pitches are used.

3. Method

The methods used in this study were carried on based on previous studies regarding the roof system that existed by using a small scale model with the detailing of 700mm (length) x 600mm (width) 700mmm height. The model were made in cubical boxes with a mono-pitch roof with an angle 30 degrees of inclination. The roofing material component are made of 6 pieces roof tiles with a thickness of 4mm (dimension: 445mm x 275 mm). The other roof system was insulated by insulation of Polyurethane (PU). The thickness for PU is 25 mm, and 0.89 m2 K/W of thermal conductivity

The sensor used in this research is T & D 72 and Hobo logger. These sensors are placed in the attic, ceiling surface, and indoors. The analysis for this study is by comparing the parameter of each study case we had obtained through data collected then using T&D recorder, Hoboware and Microsoft excel to anlysed. The data is then tabulated to be reached by listing the maximum and minimum temperatures. The parameter compared for this experiment is the attic space temperature, ceiling surface temperature, and indoor temperature of the model. Outdoor temperatures are also recorded. The comparative study of the three parameters is compared to the outdoor temperature, and differences for day and night in-between the control model and cases are compared.

Figure 1: Model 1 & 2 at testing location

Figure 2: The placement of T & D 52 T&D 51a in a model

4. Results and Discussion

In this study, House 1 serves as a control, whereas House 2 features an insulating roof, a green roof, and a double layer roof. The size gap of the air cavity was found to be 6 cm after a review of the literature, which was in agreement with experimental and studies that showed values between 6 cm and 10 cm. Two model houses are used to measure air and surface temperatures, with House 1 serving as the control house and House 2 housing the insulation, reflective, and air cavity roofs. Data was gathered for at least three days in each of the four instances (control, insulation, and air cavity). To generate an average figure, the temperature was taken every five minutes. The temperature of the air and the temperature of the surface were then compared to the outside air temperature. The temperatures were recorded in tables and the data was graphed. The hour was shown on the x-axis, while the temperature (°C) was displayed on the y-axis.

Table 1: Summary of Result

Case Study	House Type	Temperature	Attic Temperature °C	Ceiling Temperature °C	Indoor Temperature °C
1	House 1	Maximum	52.2	48.9	40.9
		Minimum	21.3	21.9	22.5
	House 2	Maximum	36.5	37.1	36.1
		Minimum	21.9	22.6	22.7
2	House 1	Maximum	56.2	52.3	42.7
		Minimum	22.7	23.4	23.9
	House 2	Maximum	36.6	40.7	39.1
		Minimum	22.1	24.0	23.6
3	House 1	Maximum	48.8	45.4	37.7
		Minimum	22.8	23.5	23.9
	House 2	Maximum	34.4	38.2	36.4
		Minimum	23.7	23.9	23.8
4	House 1	Maximum	51.5	48.3	39.9
		Minimum	21.9	22.8	23
	House 2	Maximum	35.5	39.2	37.7
		Minimum	23.3	22.8	22.7
5	House 1	Maximum	46.7	44.9	37.7
		Minimum	24.0	24.4	24.7
	House 2	Maximum	33.0	33.5	33.5
		Minimum	24.1	24.1	24.4

4.1 Comparative study of the effect between study cases

The significant different of data are compared with outdoor data to identify the reduction of temperature with outdoor data.

4.1.1 Attic temperature

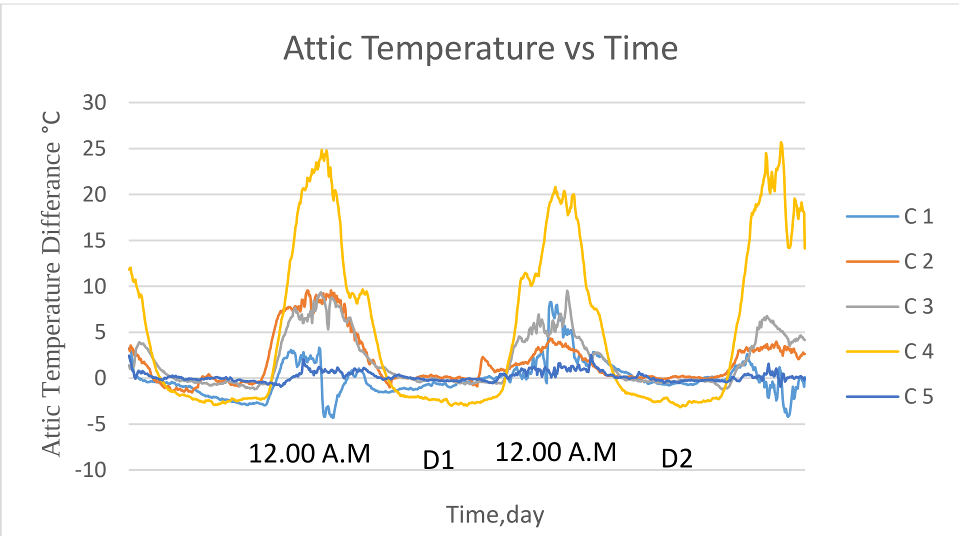

Figure 3: Graph of Attic Temperature vs. Time

Figure 3 depicts the variations in attic temperature in all five scenarios when compared to outside temperature on different days. Case 1 has a lowest -4°C and a highest 8°C, whereas Case 2 has least temperature of -1°C and at most temperature of 9°C, as seen in the graph below. Case 3 has a -1 ° C. and a hotness of 9° C, whereas Case 4 has as low -3 ° C. and highest at 25 ° C. Finally, case 5 has the least temperature of -1°C and 2°C at most. As a result, it is clear that Case 5 was better because of the amount of reduction was higher as the maximum temperature is low compared to other cases.

4.1.2 Ceiling surface

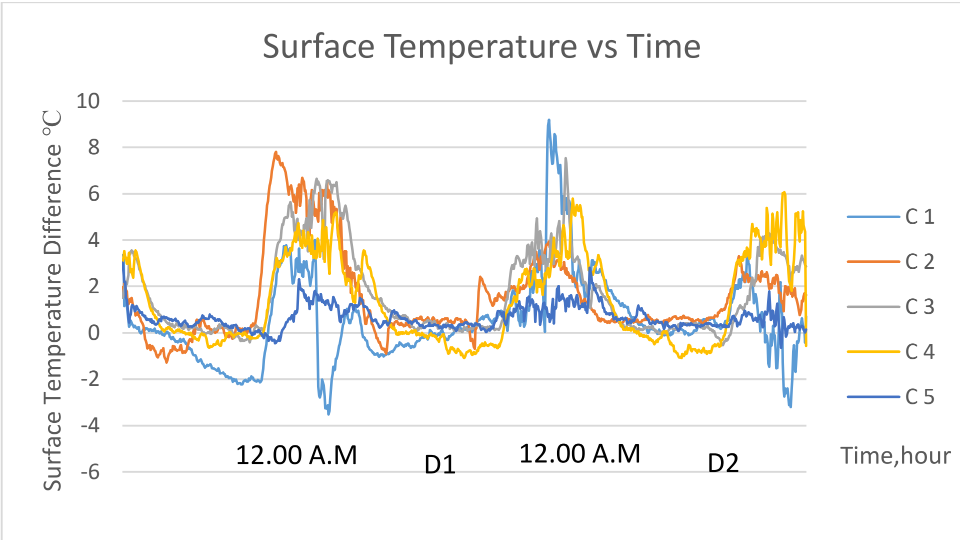

Figure 4: Graph of Surface Temperature vs. Time

Figure 4 depicts the variations in attic temperature in all five scenarios when compared to outside temperature on different days. Case 1 has a lowest -3.5°C and a highest 9°C, whereas Case 2 has least temperature of -1°C and at most temperature of 7°C, as seen in the graph below. Case 3 has 0 ° C. and a hotness of 7° C, whereas Case 4 has as low as -1 ° C. and highest at 6 ° C. Finally, case 5 has the least temperature of -5°C and 3°C at most. As a result, it is clear that Case 5 most effective because it has the capability to reduce the temperature and the highest is lower.

4.1.3 Indoor temperature

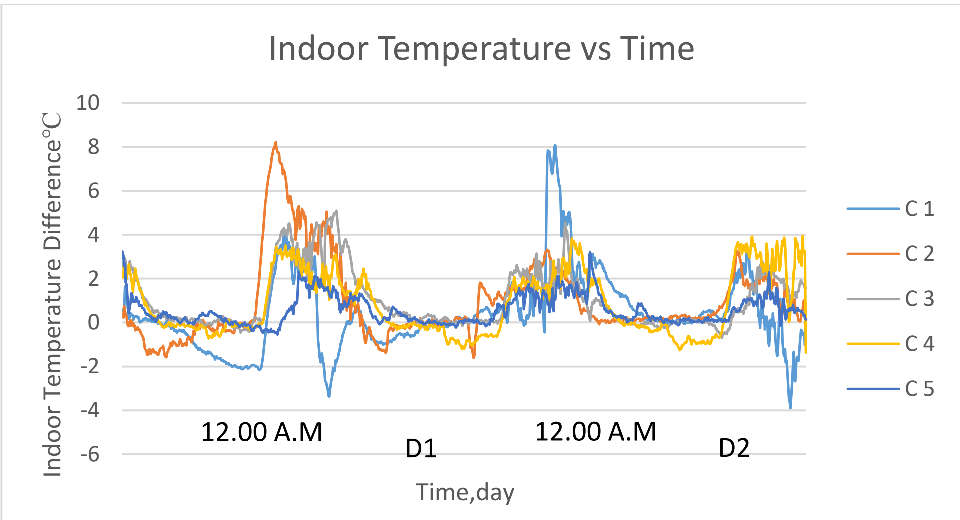

Figure 5: Indoor Temperature vs. Time

As in Figure 5, the variations in attic temperature in all five scenarios when compared to outside temperature on different days. Case 1 has a lowest -3°C and a highest 8°C, whereas Case 2 has least temperature of -1°C and at most temperature of 8°C, as seen in the graph below. Case 3 has a 0 ° C. and a hotness of 5 ° C, whereas Case 4 has as low as -1 ° C. and highest at 3 ° C. Finally, case 5 has the least temperature of -4°C and 3°C at most. As a result, the trend of the graph is almost similar but it is clear that Case 5 most effective because it have the lowest temperature in maximum.. This is due to the less hot air accumulated in attic space which is exited through the ventilation opening. Ventilation is one method of naturally transporting hot air from the inside to the outside through roof vents. It rises because hot air has a lesser density than cold air [15].

4.1.4 Differences during the day

Table 2: Differences during the day

Case Study	Attic Temperature °C (H2-H1)	Ceiling Surface Temperature, °C (H2-H1)	Indoor Temperature °C (H2-H1)
1	-17.07	-14	-5.3
2	-12.47	-2.6	-1.9
3	-8.19	-7.2	-1.7
4	-1.23	-9.4	--3
5	-13.75	-11.6	-4.4

The variations in attic temperature, ceiling surface temperature, and indoor temperature of all five instances during the day are shown in the table above for House 1 and House 2. The negative value implies that the home is somewhat colder, while the positive value suggests that the house is significantly warmer. Case 4 has the greatest attic temperature of 1.23°C, while Case 1 has the lowest attic temperature of -17.07. Case 2 has the greatest ceiling surface temperature of -2.6°C, while Case 1 has the lowest temperature of -14°C. Furthermore, Case 2 has the greatest interior temperature value of -1.9°C and Case 1 has the lowest indoor temperature value of -5.3°C.Therefore, during the day Case 1 and Case 5 of House 2 is cooler while Case 3 is slightly warm.

5. Conclusion

The purpose of this study was to compare different roofing systems for lowering heat in residential buildings. The first goal is addressed by identifying an innovative roof building method based on literature analysis there 5 roof system which is identified though out this process. The roof system is conventional roof, Insulated, reflective roof, insulated ceiling and double layer roof using. This first objective are achieved. The second objective is also met, since several roof systems, such as the insulation roof and the air cavity roof, are investigated through field measurements. The air temperature and surface temperature drop at the parameters. As a results, the third target was also met since the ventilated roof performed the best, with an attic temperature decrease of about - of -1°C and 2°C at most, as well as a drop in interior temperature of around -4°C and 3°C at most. The large difference in the results is attributable to the fact that three other examples are airtight without ventilation, as the case did not contain an air cavity, which traps more heat in the attic area of the structure. It may be determined that the heat generated by the environment is substantially greater than the heat generated by the roof. As a result, the most effective roof system configuration would be a double roof with additional ventilation opening modification since, when compared to a vented model with a 10cm opening, the decrease of all three temperatures is comparable. There isn't much of a drop in the interior temperature based on the final readings of all the cases. A residential building's excellent comfort will undoubtedly be enhanced by a double roof efficiently thus this can help cooling the houses without the help of mechanical cooling mechanism and it is resulting in energy and cost saving.

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