Active cool roof system for attic temperature reduction

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Abstract. The purpose of this project is to investigate the active cool roof system for the attic temperature reduction by using harvested rainwater system. A small scale metal roof model was designed and constructed to evaluate the attic temperature cooling performance. The measurements of the roof model were carried out indoor by utilizing the halogen lamp as the replacement for solar irradiation provided by sun. The surrounding ambient temperature was controlled to be around 25°C for the experimental. The rainwater harvesting system was implemented to cool down the roof top temperature that reduces the rate of heat transfer from the roof top to the attic region. The thermostat was installed with the water pump to reduce the roof top temperature efficiently. The hot water temperature of the heated roof was absorbed by the cool water and transferring into the small model of cooling tower and water collection tank. The result of the eco-friendly cool roof system has effectively reduced the attic temperature by 6.4 °C as compared to the conventional metal roof. The positive results of the integrated cool roof design have the ability to enhance the comfort of building occupants with sustainable renewable energy.

1. Introduction
Energy is an essential quantitative property that empower everything in our daily life. As a developing country, the rate of energy consumption in Malaysia has been risen significantly due to the expansion of construction and population. Based on the energy consumption report, buildings is one of the major energy consumer which consumed up to 40% of the total global energy. By the year of 2030, about 50% of the global energy is expected to be consumed by building sector [1].

A statistic conducted by National Energy Balance (NEB) shows that the building sector in Malaysia has consumed up to 48% of the generated electricity in the country. Residential buildings consume 24,709 Giga watts (Gwh) while the commercial building consume up to 38,645 Gwh. The demand of electricity in Malaysia was increase about 8.9 % from 132,199 Gwh in the year 2015 to 144,024 Gwh in 2016 [2]. As a tropical country, most of the places in Malaysia experiences hot and humid climate with constant mean air throughout the year. Thus, an electricity consumption of about 1,167 kWh was contributed by the air conditioners which considered as the biggest electricity consumption in Malaysia. In comparison between the roof and vertical wall of the building, most of the heat were gained by the roof due to its exposure rate from the sun is higher during the daytime. In general, most of the roof top designs in Malaysia were constructed by the uppermost roof top and a
gypsum ceiling board below it. The roofing materials commonly used in Malaysia are the concrete roof tiles (85%) followed by clay tiles (10%) and also metal deck (5%) for the low cost houses and factories [3]. By using all those materials without insulation coating, heat will easily transmitted through the roof which will generate the heat in the attic region. Furthermore, most of the buildings ventilation are poor and fairy airtight that mostly due to the lack of air circulation. As results, the heat transmitted through the roof would keep circulating in the attic region which produce heat to the ambient air inside the building. Therefore, several effective cool roof systems had been developed. A cool roof system is considered as a roofing system that have the capability to reflect the radiated heat from the sun and reduce the rate of heat transferring through the roof by reducing the heat transmission as compared to the standard designed of roofing system [4]. By introducing this roofing system in the tropical country, it has the ability to improve the comfort level inside the buildings towards a low cost method by saving the energy. Besides that, the attic ventilation would be improved by the cool roof system due to the mechanisms of heat transmission have been reduced which mean that the heat transfer through the roof to attic region was greatly reduced. Consequently, the heat gained by the ceiling of the building was tremendously decrease which also greatly reduce the need for mechanical cooling system such as air conditioner [5-7].

Malaysia is considered as an equatorial climate country which having a hot-humid climate all the year. According to the statistics from year 1825 to 2015, the average temperature in Malaysia was around 32 °C and 23 °C, respectively between March and August while there will be a slight decrease of maximum temperatures around 29 °C between November and January [8]. As results, this type of climate leads to uncomfortable conditions which nonconductive for human comfort and productivity. The main objective of this research is to determine the performance of the cool roof system that utilises the water source from the rainwater harvesting system for attic temperature reduction by controlling it using the thermostat and water pump [9].

2. Experimental design

2.1. Materials and method

Attic region is the major skeleton for the model in this cool roof model. A Perspex with a thickness of 5 mm is used to fabricate the attic region of the model. The dimension of the attic region is 340 mm long x 360 mm wide x 490 mm height with an inclination of 30 ° from the horizontal line as shown in Figure 1. An attic inlet with a dimension of 120 mm long x 100 mm width was opened at the side of model and it can be covered by a sliding door which specially designed to close the attic inlet. The purpose of this design was used to provide ease of thermal couple installation inside the attic region.

![Figure 1. Dimensions of small-scale attic region model.](image)

2.1.1. Rainwater harvesting system. Rainwater harvesting system is mainly implemented to cool down the roof top temperature that reduces the rate of heat transfer from the roof top to the attic region. As the name of the system, rainwater was utilized as a cooling agent that directly absorbs the heat from the roof top. This system applied the sustainable environment concept by using renewable source as the main cooling agent that performs the cooling without environmental damaging effect. The
rainwater harvesting system usually comprises three major components which are the catchment area, conveyance system, and the water storage system. The cooling flow cycle can be illustrated by the schematic drawing as shown in Figure 2. The rainwater harvesting system incorporated in this model was controlled and triggered by the thermostat which applied the cooling effect at the specific temperature. In this model, the area of the roof tile was considered as the catchment area for the harvesting system. Water flowed from the roof tile will be collected at the gutter which made by a half-cut cylindrical pipe. The conveyance devices such as gutter, funnel, cylindrical plastic container, and the L-shape fixed support are set up to convey the water from rooftop to the cooling tower. After the water flowed through a small scale self-fabricated cooling tower, it will enter to the plastic container that used to store the collected water which shown in Figure 2. The cooling system of this rainwater harvesting system was investigated in order to reduce the temperature of the attic region. The water collected in the storage tank was used as the cooling agent to cool down the temperature of the roof top which indirectly reduce the attic temperature. When the roof top temperature reached 40 °C, water pump will be triggered by the thermostat to pump the cool water to the roof top through the rubber pipe in order to cool down the roof top temperature. The heated water was collected by the gutter and flow to the cooling tower in order to release the heat absorbed during the flow path at the roof top. As result, the water was cooled and stored in the water tank which considered as a complete flow cycle in this cool roof system.

[Figure 2. Cooling flow cycle of rainwater harvesting system.]

2.1.2. Water pump integrated with thermostat. A submersible water pump was used as an actuator that transfers the cool water from the water storage tank to roof top. The maximum pressure head of this pump is 1.3 meter which energized by an AC current as shown in Figure 3 (left). As mentioned, the water pump will be triggered by the thermostat when the desired temperature achieved in the setting of temperature sensor. The variation of the temperature sensing for this thermostat is around ±5 °C which means the pump will be triggered between 35 °C to 45 °C as the pre-setting temperature is 40 °C.

This water pump was specially designed and modified with the thermostat that performed an automation control which mentioned above. Thermostat was used as a regulator that triggered the water pump based on temperature value pre-set in the data. It has one connected temperature sensor and four connectors which are labelled as “1”, “2”, “C”, and “E” (earth). The live wires of the water pump and power filter were connected to the connector “C” which indicated as the output of the thermostat. Meanwhile, the neutral wires of the three pin plug (power source) was connected with the water pump and power filter. The connector “E” which indicated as the earth of the circuit was connected to the earth wire from the power source as illustrated in Figure 3 (right). In addition, the
live wire form the three pin plug was connected to the connector “2” that complete the circuit design for this thermal sensing triggered pump.

Figure 3. Water pump (a) and circuit connection of thermal sensing triggered pump (b).

3. Results and discussion

3.1. Metal deck roof with normal coating

Figure 4 shows the maximum roof temperature and attic temperature of the metal deck roof were 47.5 and 32.5 °C respectively. The maximum difference of the roof temperature and the attic was 15 °C. The roof temperature increases with a rate of 4.1 °C per minute in the first four minutes. These data show that the rise of attic temperature can be attributed to the low reflectivity of the metal roof surface. The results appear to confirm that attic and roof temperature for metal deck without cool roof system absorbed the thermal load within the Perspex.

The attic temperature and roof temperature become constant after the 17 min of halogen lamps irradiation. The results after 17 min demonstrates that the cooling of the roof surface by natural convection and radiation in an ambient temperature 24 °C without irradiation.

Figure 4. Performance of natural convection on roof and attic temperatures (°C) against time (minutes) for metal deck roof without cooling roof system.

3.2. Metal deck roof with cooling roof system (Thermostat T = 40 °C)

The results for this system are shown in the Figure 5. The roof surface reached maximum temperature of 41.1 °C. The heating rate was around 4.5 °C per minute in the first four minutes. The cooling of roof surface takes 10 minutes to reach constant temperatures at 14 minutes. The roof temperature at constant was 28.3 °C while the attic temperature was 26.1 °C. The cooling rate of roof surface was around 1.2 °C per minute.

In addition, the attic temperature reached maximum temperature of 26.1 °C due to the fact that the heat was trapped in the attic region. This does not imply that the cooling roof system gives no effect
on attic temperature. From the effective reduction of roof temperature, it can be deduced that the water flow was removed the heat on the roof surface to surrounding easily.

**Figure 5.** Performance of cooling roof system on roof temperature and attic temperature (°C) against time (minutes) for thermostat temperature at 40 °C.

### 3.3. Metal deck roof with cooling roof system (Thermostat T = 45 °C)

The results for the design are shown in the Figure 6. The roof surface reached maximum temperature of 45 °C. The heating rate is around 4.4 °C per minute at the first four minutes. The cooling of the roof takes 11 minutes to reach constant temperatures. The roof temperature and attic temperature at constant was 29.8 °C and 28.3 °C, respectively at 16 minutes. The cooling rate of roof surface was around 1.3 °C per minute. The maximum difference of attic temperature and roof temperature was 16.2 °C.

The attic temperature at maximum was 28.8 °C which then cooled down to 28.3 °C. This provides clear evidence that the cooling of attic region can be achieved with the cooling roof system. The small range of temperature reduction can be adequately explained by the factor of lower pressure of water flow rate applied during cooling process. An alternative explanation would be the water flow rate decrease as water level decrease due to water pump gradually used up the water in tank. Therefore, the rate of heat transfer from attic region to roof surface reduced when the fluid velocity on the roof surface decreased.

**Figure 6.** Performance of cooling roof system on roof temperature and attic temperature (°C) against time (minutes) for thermostat temperature at 45 °C.
3.4. Metal deck roof with cooling roof system (Thermostat $T = 50 \, ^\circ C$)
The performance of the cooling effect on the roof and attic temperatures is shown in Figure 7. The roof surface and attic reached maximum temperatures of 50.1 and 34.1 °C. The heating rate was 4.7 °C per minute at first four minutes. The cooling of roof surface takes 19 minutes to reach constant temperature. The roof temperature and attic temperature at constant were 29.3 and 28.5 °C respectively at 36 minutes. The cooling rate of roof surface was around 1.1 °C per minute. The maximum difference of roof temperature and attic temperature was 16 °C. The attic temperature was effectively reduced by 5.6 °C due to the fact that the thermal load at attic region transfer to surrounding through the roof surface with water flow on it. The results suggest that the performance of the cooling effect on the attic temperature is the highest for the thermostat setting at 50 °C as compared to earlier setup. The inconsistency of the temperatures shown in Figure 7 in between 25th minutes and 35th minutes is accountable for the cutoff of the water pump. An alternative explanation would be the cooling roof system stop working at 25th minutes as the roof temperature was below the thermostat set point. Hence, the roof surface temperature increase.

![Temperature (degree Celsius) vs Time](image)

**Figure 7.** Performance of cooling roof system on roof temperature and attic temperature (°C) against time (minutes) for thermostat temperature at 50 °C.

3.5. Comparisons of performance of cooling effect on attic temperature
Figure 8 compares the attic temperatures of three sets of different maximum roof surface temperatures which are 40 °C, 45 °C and 50 °C. For the bare metal deck roof was observed has the hottest attic temperature of 31.5 °C compared to the roof designs with cooling roof system at 15th minutes. The high attic temperature of metal deck was due to the fact that the high temperature of particles at the roof surface transfers into the lower temperature region in the Perspex. However, this showed that providing cold moving fluids on the roof surface was effective to transfer the heat from the attic region to the roof surface. The results indicate that roof design with cooling roof system has lower attic temperature below 30 °C which were 26 °C and 28.4 °C. The attic temperature difference between the roof with cooling roof system and without cooling roof system was 3.2 °C.
3.6. Comparisons of roof temperature on cooling roof system

Figure 9 compares the roof temperatures at period of heat up the roof surface to after cooling process. The roof temperature with 40 °C was observed has cooled down to 28.3 °C within 10 minutes. The roof temperature with maximum 45 °C was cooled down to 29.8 °C within 11 minutes. The roof temperature with maximum 50 °C was observed has cooled down to 29.3 °C within 19 minutes. The cooling rate of roof surface at 40 °C, 45 °C and 50 °C were 1.2 °C per minute, 1.3 °C per minute, and 1.1 °C per minute, respectively. As expected, the lowest cooling rate was roof surface temperature of 50 °C. Table 1.0 shows the maximum temperature results for roof surface and attic with and without cooling effects at different temperatures setting of thermostat.

![Figure 8](image8.png)

**Figure 8.** Comparisons of attic temperatures (°C) against time (minutes).

![Figure 9](image9.png)

**Figure 9.** Comparison of roof surface temperature (°C) against time (minutes).

| Temperature setting of thermostats (°C) | Maximum Roof surface temperature, (°C) (before cooling) | Maximum Attic temperature, (°C) (before cooling) | Roof surface temperature (°C), (after cooling) | Attic temperature (°C), (after cooling) | Time required for constant temperature (minutes) |
|----------------------------------------|----------------------------------------------------------|--------------------------------------------------|-----------------------------------------------|------------------------------------------|-----------------------------------------------|
| 40                                     | 41.1                                                     | 24.7                                             | 28.3                                          | 26.1                                      | 10                                            |
| 45                                     | 45                                                       | 28.8                                             | 29.8                                          | 28.3                                      | 11                                            |
| 50                                     | 50.1                                                     | 34.1                                             | 29.3                                          | 28.5                                      | 19                                            |

**Table 1.** Temperature setting of thermostats at 40 °C, 45 °C and 50 °C.
4. Conclusion
In this research project, an active cool roof system that integrated with different roof configurations was investigated to enhance the attic temperature reduction. The cool roof model was fabricated and tested indoor with a solar simulation by halogen lamp. The rainwater harvesting system showed a significant reduction in roof top temperature by up to 19.2 °C (from 47.5 °C to 28.3 °C). The heat radiated by the halogen lamp was directly absorbed and insulated by the cooling water in this system that resulted a temperature reduction in roof top temperature. As result, the rate of temperature in the attic region was reduced by the reduction of heat energy transferred from the roof top to the attic region. This integrated cool roof design showed a significant improvement with a reduction of up to 6.4 °C (from 32.5 °C to 26.1 °C) in the attic temperature as compared to conventional metal deck roof by setting the trigger temperature point of thermostat at 40 °C. In conclusion, this smart and eco-friendly cool roof system has proven to reduce the attic temperature by enhancing the comfortability inside the building with zero damaging effect on the environment.

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