Development of Innovative Coating Methods for Metal Based Roof

Firdaus Basrawi[1,*], Liew Khee Yan[1], Luqman Abdul Halim[1] and Thamir Khalil Ibrahim[2]

[1]Faculty of Mechanical Engineering, University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

[2]Mechanical Engineering Departments, College of Applied Engineering, Tikrit University, Iraq

Abstract: Metal panels are one of the most common roofs covering in Malaysian buildings. Nevertheless, the commercial metal roof is generally known as not being effective enough in reflecting sunlight and emitting thermal energy. Hence, innovative coating solutions were developed and analysed in terms of their thermal performance. Seashells and woodchips were used as the raw materials to develop the innovative coating. Thermocouple modules were integrated with Arduino to measure the surface temperatures of 3 roof prototype, Prototype A (commercial metal panel), Prototype B (with woodchips coating) and Prototype C (with seashells coating). Their temperature profiles were investigated, and their thermal performance was analysed, and from that, the overall heat transfer coefficient (U *value*) was calculated. It was found that temperature for Prototype C was the lowest in the range of 32 to 50ºC, while Prototype A were in the range of 32 to 60ºC, and there is no significant difference between prototype A and B. In addition, temperature difference for Prototype C are always in positive values, reaching as high as 6ºC in the afternoon. The other 2 prototypes fluctuated between the range of - 4ºC and 4ºC. These results were proved with the U-*values* calculated in which U_A was $217\ W/m^2K$, U_B was $44\ W/m^2K$ and U_C is $69.6\ W/m^2K$. However, U_B contradicts with the temperature profile results. Overall, Prototype C, with seashells coating shows promising results as material of innovative roof based coating.

Keywords: Cool roof, thermal performance, acoustic performance, seashells, woodchips, metal based roof.

1. INTRODUCTION

The roof of a building is the component which were exposed to most of the sunlight during the day. Thus, attention should be given to improve the solar reflectance and thermal emissivity of the roof. Large building such as warehouses, agricultural buildings, factories and airports have large roof area, leading to higher power consumption due to the need of ventilation and cooling. Figure **1** shows the energy balance on a roof surface. The net heat flux is the heat gained from the solar radiation, minus the reflected radiation, re-emitted energy and heat loss due to convection.

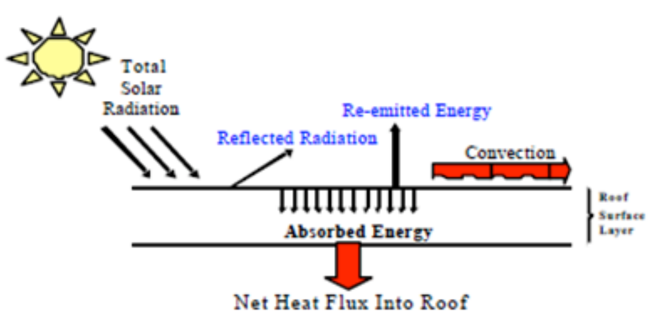

Figure 1: Energy balance on roof surface.

Cool roof is a promising solution to mitigate the absorptivity of solar radiation, which will result in reducing the temperature inside buildings [1-4]. Cool roofs can improve solar reflectance and emittance of conventional roofs such as clay roofs, without much alteration towards the original roofing architecture [1]. By employing passive cooling technique, cool roofs has been evaluated and shown to increase building thermal performance both in summer and winter conditions [2].

Some common types of roof used worldwide includes concrete tiles, clay tiles, stainless steel roof, wood shake, and shingles roofs. Table **1** presents various commercially available roofing materials with their prices and properties, respectively [5-10].

Among the various types of roofing in Malaysia, metal roofing is widely used for industrial buildings and commercial buildings. It has diverse appearances and available in a wide variety of substrates, colours, textures and profiles. Metal roofing is suitable for most types of building because of their excellent in durability, fire resistance, recyclability, low life cycle cost and sustainability. With proper design, metal roofing can become very efficient in saving energy in building by reducing a building cooling load. Furthermore, metal roofing is cheaper compared to other materials due to its easy installation. Table **2** shows the cost per square meter for metal roofing [11].

In Malaysia, metal based roofs are usually coated with only a thin layer of paint as protection from solar radiation. This thin layer of low quality paint is not durable against the weather cycle. Furthermore, the

*Address correspondence to this author at the Faculty of Mechanical Engineering, University Malaysia Pahang, 26600 Pekan, Pahang, Malaysia; E-mail: mfirdausb@ump.edu.my

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Table 1: Comparison of Prices and some Properties among Various Roofing Materials

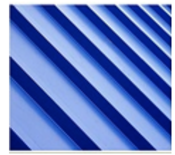
					
	Concrete Tile	Clay Tile	Stainless Steel	Wood Shake	Shingle
Price per m^2 (RM) Price per m^2 (USD)	191.71 53.85	115.02 32.30	38.33 10.76	38.33 10.76	19.16 5.38
Life span (years)	20-25	20-25	20-25	15-20	7-15
K value (W/m.K)	3.33	1.15	16	0.12	2.27

Table 2: Range of Metal Roofing Materials

	Price Per Roofing m^2	
Metal Roofing Materials	**(RM)**	**(USD)**
Stainless steel panels	38.33	10.76
Corrugated steel panels	46.01	12.92
Galvanized steel panels	57.51	16.15
Steel or aluminium shingles	101.00	28.37
Stone-coated steel	134.18	37.69
Standing seam	153.37	43.08
Copper or zinc	268.39	75.39

paint is ineffective in terms of reflecting sunlight and emitting thermal energy [12, 13].

In this paper, innovative coating methods were developed for metal based roofs. The main materials employed in this coating are woodchips and seashells. Woodchips are small sized solid material made by chipping or cutting larger pieces of wood [14]. They are recyclable and usually are the by-products from industrial activities such as the furniture industry, wood craft and sawmill. There are many advantages of using woodchips membrane as coating material. It is a natural heat insulator, which can lead to a more comfortable indoor environment with adequate room temperature, thus cutting down electricity consumption [15, 16]. Woodchips coating will also be able to protect the metal based roof against corrosion thereby increasing its durability, making the metal roof last longer. Another advantage of having woodchips membrane on metal roof will reduce noise during raining day [17]. Woodchips membrane in coating material has excellence flexibility, is weather resistance and application is simple.

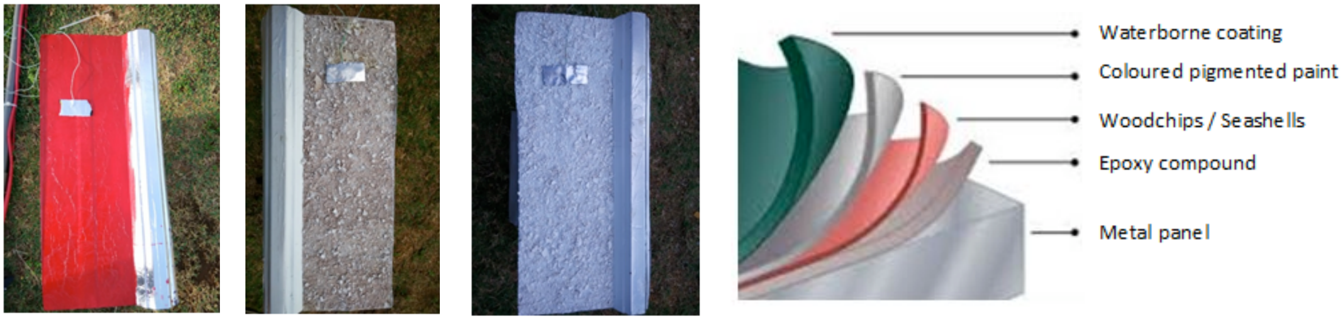
Seashell is a hard-protective layer created by an animal that lives in the sea. Seashell is made of 98% of calcium carbonate and only 2% of protein. It is used as one of the raw materials for cool roof coating because it is rich of calcium carbonate which have opaque property [18]. It means that sunlight is very hard to penetrate through the seashell.

The temperature performance problem of metal roofs is common, yet there is very little research focusing on their enhancement. Therefore, this study was carried out to develop an innovative coating for metal based roof to improve their thermal performance.

2. METHODOLOGY

2.1. Preparation of Roof Prototypes and Experimental Setup

Each coating layers on top of a metal roof panel serve different functions to extend the durability of the metal roof. The metal panel itself have several weaknesses such as not attractive, prone to rusting when exposed directly to outdoor conditions as well as being an effective heat conductor. Therefore, it is vital that the materials for the roof coating is carefully selected to reduce, improve and ultimately eliminate the drawbacks of metal panel roofs.



(a) (b) (c) (d)

Figure 2: (**a**) Prototype A, (**b**) Prototype B, (**c**) Prototype C and (**d**) illustration on the arrangement of coating layers for each prototype.

In this experiment, metal panel roofs are coated with several layers of coatings. Figure **2** shows the different layers on the metal panel, including epoxy compound, wood chips or seashell, coloured pigmented paint and waterborne coating. To develop coating methods for metal based roof, metal panels were first cut into similar dimensions (45 cm x 19 cm).

Then, the paint on the prototypes was removed using thinner to ensure the metal surfaces have no coating layers. The figure shows Prototype A, a commercial metal panel, Prototype B, metal panel with woodchip coating, and Prototype C, metal panel with seashell coating. Illustrated is the arrangement of the coating layers on each prototype.

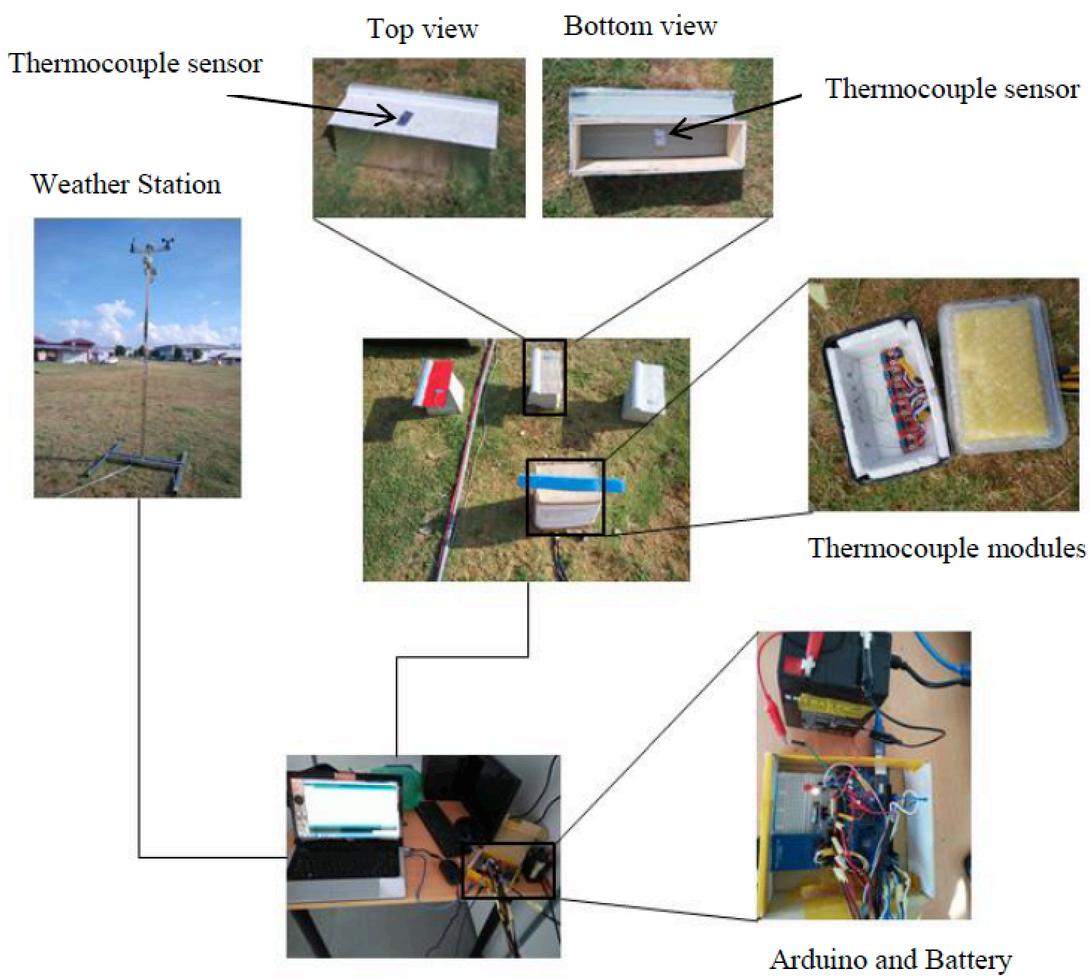


Figure 3: Experimental Setup.

Table 3: K Values and Thickness of Different Layers of Prototypes

Layers of Prototype	Materials	K Values (W / m.K)	Thickness (l)
1	Roof paint (resin)	0.15	0.0001 m
2	Woodchips Seashells	0.12 0.24	0.002 m
3	Air	0.0262	0.0001 m
4	Epoxy	0.35	0.0005 m
5	Stainless Steel	16	0.002 m

Table 4: Layers of each Prototypes

Materials	Prototype A (Commercial)	Prototype B (Woodchips)	Prototype C (Seashells)
Roof paint (resin)	Layer 1	Layer 1	Layer 1
Woodchips	/	Layer 2	/
Seashells	/	/	Layer 2
Air	Layer 2	Layer 3	Layer 3
Epoxy	/	Layer 4	Layer 4
Stainless Steel	Layer 3	Layer 5	Layer 5

The experiment setup is as shown in Figure **3**. The setup was designed to collect the data of surface temperature using thermocouples from the surface at top and at bottom of each prototype for duration of 9 am until 7 pm. The pyranometer at the weather station was used to measure the total amount of sunlight received by the prototypes. The surface temperatures on top of roof and below the roof were measured over duration of time using thermocouple modules. The temperature was collected for a day to simulate the variation of temperatures in the condition of sunlight exposed to a roof. This complete data was analysed later to compare among the three prototypes in order to study the effect of the different coating methods on the surface temperatures.

2.2. K Values, R Values and U Values

Thermal conductivity (K-value) is the rate at which heat passes through a material. The lower the conductivity, the more thermally efficient a material is. Thermal resistance (R-value) is the ability of a material to prevent the passage of heat. It is the thickness of the material divided by its conductivity. Thermal transmittance, (commonly denoted as U-value) is a measure of the rate of heat loss of a building component. The U-value is the sum of the combined thermal resistances of all the elements in a construction. The lower the U-value, the better the material is as heat insulator. Table **3** shows the information about thicknesses and K values for the layers of prototypes.

The prototypes A, B and C had different layers of coatings and materials. The arrangement of coating and materials for each prototype are as shown in Table **4**.

Formula:

$$R = \frac{l}{K_1} + \frac{l}{K_2} + \frac{l}{K_{n+1}} \quad (1)$$

$$U = \frac{1}{R_{total}} \quad (2)$$

3. RESULTS AND DISCUSSION

The experiments for the three prototypes were carried out and their data are collected from 9 am until 7 pm on the same day. Thermocouples were attached on the surface above of each prototype exposed to sunlight directly. Comparing the temperatures data at top surfaces, Figure **4** showed that Prototype A was almost always at the highest position and Prototype C was always at the lowest position among the three prototypes throughout the experiment. Meanwhile, the upper temperature of Prototype B had very small gap

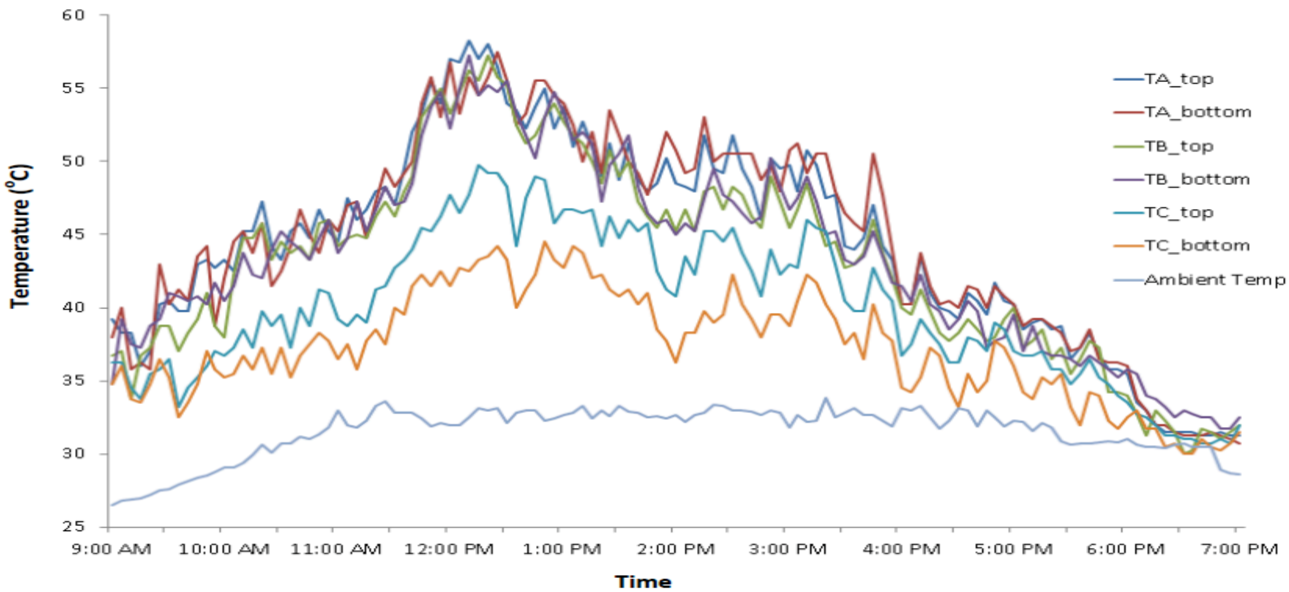


Figure 4: Temperature profile at the top and bottom surfaces for each prototype, and ambient temperature.

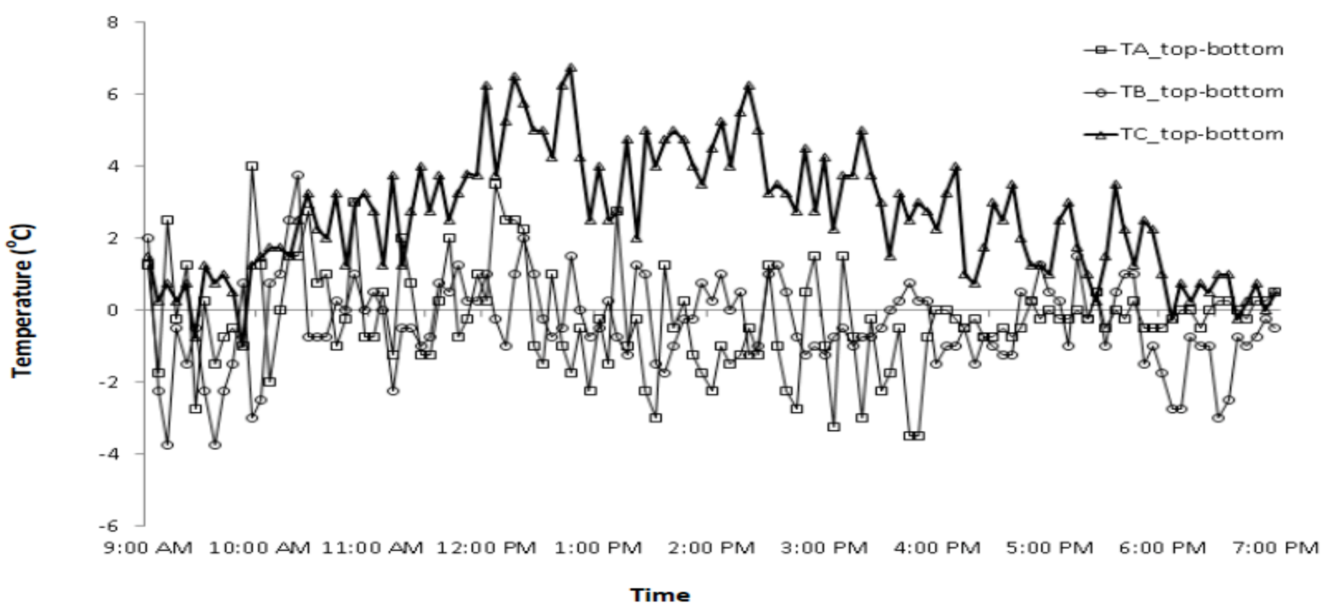


Figure 5: Temperature difference between top and bottom surfaces for each prototype.

compare to that of Prototype A. This result indicated that the metal panel with seashell coating reflects most sunlight to keep its upper surface cool. The reflection of sunlight for both commercial metal panel and metal panel with woodchips coating was moderate.

Viewing the perspective of the surface temperatures at bottom of each prototype, Prototype C was always at the lowest position, while the lower Prototype A and B fluctuated at higher position and almost were having the same trend. The surface temperatures measured at top and bottom of Prototype C, they were always smaller than that of Prototype A and C. It shows that thermal performance of seashell coating had better cool roof effect compared to the others.

According to Figure **5**, it shows the differences between surface temperature at top and at bottom (T_{top} $-T_{bottom}$ = T_{Δ}) for respective prototypes, it was observed that the T_{Δ} of prototype A (commercial) and Prototype B (woodchips) were volatile between 4°C and –4ºC from 9 am until 7 pm. Negative sign indicates that the surface temperatures at the bottom were higher than that at the top. While the T_{Δ} for prototype C

Table 5: *R-Values* and *U-Values* of Prototypes Investigated

Thermal Properties	Prototype A (Commercial)	Prototype B (Woodchips)	Prototype C (Seashells)
R (m^2K/W)	0.00461	0.02270	0.01437
U (W/m^2K)	217.0	44.0	69.6

(seashells) fluctuated mostly in the positive range and it went up as high as 6°C and more in afternoon. The graph explains that prototype C had better cool roof characteristic which outperformed that of prototypes A and B. The results also prove that Prototype C coated with seashell was more suitable to replace the commercial metal panel as it had outstanding “cooling” effect under the hot sun.

Table **5** showed the *R-values* and *U-values* generated from *K-values* and thicknesses of each layers of prototypes. Prototype A had the highest *U-value*, while prototype B had a better insulation than prototype C as U_B was lower than U_C. Temperature differences, $T_{A\Delta}$ and $T_{B\Delta}$ were having similar trend as shown in Figure **5** while $T_{C\Delta}$ was always the highest. This experimental result did not match with the theoretical result, as $T_{C\Delta}$ was supposed lower than $T_{B\Delta}$. During the preparation of coatings, air bubbles appear between the recycled materials (woodchips or seashells) and epoxy adhesive layer, this defect can significantly affect the conductivity of heat from sunlight. There were also a few other factors influenced the results such as heat loss, convection and radiation were not considered in the determination of *U-values*. Although this calculation could explain why Prototype C is significantly better than Prototype A, other thermal factors stated above need to be further carried out to explain why Prototype B had similar results with Prototype A.

CONCLUSION

An experimental investigation was carried out to compare the thermal performance of roof coating from woodchips and seashells. It was found that metal panel with seashells exhibited temperature profile in the range of 32 to 50ºC, while the other prototypes was in the range of 32 to 60ºC. Seashell coating has “cooling” effect with temperature gap between upper surface and lower surface as high as 6ºC in afternoon. This was proved by U value calculated, although U value for prototype with woodchips contradicted the temperature profile results. Thus, seashells coating shows promising result for metal based roof based coating which is valuable for further research. Besides, the thermal factors such as heat loss, convection and radiation should be considered in the future research.

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