

Influences of Lightweight Foam Concrete Roof Tile Hollow Sections and Thermal Reflective Coating in Cool Roof System

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ABSTRACT

Modern civilization is increasing the commercial and residential buildings demand, while a big part of the energy consumed in buildings is for cooling purposes. Modern building design requires sustainable cooling facilities when an excellent roofing system plays an important role. This paper investigates the performance of a cool roofing system that integrates lightweight foam concrete roof tile and a passive cool roofing system. The concrete fabrication process introduced the concrete roof tile hollow sections to improve the roof's thermal resistance. The densities of the lightweight foam concrete roof tile were varied at 1300 kg/m³ and 1100 kg/m³, respectively, to determine a better performance of roof tile than a basic concrete roof with a density of 2500 kg/m³. Two spotlight lamps that imitated solar irradiation in the afternoon were used as the heat supplied on four roof prototypes. The results showed that the attic temperature dropped from 40.8 °C to 33.5 °C (-7.3 °C) after 60 minutes of heat exposure when the roof was a foam concrete, the roof density was lower, with hollow longitude sections and thermal reflective coating. Furthermore, the average attic temperature increment rate was reduced by 70.2 % when an ideal cool roofing system was applied.

Keywords: Lightweight foam concrete; thermal reflective coating; cool roof; building

INTRODUCTION

People spend 90 % of their daily activities indoors and have high indoor thermal comfort levels. The cooling system encountered for building activities occupied 20 % of worldwide building energy consumption (Qi et al. 2012). The energy consumed for the operation of air conditioner and fan rises with building and construction demand. Roof is the major components that causes the increasing of indoor temperature, especially in lower buildings (Hernández-Pérez et al. 2014). It becomes essential to redesign the traditional roof system to reduce the energy consumption of a building's cooling system. The up-gradation of the roof system to have higher thermal resistance and lower internal load density can reduce the operational load of heating, ventilation and air conditioner (HVAC) system (Saber et al. 2019).

The excellent cool roof system is one of the upgrades of the roof system that can reduce the building's thermal load. Concrete with excellent specific heat and low thermal conductivity is an appropriate structure for the fantastic cool roof system. It possesses excellent insulation properties and can provide indoor thermal comfort by increasing the system's thermal mass (Asadi et al. 2018). The application of fibre-reinforced lightweight foam concrete in building

construction reduced the building energy by between 3.2 % to 14.8 % (Muda et al. 2020). Fibre-reinforced lightweight foam concretes with density ranged between 1000 to 1900 kg/m³ can achieve compressive strengths of 10 to 70 MPa (Amran et al. 2020). Besides, the benefits of implementing lightweight concrete roof include fire resistance, cost saving, lower weight loading to the supporting structure and environmentally friendly (Amran et al. 2022).

Lightweight foam concrete with a higher porosity level than regular concrete mainly influences its lower thermal conductivity (Strzałkowski et al. 2021). When the porosity of the concrete roof increases, study results showed a decrement in concrete's thermal conductivity and an increment in concrete's specific heat (Vejmelková et al. 2015). The thermal conductivity of foam concrete is decided by the thermal conductivities of its materials. Foam concrete with high void ratio as well as the very low thermal conductivity of air compared with other materials, greatly reduced the thermal conductivity of foam concrete (Mugahed Amran, 2020). To determine the role of concrete's density in the roof's thermal resistance, the lightweight foam concrete roof in this study was fabricated with densities 1100 and 1300 kg/m³. The fabrication method applied for lightweight foam concrete is trial and error density method (Othman et al. 2021).

Increasing the roof's thermal insulation properties can efficiently reduce the building's heat gain (Mohd Ashhar & Lim, 2022). The introducing of thermal insulation effect in the roof system is commonly achieved with the adding of insulation material and reflective technology (Lee et al. 2016). In this study, the thermal insulation effect in hollow section was introduced at the beginning of concrete fabrication stage, which is lower in cost and requires lesser to zero maintenance. Hollow concrete blocks, widely used in Morocco for roofing systems, can significantly decrease the electricity consumed for cooling loads with its higher thermal resistance than blocks without hollow cavities (Chihab et al. 2021). Concrete hollow-core slab can be used as the roof structure. The circle hollow cores in roof are the ventilation centre for the cool air to remove the stored heat (Yu et al. 2020). Further, a cool roof system with a high solar reflectivity surface can reduce air conditioners usage. Roofs with a high solar reflectivity surface (bright white surface) can have solar reflectance as high as 0.8 (Alchapar & Correa, 2016).

The combination of insulation and reflective material is the most convenient approach to be integrated in existing roof system to reduce the building's heat gain (Hernández-Pérez et al. 2014). In this study, the insulation and reflective material are combined as hollow sections fabrication in lightweight foam concrete roof tile and thermal reflective coating applied on the concrete surface. As far as the author's knowledge, there is no study that based on the efficiency of improving the roof thermal resistance with the combination of lightweight foam concrete technology, hollow sections fabrication and thermal reflective coating application. The aim of this study is to evaluate the efficiency of proposed cool roof system by the performance of heat reduction in the attic region and roof surfaces.

METHODOLOGY

The materials to fabricate the concrete roof prototypes were selected carefully based on the standard regulations. The concrete roof prototypes were fabricated with densities 2500, 1300 and 1100 kg/m³, respectively. To fabricate the roof prototypes, the traditional concrete fabrication method and lightweight foam concrete technology were adopted. Additionally, hollow concrete fabrication was followed to create a hollow roof prototype. Thus, four roof prototypes were created and were conducted laboratory experiment measurements to study the thermal performances of roof prototypes.

The Ordinary Portland cement manufactured by YTL Cement Sdn. Bhd., Malaysia was chosen as the main material for concrete casting. The solid state of Ordinary Portland cement can achieve compressive strength of 75.8 MPa, adhering to ASTM Type 1 cement requirement (Mugahed Amran, 2020). A conventional concrete roof with a density of 2500 kg/m³ was casted for the reference experiment. The structure of the cool roof system, lightweight foam concretes were casted with densities 1100 and 1300 kg/m³, respectively. Besides, fine sand is commonly used in lightweight foam concrete casting for an evenly distributed porous cell (Mugahed Amran, 2020).

The primary ingredients for lightweight foam concrete fabrication were cement, sand, water and foam. For conventional concrete roof, the primary fabrication ingredients were cement, sand, water and coarse aggregate. The fine sand was sieved with 600 m sieve before the concrete casting to follow the regulation in No. 30 ASTM E-11. To get rid of the hydration, the fine sand was dehydrated in an oven for more than 25 hours at a temperature of 105 °C ± 5 °C (Othman et al. 2021). For foaming agent, the protein foaming agent manufactured by LCM Technology Sdn. Bhd., Malaysia was used according to the standards in ASTM C796-19. The protein foaming agent works by separating its large molecule bonds and reassembling with cement slurry molecule. Air bubbles were formed through the bond separation process (Amran et al. 2022).

THE CASTING OF CONCRETE ROOF

The foam concrete casting process was following the concrete making regulations in ASTM C796 under trial and error density method (Othman et al. 2021). At the beginning, the dry ingredients were weighted and combined in two mixer drums separately before adding in the tap water. Each mixer drum represented roof cement slurry with densities 1100 and 1300 kg/m³, respectively. Besides, at an opportune foam generator, protein foaming agent was mixed with tap water at a ratio of 1:30. Compressed air was injected into the opportune foam generator to produce foam. Then, the produced foam was combined with cement slurry bit by bit. The density of cement slurry was measured by filling up and weighting a 1-liter beaker. The combinations of produced foam and cement slurry were repeated until the measured densities reached 1100 and 1300 kg/m³, respectively.

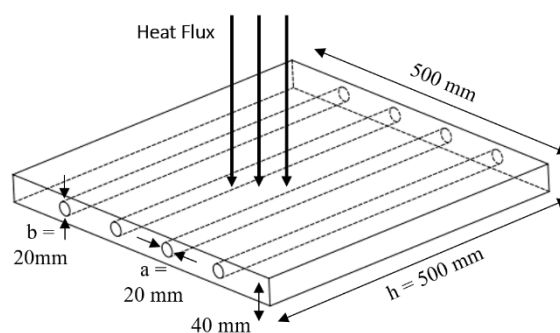


FIGURE 1. Hollow longitudinal sections

After that, the foam cement slurries were mixed with a vertical mixer at 3000 rpm. The vertical mixer requires high speed to generate a fine cement slurry which can increase the concrete's mechanical properties (Falliano et al. 2020). Besides that, the high-speed mixing can decrease the size of air pores and let the air pores spread out evenly in the cement slurry (Sang et al. 2015). The foam cement slurries were set in steel moulds of size $0.5 \times 0.5 \times 0.04$ -m and after drying, the roofs were brought to water curing for 2 weeks. The water cement ratio, sand cement ratio and coarse aggregate cement ratio were fixed at 0.6, 1.0 and 3.0, respectively.

HOLLOW SECTIONS

The lightweight foam concrete of density 1100 kg/m^3 was casted with hollow longitudinal sections to increase the roof's thermal resistance. Figure 1 shows the design of hollow longitudinal sections inside a lightweight foam concrete roof tile. Four PVC pipes of diameter 20 mm were fixed in the steel mould to create the hollow longitudinal sections inside of lightweight foam concrete roof tile as shown in Figure 1. The PVC pipes were fixed 84 mm apart with each other inside the steel mould.

The values required to calculate the aspect ratio of a hollow slab is shown in Figure 1 (a, b and h). In hollow slab design, the aspect ratio is one of the important factors affecting the thermal performance. The aspect ratio affects 30 % of the slab's total heat transfer rate (Mahmoud et al. 2012). Values a is the length of hollow cavity perpendicular to the entering solar radiation, b is the length of hollow cavity parallel to the entering solar radiation and h is the extend of hollow cavity covered by the entering solar radiation, respectively. For a high thermal resistance hollow slab, a high aspect ratio (a/b) is required as well (Al-Tamimi et al. 2020). Besides, according to the study from researcher

Oluwole et al. (2012), a concrete with four hollow sections had the best thermal performance. When the concretes were studied with the MATLAB software, results proved that for concretes with more than four hollow sections, the concretes did not show better thermal performance (Oluwole et al. 2012).

Further, when the cavities (hollow sections) inside the concrete were ventilated, the internal side of cavities are 1.8 lower in temperature than enclosed cavities (Huang et al. 2018). Cavities without the ventilation of surrounding air had higher internal temperatures due to the absence of conventional heat exchanges between the surrounding air and thermal energies inside the cavities. The abovementioned hollow slab design assessments were considered in the design of hollow longitudinal sections as shown in Figure 1.

Roof Prototypes

The roof prototypes had the same dimensions as shown in Figure 1. Roof Prototype A was the conventional concrete roof tile. Roof Prototype B was the lightweight 1300 kg/m^3 foam concrete roof tile. Roof Prototype C was the lightweight 1100 kg/m^3 foam concrete roof tile with hollow longitudinal sections. Lastly, roof Prototype D was the same as Prototype C but with an extra layer of thermal reflective coating. The solar reflectivity of a conventional grey concrete tile is 0.18 to 0.25 (Rawat & Singh, 2022). When the concrete is applied with a reflective coating, the solar reflectivity can be increased to 0.8. A layer of reflective coating has the same thermal performance as a 14-107 mm insulation blanket (Qiu et al. 2018). The roof prototypes were placed above an attic model. The dimensions of the attic model and the design of roof Prototype D were shown in Figure 2.

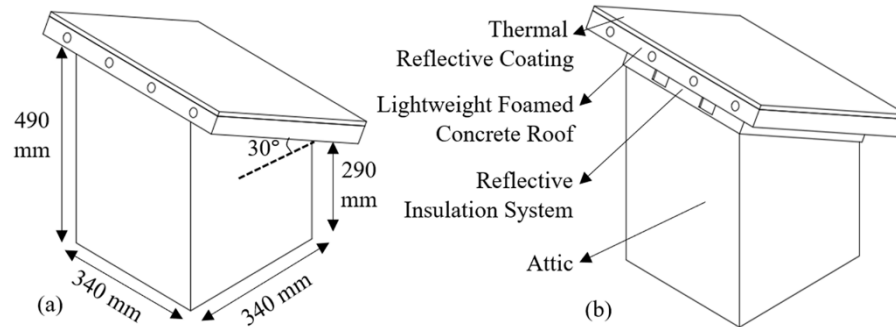


FIGURE 2. (a) Dimensions of attic model and (b) roof Prototype D, respectively.

EXPERIMENT SET UP

The accuracy of indoor experiment measurement with test models are high because the surrounding and experimental parameters can be fixed and controlled (Mohd Ashhar & Lim 2022). Thus, the roof prototypes experiment studies adopted the indoor experiment measurement and test rig methods. The roof mock-ups were built with four roof prototypes, each of them studied the efficiency of different cool roof elements. The experiment set up was shown in Figure 3. The apparatuses adopted to study the roof prototypes were solar spotlight lamp, lamp stand, attic model, thermometer and data logger. Two 500 W and 240 V solar spotlight lamps were adopted to provide solar thermal radiation to the roof prototypes as shown in Figure 3. The spotlight lamp composed of a tungsten film and a 500 W halogen light bulb.

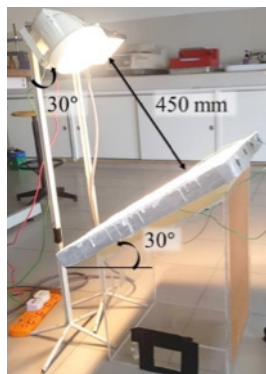


FIGURE 3. Experiment set up

The solar spotlight lamps were inclined 30° from the vertical axis, which equaled to the roof pitch as shown in Figure 3. When the solar spotlight lamps were fixed on the lamp stands of height 1 m, the distance between the surfaces

of lamp and roof prototype was 450 mm. Two surface temperature sensors were placed on the surfaces of roof (upper and lower) with aluminium tape. Besides, two air temperature sensors were used to measure the temperature performance of the ambient and attic. The ambient temperature recorded was $30 \pm 1^\circ\text{C}$. For each experiment, the roof prototypes received 60 minutes of solar thermal radiation. The temperatures were recorded at every 1 minute with data logger.

RESULTS AND DISCUSSION

ATTIC REGION

The performance of each roof prototypes was compared according to its attic temperature variation with basic concrete roof, the reference roof. The attic temperature variations of four roof prototypes with different features are as shown in Figure 4. The initial attic temperature was controlled at 30.4°C .

According to Figure 4, the roof Prototype A had the highest attic temperature trend among all the roof prototypes. The prototype A was the basic concrete roof structure built with commercial reinforced concrete of density 2500 kg/m^3 . The average temperature increment rate was $0.1733^\circ\text{C}/\text{min}$. After the basic concrete roof was upgraded to lightweight foam concrete roof tile with a density 1300 kg/m^3 (roof Prototype B), the attic temperature after 60 minutes of heat exposure dropped from 40.8°C to 36.5°C . The concrete modification process involved changing the ingredient coarse aggregate to foam. Furthermore, the attic region inside of roof Prototype C reached 34.6°C at 60th minutes when the concrete's density was further reduced to 1100 kg/m^3 .

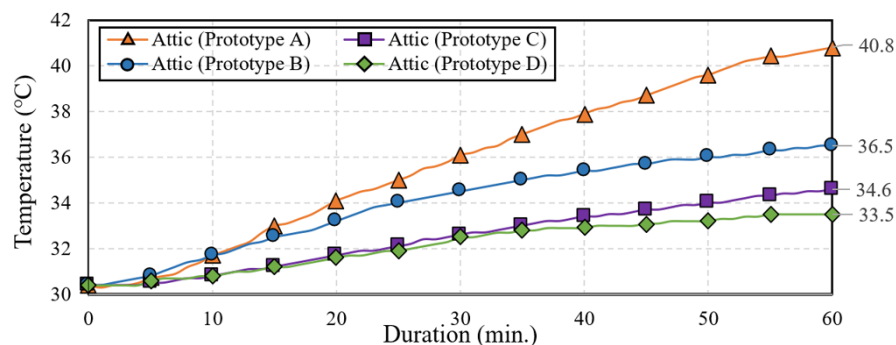


FIGURE 4. The attic temperatures

The attic temperature showed a 6.2 °C reduction after the density of concrete was reduced from 2500 to 1100 kg/m³ and had four hollow longitude sections in the concrete mass. The density of concrete was reduced by increasing the mass of foam in the cement mixture while directly reducing the cement content. The void structures produced during the foaming process that was later combined with the cement slurry caused the decreasing of structure's weight while keeping the structure's volume (Saygılı & Baykal, 2011). The cement mixture of lower density concrete contained more compressed air foam; hence its porosity level is higher. Higher foam quantity concrete tends to have lower thermal transmission rate (Alengaram et al. 2013). The lower graph's gradient in Prototype C (0.07 °C/min) proved that higher porosity level concrete transferred lesser and slower heat. Porous low-density concrete achieved low thermal conductivity and high specific heat properties due to the existence of air. The low thermal conductivity of air enabled a high amount of conduction heat permitted through the roof structure (Ng & Low, 2010).

Besides, the experiment results proved that the addition of hollow longitude sections decreased the attic thermal increment rate as well as increased the roof thermal insulation performance. The average temperature increment rate of roof Prototype B was 0.1017 °C/min, while Prototype C was 0.07 °C/min (a 36.95 % decrease).

The existence of hollow sections in concrete played a significant role in reducing attic temperature increment rate. Filling concrete structure with open passages was introduced as a passive technique to improve the concrete's thermal optimization. When environmental air streams the passages of hollow sections, it creates a trapped air gap inside the concrete which can be interpreted as an insulation layer. These insulation layers reacted as barriers and delayed the thermal wave penetration across the roof structure to the attic space. The

roof's thermal insulation performance is enhanced when the thermal wave in hollow sections exchanged the heat with the streaming air inside the cavities (Yu et al. 2015). The convective heat exchange can also be triggered by thermal wave upwards flowing buoyancy force in hollow sections that draws in the ambient air (Chen et al. 2022). Heat flux was thus transferred slower to the attic region in Prototype C, proved that the attic temperature was an all-time cooler in Prototype C than B.

In addition, for roof Prototype D with an accessional thermal reflective coating, the attic temperature increment rate was 0.0517 °C/min, and it achieved a final attic temperature of increment rate and final attic temperature showed a decrease of 70.19 % and 17.89 % compared to roof Prototype A. The integration of the cool roof system had the attic temperature of roof Prototype D accomplished a steady temperature of 33.5 °C after 55th minutes. Roof Prototype D with the combination of a higher thermal insulation concrete design and a higher solar reflectance than the basic concrete roof can produce a cooler roof surface. The cooler the roof surface, the cooler the structure's inner temperature (Wu et al., 2017).

UPPER ROOF SURFACES

The upper roof surface temperatures of four roof prototypes are shown in Figure 5. The upper roof surface temperature of the basic concrete roof (Prototype A) was the highest among other prototypes, it hit 62.7 °C after 60 minutes of heatwaves exposure, while Prototype D reached 51.8 °C. This indicated a decrease of 17.38 % in upper roof surface temperature when the roof was upgraded with a cool roof system that integrated lower density concrete, hollow sections and thermal reflective coating.

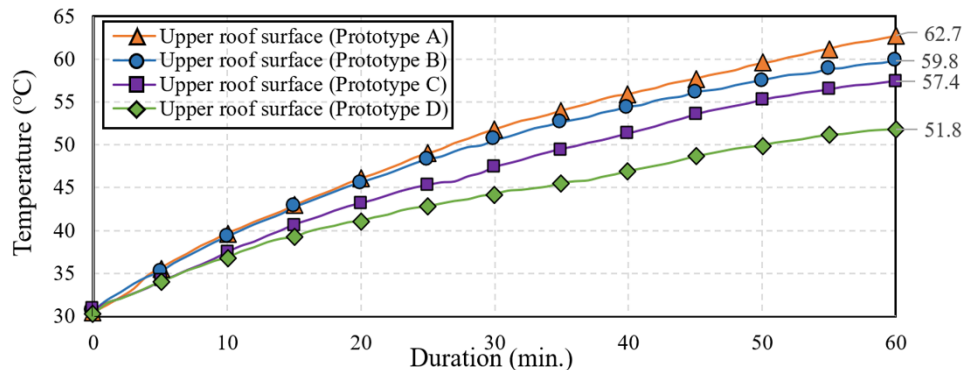


FIGURE 5. The upper roof surface temperatures

ROOF LOWER SURFACE

According to Figure 5, the upper roof surface temperatures of roof prototypes showed a bigger drop in peak temperatures when the roofs were additionally applied with thermal reflective coating than reducing the concrete density. When the density of roof was reduced, the peak temperature reduced from 62.7 °C to 57.4 °C (-5.3 °C). When the same roof was applied with reflective coating, the peak temperature reduced from 57.4 °C to 51.8 °C (-5.6 °C). The addition of reflective coating is more pronounced in reducing the upper roof surface temperature, as well as providing a cooler roof. The reflective coating application increased the roof surface solar reflectivity from 0.18 to 0.8 (Rawat & Singh, 2022). The high solar reflectivity plays a critical role in reflecting incident solar irradiation. Standard roofs with lesser solar waves reflected tend to absorb higher thermal waves due to its darker surface color.

Besides, when the roofs densities were reduced from 2500 kg/m³ to 1300 kg/m³ (Prototypes A to B), the decrease in surface heat gain was 9.63 %. In another case, when Prototype D was coated with reflective paint, it leads to a 18.8 % decrease in surface heat gain compared to Prototype C without the coating. The higher decrease in surface heat gain after the application of reflective coating was mainly due to 80 % of the incident solar irradiation was reflected by its high solar reflectivity. The integration of reflective paint can reduce the roof surface temperatures in the range of 1.4 °C to 4.7 °C (Rawat & Singh, 2022). In Prototype D, the roof surface temperature was brought down by 5.6 °C, besides proven higher than the temperature range, its effectiveness in providing a cool lightweight foam concrete roof tile surface was proven too. Practically, the accumulation of dirt on roof surface can decrease the roof's solar reflectivity. However, with annual washing practices, the solar reflectivity of roof's surface can recover up to 90 % (Al-Obaidi et al. 2014).

The roof lower surface temperatures of four roof prototypes are shown in Figure 6. When a standard roof (Prototype A) was upgraded to a lower density roof tile with lightweight foam concrete technology, its density decreased from 2500 kg/m³ to 1300 and 1100 kg/m³ (Prototypes B and C), respectively. For instance, the density of roof influenced the roof lower surface temperature. Roof Prototype A reached 60.4 °C, while Prototype C achieved 48.8 °C after 60 min of exposure to heatwaves. The roof lower surface temperatures gained a decrease of 19.20 % when the roof structures were changed from Prototypes A to C. The initial roof's lower surface temperatures of Prototypes A and C were 30.1 °C and 30.5 °C, respectively. The increase of roof lower surface temperatures in Prototype A was 30.3 °C, while for Prototype C, it was lower at 18.3 °C. The differences in the increment of lower roof surface temperatures among these two prototypes was 12 °C, and their lower roof surface temperature increment rates were 0.505 °C/min and 0.305 °C/min, respectively.

One of the factors affecting the amount of heat attained at roof lower surface in the prototypes are their thermal conductivities. The thermal conductivity of the basic concrete roof was 2.0 W/m.K (Wu et al. 2017). For lightweight foam concrete roofs with densities 1300 and 1100 kg/m³, their thermal conductivities were 0.39 and 0.29 W/m.K, respectively (Cong & Chen, 2015). A huge drop of thermal conductivities from 2.0 to 0.39 W/m.K caused the roof lower surface heat gain to experience a decrease of 28.38 %. Further reduction of thermal conductivity values to 0.29 W/m.K had reduced the lower roof surface heat gain at a greater extend by 15.67 %. Thermal conductivity is explained as the quantity of heat transferred across the specimen with a constant specimen's distance between the planes and surface area ratio (Sengul et al. 2011). According to the definition, when the thermal conductivity of the specimen is lower, the heat transferred across the specimen to another plane is lesser.

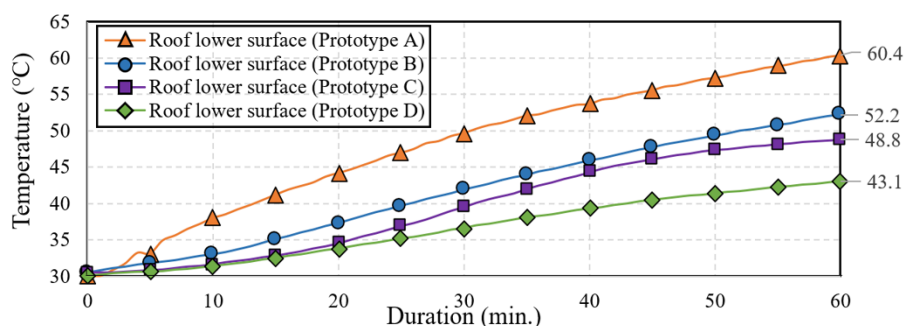


FIGURE 6. The roof lower surface temperatures

In addition, the temperature differences in upper and lower roof surfaces temperatures by the end of experiment for Prototypes A and C were 2.3 °C and 8.6 °C, respectively. The distance between the planes of concretes were fixed at 50 mm. Thus, their temperature gradients were 46 and 172 K/m, respectively. A higher temperature gradient indicated a higher thermal lagging effect as more thermal energies are opposed to flow through the lightweight foam concrete. The cellular microstructural roof is the main reason of its excellent thermal lagging effect (Ramamurthy et al., 2009).

The roof lower surface temperature can be decreased by 8 °C when a basic roof was upgraded to lightweight concrete roof with reflective coating (Wu et al. 2017). In Prototype D, the lower roof surface temperature achieved 43.1 °C, as in 12.7 °C cooler than the Prototype A. Besides the introduction of hollow longitude sections causes the higher reduction in lower roof surface temperature than the experiment studies in Wu et al. (2017), the higher efficiency of thermal reflective coating in the roof prototype is noticeable. Moreover, the heat gain attained at roof lower surface was observed to reduce by 57.10 %. A roof with reflective coating tends to have lower stored thermal energy owing to its lower temperatures in roof upper and lower surfaces (Revel et al. 2014).

The merging of a low thermal conductivity concrete and a high surface reflectance roof had brought down the lower roof surface temperature increment rate. From Prototypes A to D, the lower roof surface temperature increment rates were 0.505 °C/min and 0.271 °C/min, respectively. Thermal performance in roof lower surface equals to the thermal performance in building interior, accordingly, the low temperature increment rate represents the high performance of roof's thermal lag (Wu et al. 2017). Roof Prototype D is an appropriate cool roof structure due to its roof lower surface temperature trend and low increment rate that can lead to low building interior temperature and high thermal lagging.

BUILDING INTERIOR HEAT GAIN

The efficiency of the cool roof system that merged the lightweight foam concrete technology, hollow sections fabrication and reflective coating application was determined based on the building interior (attic model) heat gain. Table 1 shows the roof prototypes' attic thermal performances. The thermal performances of different cool roof systems in Prototypes B, C and D were compared with the conventional roof, Prototype A, the basic roof without the cool roof features.

TABLE 1. The attic thermal performances.

Roof	Features	Density (kg/m ³)	Final attic temperature (°C)	Average attic temperature (°C)	Standard deviation (°C)	Coefficient of variation (%)
A	Basic roof	2500	40.8	35.78	3.400	9.50
B	Lightweight foam concrete	1300	36.5	34.03	1.936	5.69
C	Lightweight foam concrete, hollow sections	1100	34.6	32.48	1.367	4.21
D	Lightweight foam concrete, hollow sections, reflective coating	1100	33.5	32.16	1.060	3.30

According to Table 1, it was noticeable that the thermal performance standard deviations in attic models experienced a huge decrease in Prototypes B than A, from 3.400 to 1.936. The standard deviation is defined as the extend of deviation from the average temperature. The standard deviation of roof prototypes decreased by 43.06 % when the lightweight foam concrete technology was introduced. The high standard deviation in Prototype A indicated its low roof thermal resistance that allowed a high amount of thermal energy passing through, whereby the attic received high amount of thermal energy that greatly changes its internal temperature. The modification of conventional concrete roof is necessary to create a cooler building interior temperature.

The lightweight foam concrete technology introduced in Prototype B showed the biggest drop of attic temperature standard deviation. The 80.5 % decrease in roofs thermal conductivities are the reason of its higher internal temperature preservation behaviour than Prototype A, as proven that the attic temperature deviated lesser from the average temperature. Prototype B with a lower density as a result of foaming process has lower heat transfer rate, as well as owns greater air content in its cement mass than the conventional concrete roof that allowed lesser heat penetrates the attic region (Alengaram et al. 2013).

Moreover, Prototype D with all the cool roof features had the lowest temperature deviation from the average value (1.060), best internal temperature preservation behaviour, and a coefficient of variation as low as 3.30 %. This proved the introduction of cool roof system produced a better thermal performances roof than the conventional roof. The introduction of hollow sections in concrete fabrication was recommended to increase the roof's thermal capacity (Zhang et al. 2014). Further, the reflective coating paint is appropriate to apply on almost any roof types (Tong et al. 2014). The differences in attic initial and final temperatures for Prototypes A, B, C and D were 10.4 °C, 6.1 °C, 4.2 °C and 3.1 °C, respectively. The reduction of internal heat gains when Prototype A was changed to Prototypes B, C and D were 41.35 %, 59.61 % and 70.19 %, respectively. The heat energy transferred across the roof body can decrease by 37 % with the increasing of roof surface reflectivity from 0.5 to 0.8 (Uemoto et al. 2010). The cool roof system that integrated not just the high solar reflectivity effect proven to have higher reduction in heat energy transferred (70.2 %) than the previous experimental study of researchers Uemoto et al. (2010). The accomplished high reduction of heat gain in internal space validated the efficiency of cool roof system that merged the several cool roof features for a high thermal lagging effect.

CONCLUSION

The paper provides the experimental study of a cool roof system that integrates lightweight foam concrete roof tile, hollow longitude sections and thermal reflective coating. When the densities of the concrete roof tiles reduced

from 2500 to 1100 kg/m³, the attic temperature of the roof prototypes decreased from 40.8 °C to 34.6 °C (15.2 % decrease). The temperature increment rate was also reduced by 36.95 % fabricating hollow longitude sections and lowering the lightweight foam concrete roof tiles densities from 1300 to 1100 kg/m³. A lower density roof achieved lower thermal conductivity. A lesser thermal wave was transmitted to the attic, which caused a reduction in the rate of attic temperature increment.

The efficiency of thermal reflective coating to reduce the roof thermal load that allowed lower heat penetrates the attic is proven. When the roof prototype was additionally applied with a thermal reflective coating, the attic temperature was further reduced to 33.5 °C. The attic temperature increment rate experienced a decrease of 70.2 % than basic roof with the abovementioned features. The roof lower surface heat gain was reduced by 57.10 % and the roof lower surface temperatures decreased from 60.4 °C to 43.1 °C when the cool roof system was integrated. Further, the attic temperature standard deviation performed 68.82 % lower from 3.400 to 1.060. The cool roof system in this study that combines the effect of high porosity concrete, insulation and high solar reflectance surface is proven to be effective in improving the roof's thermal optimization and providing a cooler internal space.

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DECLARATION OF COMPETING INTEREST

None

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