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Double Skin Bio-thermal Insulation with Radiation Reflector Cool Roof to Enhance Energy Efficiency and Indoor Comfort Conditions in Extreme Climates

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Abstract- Global warming in arid regions raises the indoor air temperature and increases energy utilisation of residential buildings. The development of effective passive cooling solutions is critical for reducing room air temperature and improving building energy efficiency. Numerous studies have analysed the impact of non-renewable and non-degradable thermal insulators on building thermal performance. There remains a conspicuous scarcity of research dedicated to harnessing the potential of naturally available and cost-effective bio-thermal insulators. This study aims to examine transformative potential of naturally abundant and renewable date palm tree leaves (DPL) as a thermal insulator on a cool roof. Additionally, the research delves into the benefits of integrating a bio-thermal insulator, derived from date palm tree leaves, with a double skin aluminium radiation reflector (ARR) within demanding climatic conditions of Oman during the scorching summer seasons. Furthermore, the study scrutinises the implications of dynamic air ventilation as an integral component of the cool roof system. As compared to a typical reinforced bare concrete roof, field experiments have clearly demonstrated that bio-thermal insulator cool roofs significantly reduced indoor and roof surface temperatures. The test results showed that the room air temperature of bio thermal insulator cool roof was reduced by 3.04 ºC (7.5%), 4.37 ºC (10.3%), and 6.01 ºC (16.3%) for air ventilation gaps of 0 cm, 20 cm, and 40 cm, respectively, between the date palm leaves and radiation reflector roof, when compared to a conventional reference roof. The corresponding decrease in roof surface temperature was measured to be 6.87 ºC, 12.25 ºC and 14.87 ºC, respectively. Studies on heat flux further elucidated that the bio-thermal insulator cool roof, with 40 cm of air ventilation, exhibited significantly reduced peaks in heat flux, boasting an average reduction of 16 W/m^2 compared to the reference roof. The experimental studies have conclusively demonstrated that the integration of a double skin bio-thermal radiation reflector in the cool roof effectively reduced both interior air and roof surface temperatures during the summer.

Keywords Aluminium Radiation reflector, Bio-thermal Insulation, Building energy consumption, Cooling load reduction, Double skin cool roof, Energy conservation.

1. Introduction

Oman's climate is characterised by a subtropical dry, hot environment with minimal annual rainfall and extraordinarily high summer temperatures. Typically, residential constructions stand as the primary causes for substantial energy consumption in the region. The extreme solar radiation necessitates the pervasive use of energy-intensive air conditioning systems throughout the year. Considering the depletion of oil resources and the subsequent rise in electricity prices, there is an urgent imperative to curtail energy consumption. Buildings are said to be the largest energy consumers, accounting for nearly half of global electricity use [1]. The escalating demand for costly mechanical air-conditioning systems is exacerbated in arid regions due to the heightened indoor and outdoor temperatures experienced by residential and commercial structures. Several studies provide an overview of Oman's electrical system, energy efficiency and investigates the potential for renewable energy adoption. [2-4].

The amount of newly constructed buildings that integrate energy efficient measures is quite modest when compared to existing buildings that were built without considering energy conservation measures, indicating a large potential in existing buildings to conserve energy [5]. Cool roofs offer a promising solution by mitigating excessive heat transfer into buildings, thereby reducing air conditioning costs. Researchers have previously explored the use of costly non-renewable artificial cool roofs to combat the heat infiltration. Presently there is a high demand for naturally abundant bio-thermal insulators to be employed in cool roof, driven by their environmentally friendly attributes.

Bio-thermal cool roofs hold the potential to improve human comfort while reducing energy consumption within buildings. To date, numerous attempts have been undertaken to mitigate indoor air temperature through the application of various cool roof technologies, encompassing both bio and non-biomaterials, radiation shields, reflectors, double skin roofs, and PCM roofs, among others. The novelty of this study lies in its exploration a cool roof system that employs naturally abundant date palm tree leaves as a bio-insulator, and it examines the effectiveness of integrating this bio-insulator with a double-skin radiation reflector within the arid climate of Oman.

Cool roofs using environmentally friendly biomaterials have gained increasing attention in recent studies. In their research, Kumar et al. [6] evaluated the benefits of utilising naturally abundant coconut fiber bio-composite as a cool roof system through field experiments conducted in Oman during the summer seasons. Their findings indicated a substantial reduction in both roof and room temperature. The room temperature and roof surface temperature experienced reductions of 5.99°C and 8.39°C, respectively. Alvarado et al. [7] delved into the exploration of energy efficiency of cool roof systems, using galvanized steel sheets and thin aluminium sheets as radiation reflectors. To minimize heat leakage in existing homes, the authors implemented a multi-material stacking technique.In comparison to the control prototype, the experimental study revealed a notable reduction in heat conduction, ranging from 65% to 88%.

It's worth noting that the heat response of passive cooling roofs is inherently slower than that of a conventional concrete slab. In a study conducted by R.S. Al-Juruf et al. [8], the heat conductivity of date palm leaves employed as a building thermal insulator was determined. When utilised as a thermal insulator, date palm leaves exhibit remarkably low thermal conductivity, as evidenced by test data, falling within the range of 0.122-0.210 W/m K. Additionally, research conducted by P. T. R. Swain et al. [9] highlights good thermal and mechanical properties of date palm leaf and glass fibre epoxy composites. The incorporation of varying proportions of date palm leaf led to a significant increase in both mechanical and thermal properties.

In a comparative study by Mintorogo et al. [10], utilizing coconut fibres as a heat insulator on the rooftop, a decrease in interior room temperature of 2.8-3.1°C was observed in contrast to a bare concrete roof slab. Several studies have been conducted to assess the thermal performance of cool roofs employing non-biomaterials. In the research conducted by V. Kumar et al. [11], a cool roof configuration was employed, comprising a radiation reflector, air ventilation, and a polystyrene thermal insulator, during the summer seasons in Oman. The experimental tests showed that, in comparison to a conventional roof, the utilisation of a double-skinned polystyrene-aluminium radiation reflector resulted in a maximum reduction of room air temperature by 4.7°C (equivalent to a 12.8% decrease) when employing 40 cm of air ventilation. M. A. Hamdan et al. [12] conducted tests involving four different models, each incorporating various cool roofing layers. These layers included glass pieces, clay, and white cement, selected as key components of the cool roof system.

Among the different cool roofs tested, the model featuring concrete covered with clay exhibited superior cooling performance. The capability of the clay model as a thermal insulator was found to be most effective when applied up to a thickness of 0.05 m. In the study conducted by Yadav et al. [13], all room walls were constructed using bricks and featured one door (0.5m x 0.4m) and one window (0.4m x 0.3m). The roofs were constructed using 100 mm thick RCC concrete slabs. Over the course of a month-long experiment, it was observed that the implementation of passive cooling measures yielded substantially lower room temperatures when compared to non-passive cooling methods.

According to Solorzano et al. [14], a perforated object featuring a 0.05 cavity provided active protection during the hot and humid season. Integration of radiation shields and reflectors has improved the thermal resistance of the cool roofs. X.Lu et al. [15] conducted research on passive radiative cooling throughout the entire day. They investigated the thermal efficiency of the system in cooling layer test configurations employing radiation reflectors. Effective optimisation approaches have significantly enhanced cooling capacity, leading to the adoption of various system models to validate different radiator cooling system designs. In the research by M. C. Yew et al. [16], a reduction in heat infiltration in commercial structures was demonstrated through the use of metal deck roofing. This study also elucidates the impacts of solar fans, reflective coatings, and cavity ventilation on building energy consumption.

The implementation of a solar reflector and a circulating air chamber equipped with solar-powered fans led to a remarkable maximum drop of 15°C in air temperature compared to a standard roof. Torgerson et al. [17] utilised a polyethylene mesh to show daylight radiative cooling while maintaining good infrared transparency. The polyethylene (PE) mesh, through the dispersion achieved via air holes, amplifies radiation reflection while simultaneously preserving its long-wave infrared transparency. The studies have revealed that beneath the solar screen, there exists an emissive surface capable of generating a cooling power exceeding 100 W/m^2. S.Kachkouch et al. [18] employed the following passive cooling techniques: thermal insulation, shading, and white painting.

Among these, the roof coated with white cement demonstrated the highest cooling efficiency when compared to the bare roof. Also, S.Y.Jeong et al. [19] designed and produced an extremely emissive prismatic structure using polydimethylsiloxane as a thermal reflector. The measured radiative cooling power reached 144 W/m^2, surpassing previous measurements, and resulted in a temperature drop of 6.2 ^{o}C in this analysis. Alvarado et al. [20] conducted research on various polymer roof insulation options, including polystyrene, polyurethane, and polyethylene. The experimental investigation also demonstrated the advantages of using these materials in combination with radiation shields, such as galvanized steel and aluminium. In a study conducted by Dora et al., [21], humidity and temperature sensors were placed at four locations along the perimeter of a double-skinned roof filled with glass wool insulation. The concrete exterior surface effectively reduced solar radiation by up to 85%, and the ventilation system demonstrated its effectiveness.

In addition to elucidating additional advantages, disadvantages, and providing recommendations for future research concerning cool roofs, M. Rawat et al., [22] investigated the energy consumption in buildings equipped with cool roofs featuring different surface coatings across diverse climate zones. The study findings reveal that, contingent on the climate zone, the median energy-saving benefits of these roofs range from 15.7% to 35.7%. Phase-changing materials (PCM) have emerged as a recent innovation used as a heat sink to reduce heat infiltration. In experiments conducted by Krishnan et al. [23], a roof model incorporating PCMs exhibited a remarkable temperature reduction of 5 ^{o}C compared to a basic model without any PCMs in the roof, on a typical sunny day.

The study demonstrated that both outdoor and indoor temperatures of the building experienced reductions when PCMs were applied under metal roofing. Zhang et al. [24] conducted a numerical analysis to evaluate the cooling capacity of roofing layers assisted by PCMs throughout the year in Daqing, China. The study reported energy savings of 14.08% during the summer and 33.74% during the winter. M. Kadri et al. [25], the focus was on examining how a double-skinned roof and thermo-reflective paint can effectively reduce indoor temperatures and energy consumption in a residence located in southern Algeria. Using TRNSYS software, they designed a system that incorporates a double-skin roof along with thermo-reflective paint. This model successfully lowered the operative interior temperature by 5 °C.

The review shows that the majority of the studies conducted thus far have focussed on assessing the effectiveness of non-renewable, non-degradable and expensive thermal insulators to improving building thermal performance, consequently leading to reductions in air-conditioning costs.

There is a noticeable dearth of adequate studies aimed at investigating the utilisation of naturally available bio-thermal insulators and their impact on the thermal performance of roofs. These bio-thermal insulators offer significant advantages as they are cost-effective, biodegradable, and renewable, making them a promising avenue for further research in enhancing building thermal efficiency. The novelty of the current study lies in its exploration of a cool roof system that incorporates naturally abundant date palm tree leaves as a bio insulator, as well as the evaluation of the effectiveness of integrating this bio-insulator with a double-skin radiation reflector within the arid climate of Oman.

2. Methodology and Experimental Design

In the study, a conventional Reinforced Cement Concrete (RCC) slab with a thickness of 20 cm was utilised as the roofing material for two identical rooms, each measuring 160 cm x 160 cm x 230 cm. One of these rooms was equipped with a roof covered in date palm leaves and featured an Aluminium Radiation Reflector (ARR) on top, while the other room, as depicted in Fig.1, served as the traditional reference roof.

Fig. 1. Identical test rooms.

A specific frame was employed, allowing for the adjustment of the aluminium reflector's positioning, thereby enabling the modification of air ventilation between the date palm leaves and the ARR within a range of 0 to 40 cm. In contrast, the other test room featured a traditional bare reference roof comprising a 20 cm thick reinforced cement concrete slab. The date palm tree leaves utilised in the experiment are depicted in Fig.2.

Fig. 2. Date palm leaves for experimentation.

The assessment of thermal resistance for a double-skinned date palm leaf-ARR roof was conducted in two symmetrical test rooms. To prevent heat infiltration through the walls, both rooms had their inner walls insulated with a 5 cm thick layer of polystyrene foam, possessing a thermal conductivity (k value) of 0.035 W/m K. The layout of the test rooms was designed to ensure that shading did not overlap. The study was conducted in Sohar, Oman, during the hot month of May, at coordinates latitude 24°21′0.79″N and longitude 56°42′27.54″E. The cost estimation for the bio-thermal insulator (palm tree leaves) integrated with the ARR cool roof amounted to $2 per square foot.

In solid parts (palm tree leaves and concrete slab), heat transfers were dominated by conduction. The conduction heat transmission within the solid concrete slab and date palm leaves was governed by the following differential equation:

$$\rho C_p \frac{DT}{Dt} = k\Delta T \quad (1)$$

The ARR experiences convective and radiation heat transfer from both sides, whereas conduction must be considered within the radiation reflector. Due to convective heat flux between the exterior air and the metal reflector's surface and solar radiation, heat is transferred through the exterior surface of the ARR. The heat transfer via the ARR's outer surface results in,

$$-k_r \frac{\partial T}{\partial y} = h_o(T_0 - T_R) + \varepsilon\sigma\left(T_{sky}^4 - T_R^4\right) + \alpha_r E(t) \quad (2)$$

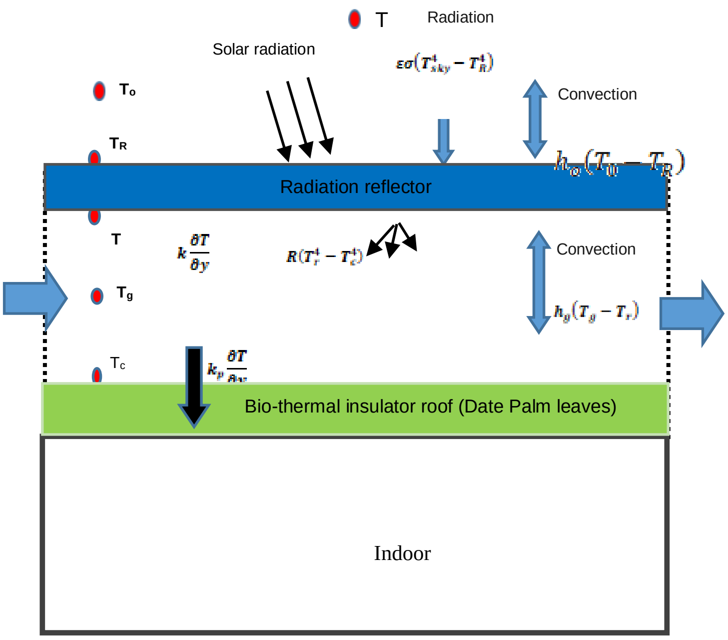


Fig. 3. Heat fluxes in a cool roof room.

Under the ARR, long wave solar radiation as well as the impacts of convective heat flow between the inside surface of the metal reflector and vented air must be taken into account. Figure 3 depicts the heat flows in a double skin date palm leaves-ARR roof.

$$-k_r \frac{\partial T}{\partial y} = h_o(T_0 - T_R) + \varepsilon\sigma\left(T_{sky}^4 - T_R^4\right) + \alpha_r E(t) \quad (3)$$

Figure 4 shows the test set- up design. The heat conduction through the concrete roof is lowered by the date palm leaves fastened to the roof. To improve convective heat flux and analyse the role of dynamic air in the air ventilation, an air gap of 0, 20 and 40 cm was created between the date palm leaves and ARR.

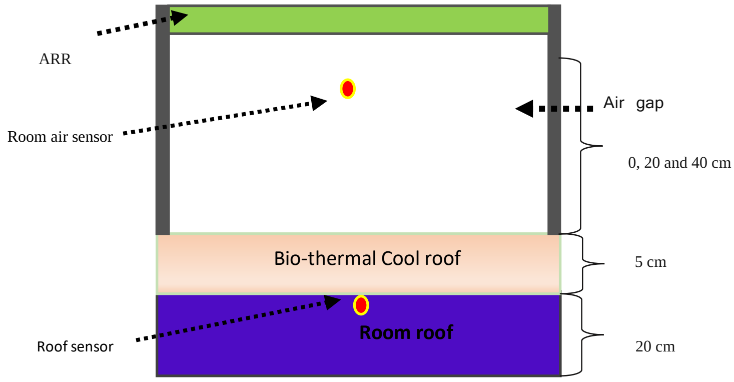


Fig. 4. Schematic diagram of experimental set-up.

A computer-assisted data acquisition system (Fig.5) was employed to record room temperature data for both the conventional and bio-thermal insulator-cooled rooms over a four-day period.

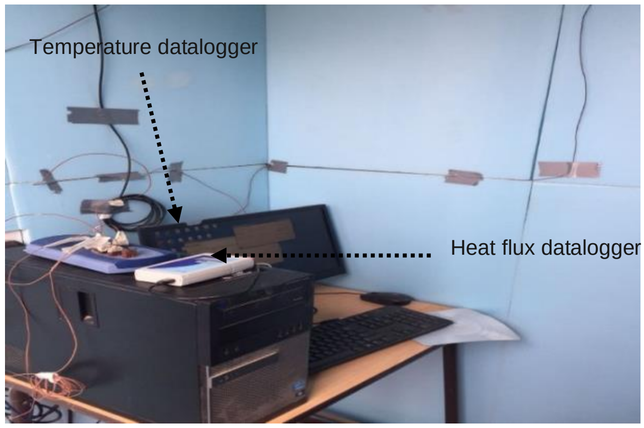


Fig. 5. Data acquisition system.

Figure 6 illustrates the experimental setup, featuring bio-thermal insulator (date palm leaves)–ARR roofs with a 40 cm ventilated air gap.

ARR

Fig. 6. Palm tree leaves –ARR roof

Table 1 provides an overview of the various layers comprising the cool roof and their respective characteristics. Temperature data recording was conducted continuously using a temperature data recorder (TC08) and Type T thermocouples for each 5-minute interval, recording both room air and roof surface temperatures. The properties of thermocouples and data loggers are shown in Table 2.

Table 1. Layers of Cool Roof

Layers	Thickness (cm)	Thermal conductivity (W/m K)
Radiation reflector (Aluminium)	0.2	221
Date palm leaves	5	0.166
Air gap	0,20,40	26
Standard concrete slab	20	1.7
Polystyrene Foam	5	0.035

Table 2. Temperature Data logger Characteristics

Model	TC08
Number of Channels	10
Sampling Rate	10S/s
Range	–270 to +1820 °C
Resolution	0.025ºC
Temperature accuracy	±O.2% of reading and ±0.5ºC
Voltage accuracy	±O.2% of reading and ±10µV
Thermcouple	Type T
Sensitivity of Thermocouples	40 µV/°C

The experiment was conducted in three stages. In the first stage, solely the bio-thermal insulator (palm tree leaves) was employed as the cool roof. In the second and third stages, the bio-thermal insulator was integrated with ARR, featuring a dynamic air ventilation gap of 20 cm and 40 cm between them. This integration aimed to enhance convective heat transfer and analyse the effect of dynamic air circulation on the heat flux to the building envelope.

3. Results

3.1 Room air temperature

3.1.1 Zero Air Ventilation

As depicted in Fig.7, there is a notable difference in indoor temperature between the conventional and bio-thermal cool roofs. The temperature profile indicates that the date palm leaves-ARR cool roof exhibits fewer thermal gradients compared to the reference roof. The temperature reduction trend was consistent in both test rooms. Without any air ventilation, the bio-thermal cool roof exhibited a maximum temperature drop, reaching 37.56°C, in contrast to the reference roof at 40.6°C (Fig.8). This reduction is attributed to decreased heat conduction through the date palm leaf insulator and the high solar albedo of the cool roof.

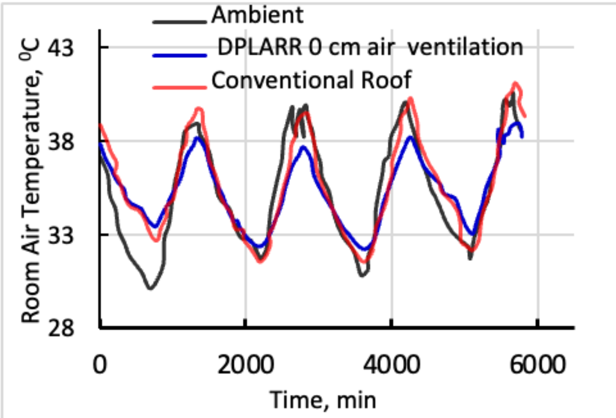


Fig. 7. Indoor air temperature profile

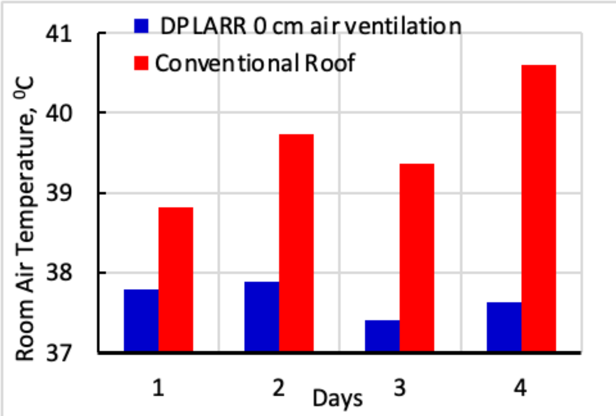


Fig. 8. Maximum difference in Indoor air temperature

3.1.2 Air Ventilation = 20 cm

In the second phase of the experiment, the air ventilation between ARR and the date palm leaves was increased to 20 cm to investigate the impact of dynamic air gap on the heat transfer process. As shown in Fig.9, the bio-thermal cool roof exhibits a significantly lower temperature pattern compared to a conventional bare room.

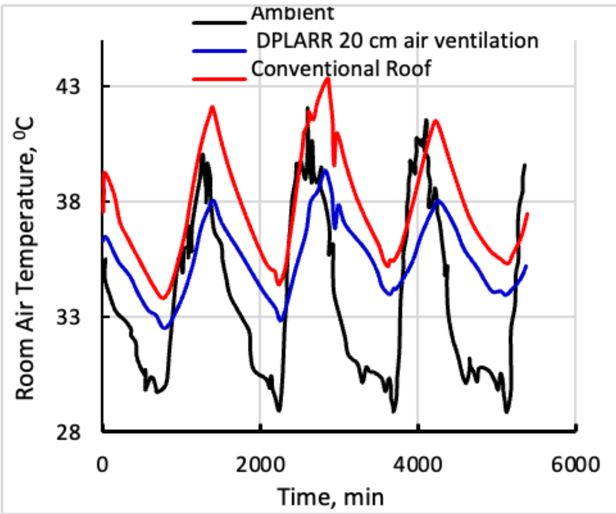


Fig. 9. Indoor air temperature profile

When compared to the typical reference roof depicted in Fig.10, the bio-thermal cool roof achieved a maximum reduction of 4.37°C in temperature. Due to this substantial temperature differential, the reference roof reached 42.33°C, while the bio-thermal cool roof registered a lower temperature of 37.96°C. This observation also highlights the role of air ventilation as a thermal barrier, effectively reducing heat flux into the room. The introduction of dynamic air ventilation of 20 cm further contributed to the reduction of indoor temperature, primarily due to convective heat flux. The dynamic air ventilation serves to enhance thermal resistance and functions as an effective thermal barrier.

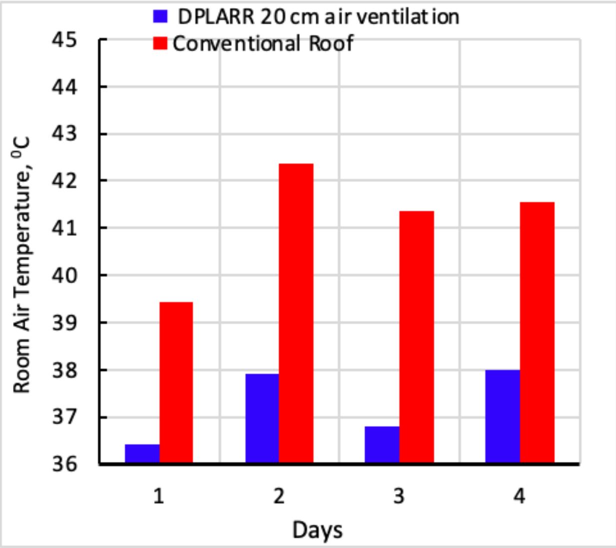


Fig. 10. Maximum difference in Indoor air temperature

3.1.3 Air Ventilation = 40 cm

In the final stage of the experiment, the air gap between the bio-thermal (date palm leaves) and the ARR was increased from 20 cm to 40 cm. This adjustment aimed to investigate the influence of dynamic air ventilation on the thermal resistance of the cool roof.

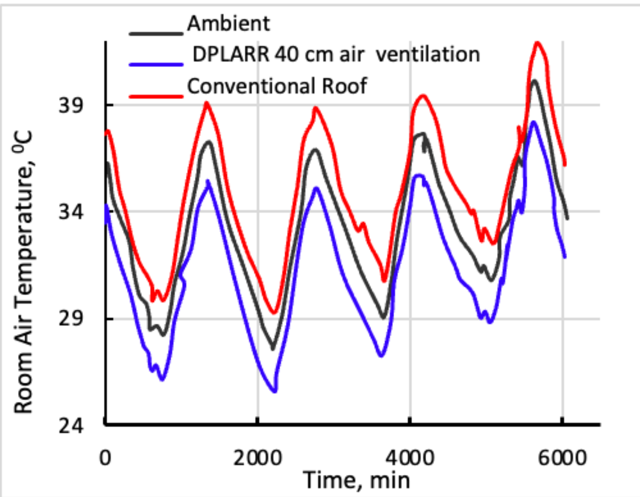


Fig. 11. Indoor air temperature profile

The bio-thermal cool roof exhibits significantly lower temperature peaks compared to a standard reference room as shown in Fig.11. This clearly indicates that the temperature within the room equipped with the cool roof room was considerably lower than that of a traditional roof room. The bio-thermal cool roof achieved the highest reduction in temperature, with a decrease of 6.01 °C when compared to the conventional roof (Fig.12). The conventional and bio-thermal cool roofs reached 36.77°C and 30.76°C, respectively, representing this maximum temperature difference. The notable temperature reduction is a direct result of the superior thermal resistance of the bio-thermal cool roof. This enhanced thermal resistance can be attributed to a reduction in heat conduction through bio-thermal insulator, increased albedo in ARR, and enhanced convective heat transfer facilitated by the dynamic air ventilation (40 cm).

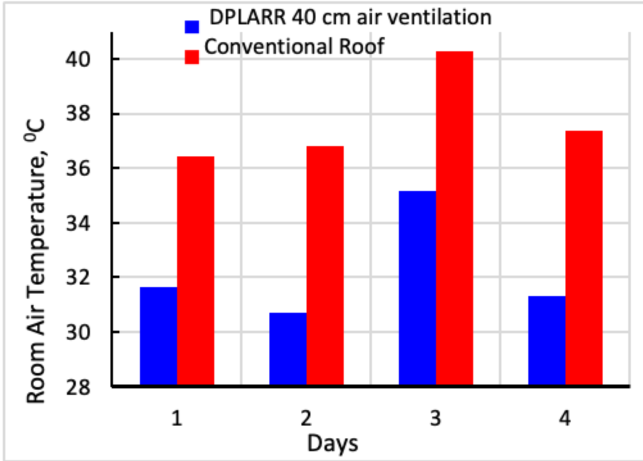


Fig. 12. Maximum difference in Indoor air temperature

3.2 Roof Surface temperature

3.2.1 Zero Air Ventilation

The results showed that the bio-thermal cool roof exhibits a more substantial reduction in roof surface temperature compared to conventional roof, as illustrated in Fig.13.

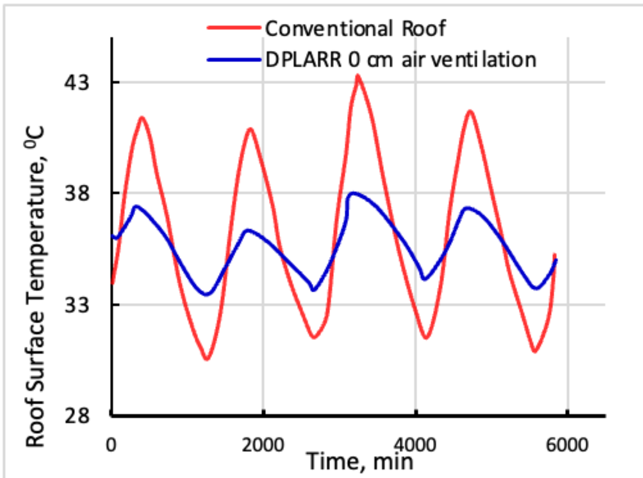


Fig. 13. Roof surface temperature profile

The temperature profile for the cool roof is significantly lower than that of a conventional bare roof. As illustrated in Fig.14, a maximum temperature difference of 6.87ºC was observed between the bio-thermal cool roof and the conventional roof. Due to this substantial temperature differential, the reference roof reached a temperature of 43.16ºC, while the cool roof maintained a significantly lower temperature of 36.29ºC, respectively. This provides a quantitative evaluation of the cool roof's thermal performance compared to bare roofs during the summer seasons. The combination of bio-thermal insulation and the long-wavelength reflection of ARR resulted in a noticeable decrease in roof surface temperature.

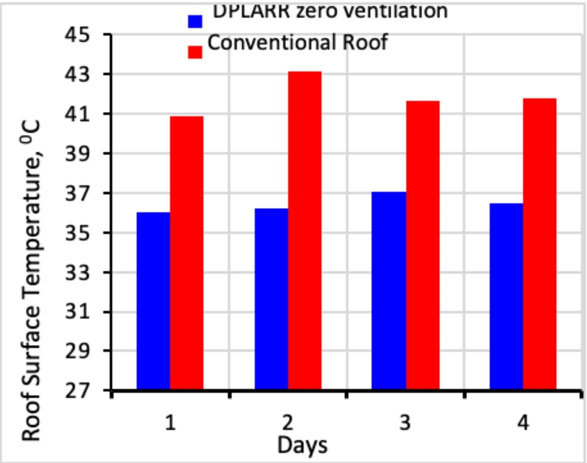


Fig. 14. Maximum difference in Roof surface temperature

3.2.2 Air ventilation = 20 cm

In contrast to the reference roof, the roof surface temperature of bio-thermal cool roof exhibited a maximum reduction of 12.25ºC, as shown in Fig.15.

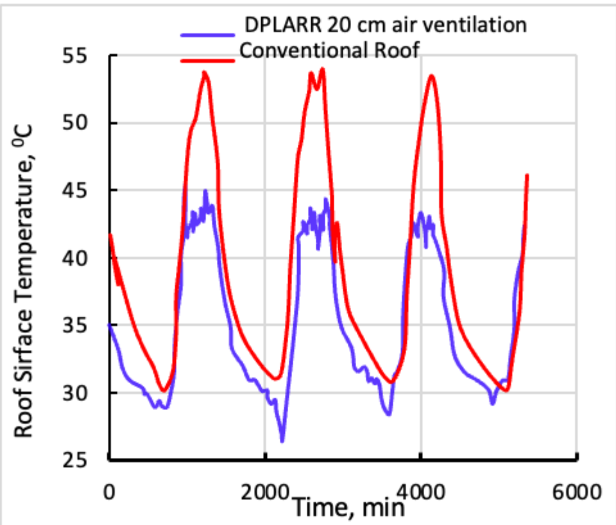


Fig. 15. Roof surface temperature profile

Specifically, the reference roof and the cool roof reached temperatures of 53.1°C and 40.85°C, respectively, representing this substantial temperature difference (Fig.16). The temperature reduction of the roof slab in the cool roof increased from 6.87ºC to 12.25ºC when the air ventilation was increased from 0 to 20 cm. This enhancement can be attributed to the increased convective heat flux facilitated by the presence of dynamic air circulation.

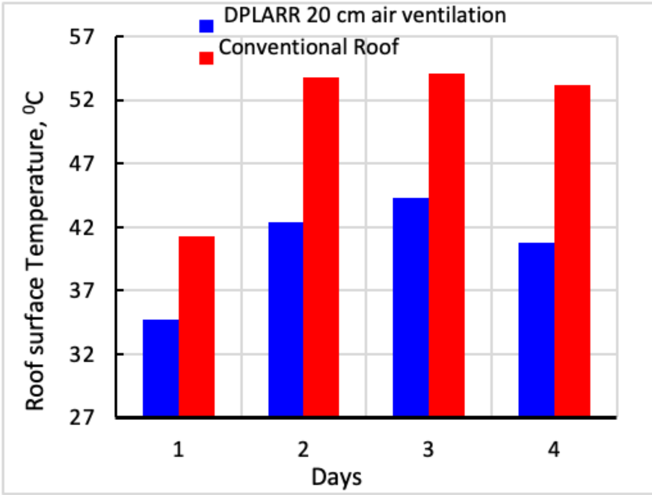
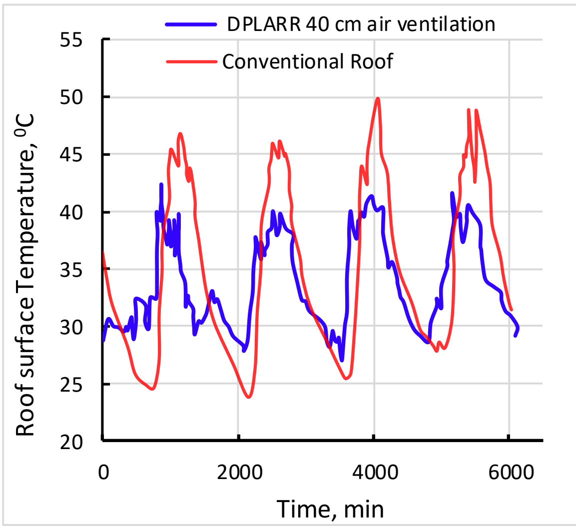


Fig. 16. Maximum difference in Roof surface temperature

3.2.3 Air ventilation = 40 cm

The bio-thermal insulator–ARR cool roof achieved an additional in its roof surface temperature, decreasing from 12.25ºC to 14.87ºC, as the air ventilation was increased from 20 cm to 40 cm. Figure 17 illustrates that the cool roof maintains a significantly lower roof temperature profile compared to a standard bare roof, which aligns with findings.

Fig. 17. Roof surface temperature profile



The maximum temperature difference observed was 14.87ºC, as depicted in Fig.18. For this significant temperature difference, the reference and cool roofs registered temperatures of 43.89ºC and 29.02ºC, respectively. The decrease in the temperature of cool roof when the air ventilation was increased to 40 cm can be attributed to the dynamic nature of air within in the ventilated space, which led to an enhancement in convective heat flux.

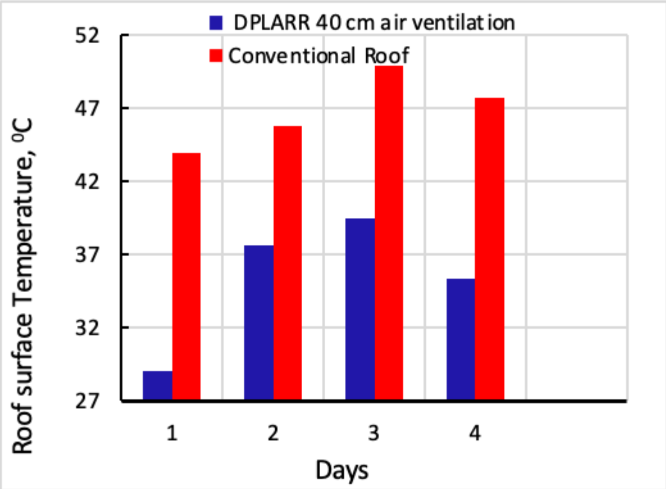


Fig. 18. Maximum difference in Roof surface temperature

3.3 Heat Flux Studies

In contrast to a reference roof, the heat flux studies showed that the bio-thermal cool roof exhibited considerably reduced peak heat flux, as illustrated in Fig.19, 20 and 21.

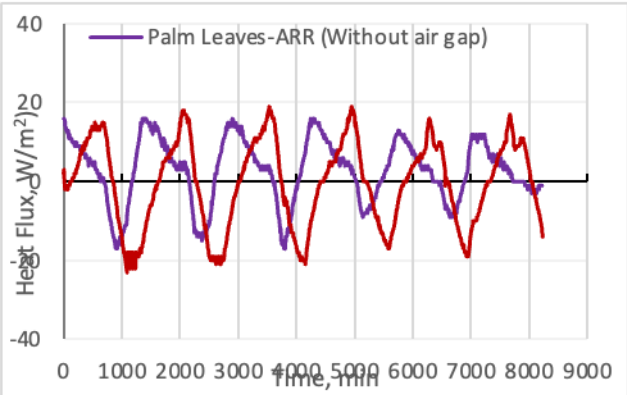


Fig. 19. Heat Flux Studies (Air ventilation=0 cm)

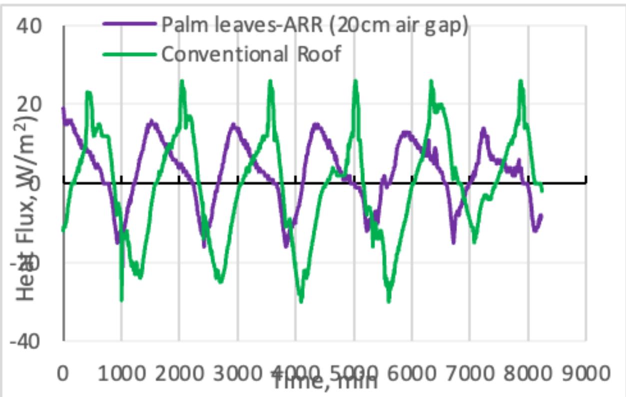


Fig. 20. Heat Flux Studies (Air ventilation=20 cm)

The bio-thermal cool roof with a 40 cm air ventilation was observed to reduce heat flux by a maximum of 16 W/m^2 when compared to the reference roof. This reduction in heat flux can primarily be attributed to several factors: a decrease in heat conduction through bio-thermal insulator, increased longwave radiation reflection within the ARR, and enhanced convective current of the dynamic air ventilation (40 cm).

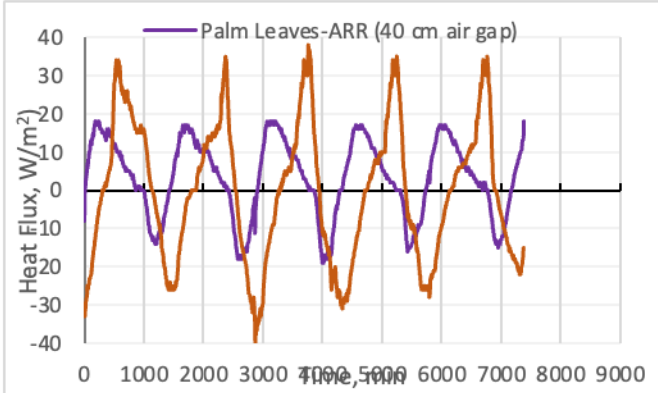


Fig. 21. Heat Flux Studies (Air ventilation=40 cm)

4. Discussions

The study assessed the effectiveness of utilising naturally abundant date palm leaves as a bio-thermal insulator and evaluated the influence of convective cooling resulting from dynamic air movement between the date palm leaves and the ARR within a double-skin cool roof. These findings were then compared to those of a conventional bare roof. Research has indicated that a bio-thermal cool roof, when compared to a conventional roof, not only reduces temperature peaks but also minimises diurnal heat fluctuations. The most significant difference was observed around 3 p.m., and the studies have demonstrated a significant reduction in heat influx through the roof. The studies have clearly shown that the bio-thermal insulator significantly reduced the heat conduction through the roofs. The presence of dynamic air ventilation and the ARR further contributed to reduction in both indoor air and roof surface temperatures, primarily due to the increased convective heat flux and high solar albedo, respectively. These findings illustrate that the bio-thermal insulator (date palm leaves), the dynamic air gap situated between the bio-thermal insulator and the ARR, and the effective longwave reflection of the ARR collectively contributed to an enhancement in the overall thermal resistance of the cool roof structure. Bio-thermal cool roofs act as a shield, protecting the roof structure from extreme temperature fluctuations. The primary factors responsible for the reduced heat flux and temperature in the cool roof include the bio-thermal insulator (date palm tree leaves), the high thermal resistance within the dynamic air ventilation gap between the bio-thermal insulator and the ARR, and the high albedo exhibited by the ARR.

5. Conclusions

The current research investigates the cooling potential of a double skin bio-thermal cool roof and the effect of dynamic air ventilation during the scorching summer months in Oman. It is important to note that the heat response of the studied cool roof is significantly slower than that of a typical concrete roof. In comparison to a bare roof, it was observed that the bio-thermal cool roof achieved a maximum drop of 3.04ºC and 6.87ºC in room air and roof surface temperatures when no air ventilation was employed. However, with 20 cm and 40 cm dynamic ventilated air gaps, the reduction in indoor air temperature of the bio-thermal cool roof increased to 4.37°C and 6.01°C, respectively. The respective decrease in roof surface temperature was measured to be 12.25ºC and 14.87ºC, respectively, with the largest indoor air temperature reduction in indoor air temperature achieved using double skin bio-thermal cool roof with 40 cm air ventilation. Furthermore, the heat flux experiments demonstrated that the bio-thermal insulator cool roof with a 40 cm vented air gap exhibited significantly lower peaks in heat flux compared to the reference roof, resulting in an average reduction of 16 W/m^2.

This research underscores the significant impact of a bio-thermal insulator combined with dynamic air ventilation in reducing heat conduction while simultaneously enhancing convective heat flux and, consequently, the thermal resistance of the roof. Additionally, the study highlights that increasing air ventilation and high albedo exhibited by the ARR have a substantial effect on reducing indoor and roof surface temperatures. The temperature fluctuations within the cool roofing are notably reduced when all three types of heat influx are minimised. In countries like Oman, characterised by a hot and humid climate and an abundant supply of date palm tree leaves, the implementation of double skin bio-thermal insulator cool roofs leads to a substantial reduction in both indoor and roof surface temperatures. However, it is essential to assess the effectiveness of this type of roof in areas with severe or prolonged winters, where heating energy demand is significant.

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