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Digital Object Identifier:
 Received 13 July 2025,
 Accepted 24 August 2025,
 Available online 25 January 2026

Field Experimental Study of the Effect of Cool Roof Coating on Indoor Air Temperature in a Typical Concrete Building in Hadhramout, Yemen

Mohammed Salem Bakhlah*, Mansoor Mohammed Binthabet and Adel Abdullah Almualllem

Department of Architecture and environmental planning, Hadhramout University, Mukalla, Yemen

*Corresponding author: bakhlah@hu.edu.ye

This is an open-access article under production of [Hadhramout University Journal of Natural & Applied Science](#) with eISSN 2790-7201

Abstract Roof heat gain is a crucial factor in determining a buildings thermal performance. However, strategies aimed at minimizing this heat gain—both during construction and in post-construction retrofitting—are frequently limited or inadequately addressed. This study examines the effect of a cool roof coating on the indoor thermal conditions of a typical concrete residential building located in Hadhramout, Yemen. Despite the growing global interest in passive cooling technologies, no prior research has evaluated the effectiveness of cool roof coatings in this specific regional and climatic context, nor has the extent of indoor air temperature reduction resulting from such an intervention been empirically established. In-situ measurements were conducted through a field survey involving two adjacent rooms of identical design, condition and specifications. The measured parameters included indoor and ambient air temperatures, in addition to indoor and outdoor roof surface temperatures, both before and after the application of the cool roof coating. Data were collected during the peak thermal stress months of July and August. The results revealed that the application of the cool roof coating led to a decrease in indoor air temperature ranging from 0.1°C to 2.4°C. Moreover, indoor surface temperatures decreased by approximately 1.2°C to 5.4°C, while the outdoor roof surface temperature exhibited a marked reduction of up to 15.9°C at midday. These findings provide empirical evidence supporting the efficacy of cool roof coatings as a viable passive cooling strategy for improving indoor thermal condition in concrete buildings situated in hot-humid climates.

Keywords: Coating, Cool roof, Solar reflective, Surface temperature

1. Introduction

In residential buildings, a significant portion of energy consumption, as well as indoor thermal discomfort, can be attributed to thermal transfer across the building envelope. In hot and humid climates, nearly all buildings require cooling systems, and the majority rely on active cooling methods. The roof, being the most exposed element of the building envelope, absorbs substantial solar radiation and consequently becomes the hottest component. The thermal performance of a building is critically influenced by the solar absorptance of its roof surface [1]. Roof heat gain is a major contributor to reduced comfort levels in non-air-conditioned buildings and leads to increased cooling loads in those that are air-conditioned [2]. However, this study

research objective was to examine the effect of cool roof coating on indoor and outdoor surface temperatures and indoor air temperature.

Givoni [3] demonstrated that the color of walls and roofs significantly affects indoor air temperature. Additionally, thermal energy flow through the roof is directly proportional to the temperature differential between inside and outside surfaces [4]. Among passive design strategies, controlling solar radiation—particularly during summer—is considered one of the most effective approaches. The surface temperature of roofing materials can exceed ambient air temperature by as much as 30°C, emphasizing the critical role that roof materials play in solar heat control [5]. Baniassadi, et al. [6] conducted

research to quantifies the potential advantages of using newly developed supercool materials to building rooftops. the results indicate that, across various climates, the rooftop surface temperature stays lower than the ambient air temperature for most of the time, yielding significant cooling benefits.

In hot and humid climates, roofs account for approximately 50% to 60% of the total cooling load in buildings [7]. Numerous studies have examined the thermal performance of several roofing materials under different climatic conditions [8,9,10,11]. Globally, a growing body of research emphasizes that improving the design of the building envelope is among the most effective strategies for reducing energy consumption and enhancing indoor thermal performance [5,12,13,14,15].

Within this context, cool roofs have emerged as a widely adopted passive cooling solution capable of significantly reducing energy requirements for air conditioning systems [1,16]. In the case of Hadramout, Bakarmom [17] explored passive cooling techniques employed in traditional architecture; however, the study did not investigate the application of solar reflective coating for roofs as a thermal mitigation measure. Yew, et al. [18] conducted an experimental evaluation of both active and passive cool roof systems, employing a thermal reflective coating (TRC). Their findings demonstrated that TRC effectively reduced attic temperatures, thereby offering potential energy savings and improvements in indoor comfort. Furthermore, Givoni [19] discussed the role of radiant cooling, particularly heat loss through longwave radiation emitted toward the sky, as a fundamental mechanism in passive cooling strategies. These insights collectively underscore the importance of roof design and material selection in enhancing thermal performance in hot-humid regions.

The term cool roof refers to a type of roofing system specifically designed to reflect a greater amount of sunlight and to emit absorbed heat more efficiently than conventional roofing materials. This dual function results in lower surface temperatures and a substantial decrease in heat absorbed by the roof [20,21,22,23,24,25]. According to U.S. Department of Energy [26] a cool roof is defined as one that reflects more sunlight and absorbs less solar energy than a conventional roof. Cool roofing materials typically exhibit high solar reflectance and high infrared emittance, allowing them to remain relatively cool even under direct solar exposure. These properties enable the roof to emit accumulated solar energy back to the sky, particularly during nighttime, thereby reducing surface temperatures. As a result, less thermal energy is transmitted into the interior of the building, which contributes to enhanced indoor thermal comfort and reduced cooling energy demand [5,16,27]. Pisello, et al. [28] conducted and discussed experimental laboratory and field analysis of water-resistance membranes for cool roof technology application. A comprehensive study conducted by Synnefa, et al. [29] evaluated fourteen different types of roof reflective coating materials, highlighting the superior performance of white-colored coatings. These coatings significantly reduced surface temperatures during peak summer conditions, with

daytime roof temperatures only 2°C higher than the ambient air, and nighttime temperatures approximately 6°C lower. The study concluded that roof surface temperatures decrease with increasing emissivity and reflectance of the coating materials. Xing-guo, et al. [30] carried out a study to evaluate the thermal performance of a new reflective coating. One room south wall was coated with the reflective surface, while the other room remained unpainted. The findings indicated that the room with the reflective surface had a lower indoor air temperature than the uncoated room, the maximum temperature difference was 4.3°C.

In a subsequent study, Synnefa, et al. [31] examined the influence of cool coatings on energy consumption and indoor thermal comfort. The findings indicated that high solar reflectance of roof surfaces could decrease cooling loads by 8 to 48 kWh/m². Additionally, cool roof applications were associated with a decrease in discomfort hours and a reduction in indoor air temperature. The study emphasized that climate conditions and the U-value (thermal transmittance) of the roof are the two primary factors affecting energy use in residential buildings. Rawat & Singh [32] carried out a study to explore the effect of thermal adaptation and roof coatings on thermal comfort in non-conditioned building, the research evaluates the performance of three commercially available reflective paints/ coatings on reducing heat gain and improving thermal comfort. These findings demonstrated that cool roof coatings significantly reduce the discomfort, and can increase comfort hours by 12-17 hours compared to conventional roofs.

Similarly, Gao et al. [33] conducted a comparative analysis between black and white roofs, revealing that the use of white roofs can decrease annual energy consumption by 3.9 kWh/m²—approximately 1.6 times greater than the energy savings achieved by sedum-tray green roofs. According to the results, the study recommended implementing white roofs as the more effective energy-saving solution. research conducted by Xue, et al [34] introduced a new cool reflective white roof coating utilizing styrene-acrylate copolymer and cement, the study revealed that this coating exhibits significantly higher solar reflectance, resulting in a significant reduction in surface temperature. Pal, et al. [35] conducted a study to evaluate the impact of using light colour on buildings to improve thermal comfort and reduce energy consumption. The results show that light colour, particularly white and yellow, reduce heat gain and lower indoor air temperature. The study revealed that building with white and yellow colours are more comfortable and environmentally friendly. Suehrcke, et al. [36] investigated the impact of roof solar reflectance in hot climate conditions and found that light-colored roofs can reduce heat gain with about 30% in comparison to dark-colored ones. Under clear sky conditions, between 20% and 95% of the incident solar radiation is generally absorbed at the roof surface. Their simulation results further suggested that replacing a colored galvanized roof with a white surface could reduce heat flow through the roof by approximately 60%. Similarly, Ashhar & Haw [37] reported that the application of reflective cool roof coatings lowered the demand for mechanical cooling

by approximately 19%. Numerous studies have examined various aspects of roof material reflectivity and its associated energy-saving benefits [38,39,40,41,42,43,44,45,46]. Quezada et al. [39] undertook a comprehensive investigation combining empirical measurements and simulations to assess the impact of modifying the solar reflectance and thermal emittance of metal and concrete roofs in warm and humid climates. Their findings demonstrated that metal roofs with reflectivity and emissivity values around 0.70 exhibited lower surface temperatures compared to concrete roofs. Furthermore, the study highlighted that high thermal mass roofing materials, such as concrete, tend to have a less favourable impact on thermal performance when compared to metal roofs, particularly in hot and humid environments. In the context of hot and humid climates, Kolokotroni et al. [45] found that the implementation of cool roof coatings resulted in an average reduction of approximately 6.8°C in indoor surface temperature and 2.3°C in indoor air temperature. These findings underscore the efficiency of cool roof technologies in improving thermal condition and reducing energy consumption in warm climate zones. An experimental study conducted by Zinzi and Fasano [47] examined the influence of cool roof on indoor air temperatures by evaluation the properties and performance of reflective coatings. The findings revealed a significant reduction in both indoor air temperature and cooling loads,

indicating the effectiveness of reflective coatings in improving thermal comfort. Similarly, Nie et al. [48] conducted a related study.

However, there is a notable lack of research evaluating the effectiveness of cool roof coatings in improving indoor thermal conditions in buildings located in hot and humid regions, particularly in the context of Hadhramout, Yemen. No prior studies have empirically established the extent of indoor air temperature reduction resulting from the application of cool roof coatings in this specific regional and climatic context. This study aims to address this research gap by investigating the impact of cool roof coating on the indoor thermal conditions of a typical residential building in Hadhramout, Yemen.

2. Methodology

2.1 Making limewash

Lime is traditionally produced by calcining limestone (calcium carbonate, CaCO_3) in specialized kilns, resulting in the formation of quicklime (calcium oxide, CaO). The subsequent addition of water to quicklime initiates a slaking process, yielding calcium hydroxide (Ca(OH)_2), commonly referred to as whitewash [49,50]. The density of the resulting lime mixture can be regulated by varying the proportion of water incorporated during the slaking process (see Figure 1).



Figure 1. A collection of photographs illustrates the preparation of whitewash, depicting the slaked quicklime both before and after its dissolution in water

According to Mold and Godbey [49] limewash offers several advantages that contribute to its widespread use as a coating material, including:

- The availability of raw materials
- Easy access to sources of these materials
- Simplicity of application, which does not require skilled labor
- Affordability compared to alternative finishing materials
- Aesthetic appeal coupled with ease of maintenance
- Stability and long-lasting durability

Since ancient times, the people of Hadhramout have employed limewash as a finishing material for plastering and painting both external and internal walls, as well as roofs. Over the centuries, the Hadhramis have developed practical experience in improving and moderating indoor thermal conditions through the application of whitewash on

roofs and walls. Notably, limewash exhibits properties characteristic of cool materials, such as reflecting solar radiation, reducing heat absorption, and maintaining a cooler surface temperature under direct sunlight.

2.2 Building description and experimental setup

The selected case study is situated in a region where the prevailing hot-and-humid climate poses significant challenges to achieving indoor thermal comfort, resulting in a high demand for cooling energy. The site is located within a newly developed urban area characterized by a grid layout and surrounded by low-rise buildings. This case study represents a typical residential building commonly found in Hadhramout, Yemen, and was chosen to evaluate the effectiveness of cool roof coating in enhancing indoor thermal conditions.

The building under investigation is a two-storey concrete house located in Mukalla city. The roof exhibits the natural gray color of reinforced concrete. The house comprises two flats; each containing six rooms (see Figure 2). The external walls are constructed from hollow clay blocks approximately 20 cm thick, while the internal walls consist of hollow concrete blocks of similar thickness. The roof is a flat structure made of hollow clay floor slabs with an average thickness of approximately 30 cm (see Figure 3).

For the experimental study, one room oriented towards the southeast was selected. This room has an area of 20 m² and includes windows with a total area of 2.6 m², featuring two-pane single-glass windows framed in aluminum, located on the southeast-facing wall. Two layers of cool coating—commonly referred to as whitewash—were applied to the roof to achieve a clear white finish (see Figure 4). Prior to application, the coating mixture was carefully filtered to remove any solid particles, ensuring a smooth consistency.

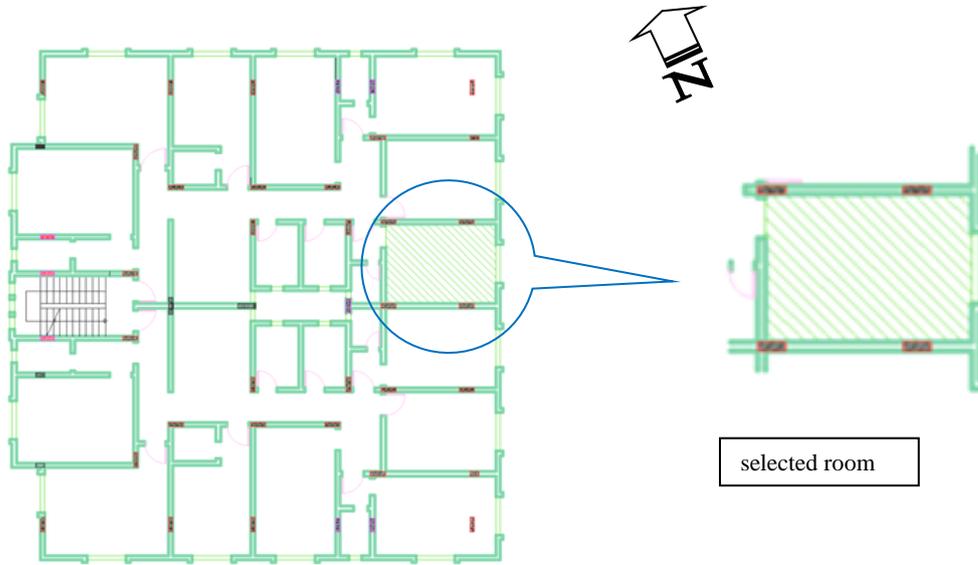


Figure 2. Building layout indicate the location of selected room for the study



Figure 3. Photo shows external wall material



Figure 4. Photos show roof before and after painted

2.3 Data collection

The survey was conducted over the period from 22th July to 3rd August, chosen specifically as it corresponds to the peak of the hottest season of the year, when the impact of direct solar radiation on roof surface temperature and indoor air temperature is expected to be most pronounced. Data were collected both indoors and outdoors within the selected room to assess thermal conditions comprehensively. Measurements included ambient air temperature, indoor air temperature, inside roof surface temperature, and outside roof surface temperature. These parameters were recorded continuously over 13 consecutive days at one-hour intervals. Comparative analyses were performed between the coated and uncoated roof conditions to evaluate the effect of the cool coating (whitewash).

Indoor air temperature measurements were taken at a height of 110 cm above the floor using an EXTECH 45160 3-in-1 Thermo-Hygro-Anemometer. Outdoor air temperature was measured by a separate sensor connected to a CENTER 342 Temperature Humidity Recorder, placed under shaded conditions at 250 cm above ground level. Surface temperatures were recorded using an IRtek IR60 Infrared Thermometer.

A limitation of this study is that it did not quantify the precise amount of solar radiation reflected or absorbed by the building surfaces. Instead, the focus was on assessing the practical impact of the cool coating on reducing surface and indoor air temperatures. Additionally, due to the lack of advanced automated data logging equipment and the necessity of frequent measurements at one-hour intervals, manual readings were deemed sufficient. The 13-day continuous measurement period was considered adequate to provide a reliable and representative assessment of the cool roof coating's performance.

3. Results and analysis

3.1 Surface Temperature Results

3.1.1 Outdoor roof surface temperature

The outdoor roof surface temperatures of the conventional roof and the cool-coated roof were analyzed to assess the thermal performance of the cool coating. As illustrated in Figure 5, the cool-coated roof consistently exhibited lower surface temperatures compared to the conventional roof, demonstrating its significant thermal advantage.

The maximum reduction in outdoor surface temperature between the conventional and cool-coated roofs reached 13.5°C. For the conventional roof, the recorded outdoor surface temperature fluctuated by 22.7°C, with a maximum temperature of 51°C observed at 12:00 pm and a minimum of 28.3°C at 4:00 am. In contrast, the cool-coated roof exhibited a smaller temperature range of 10.8°C, with a peak temperature of 37.5°C at 12:00 pm and a minimum temperature of 26.7°C recorded at 4:00 am.

The greatest difference in maximum surface temperatures between the two roofs was 15.9°C at midday (12:00 pm), while the difference in minimum temperatures recorded was only 0.8°C at 6:00 am. These findings indicate that the most substantial temperature reductions occurred during the daytime, attributable primarily to direct solar radiation exposure. The conventional roof absorbed significant solar heat, whereas the cool-coated roof reflected a larger portion of incident radiation. Additionally, the effect of radiant cooling at night contributed to lower temperatures, as roofs naturally act as nocturnal radiators due to their exposure to the sky (Givoni, 1994).

A further comparison between outside roof surface temperatures and ambient air temperatures (Figure 5) supports these findings. For the conventional roof, surface temperatures exceeded ambient air temperatures in 66.5% of the measurements, primarily from 9:00 am to 10:00 pm, with the highest differential of 15.3°C occurring at 3:00 pm. Conversely, the surface temperature was cooler than the ambient air temperature from 11:00 pm to 8:00 am, with a minimum difference of 3.7°C at 4:00 am.

In contrast, the cool-coated roof recorded surface temperatures cooler than the ambient air temperature approximately 90% of the time, with an average temperature approximately 2.6°C cooler. Surface temperatures exceeded ambient air temperatures only about 10% of the time, mostly around noon, with an average increase of 1.3°C attributed to the high intensity of solar radiation during this period. The highest recorded difference was 6.9°C below the ambient air temperature, underscoring the superior performance of the cool coating in reducing roof surface temperatures.

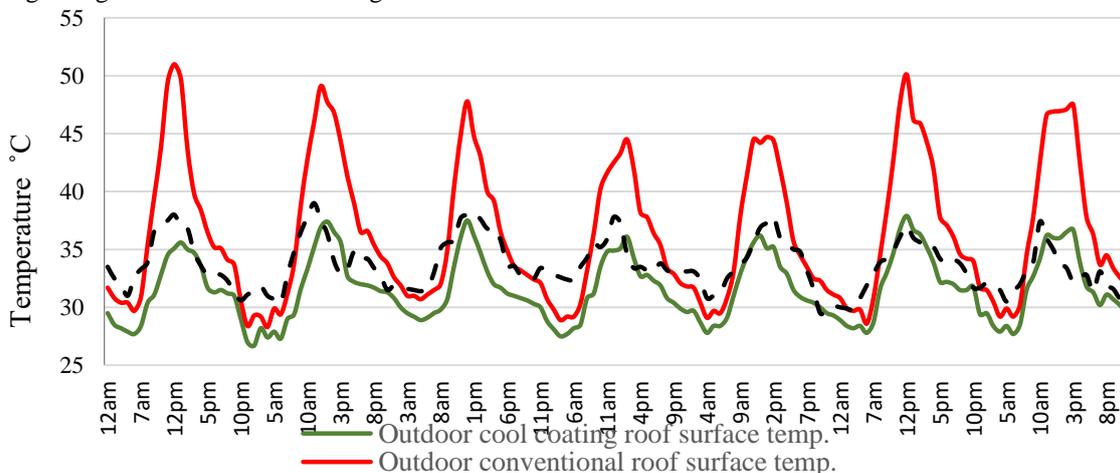


Figure 5. Outdoor air temperature and outdoor roof surface temperature of the cool coating roof and conventional roof

3.1.2 Indoor roof surface temperature

A comparison between the indoor roof surface temperatures of the conventional roof and the cool-coated roof revealed a significant reduction associated with the cool coating, as illustrated in Figure 6. The indoor surface temperature of the cool-coated roof was consistently lower than that of the conventional roof, with a mean temperature variation of approximately 3.1°C. The maximum observed difference reached 5.4°C, while the minimum difference was 1.2°C. Figure 6 also demonstrates a notable reduction in the daily temperature range for the cool-coated roof compared to the conventional roof. Specifically, the daily temperature range was reduced by approximately 2.8°C in the cool-coated roof. For the conventional roof, the indoor surface

temperature ranged between 32.6°C (minimum) and 37.5°C (maximum), resulting in a range of 4.9°C. Conversely, the cool-coated roof exhibited a narrower temperature range, with recorded temperatures between 30.6°C and 32.7°C, yielding a difference of 2.1°C.

Figure 7 shows that no significant difference was observed in the time lag between outdoor and indoor surface temperatures for the two roof types. Both conventional and cool-coated roofs exhibited a time lag ranging from 6 to 7 hours. This is attributable to the fact that outdoor roof surface temperatures were consistently higher than indoor surface temperatures, particularly during daytime hours, due to direct solar radiation exposure

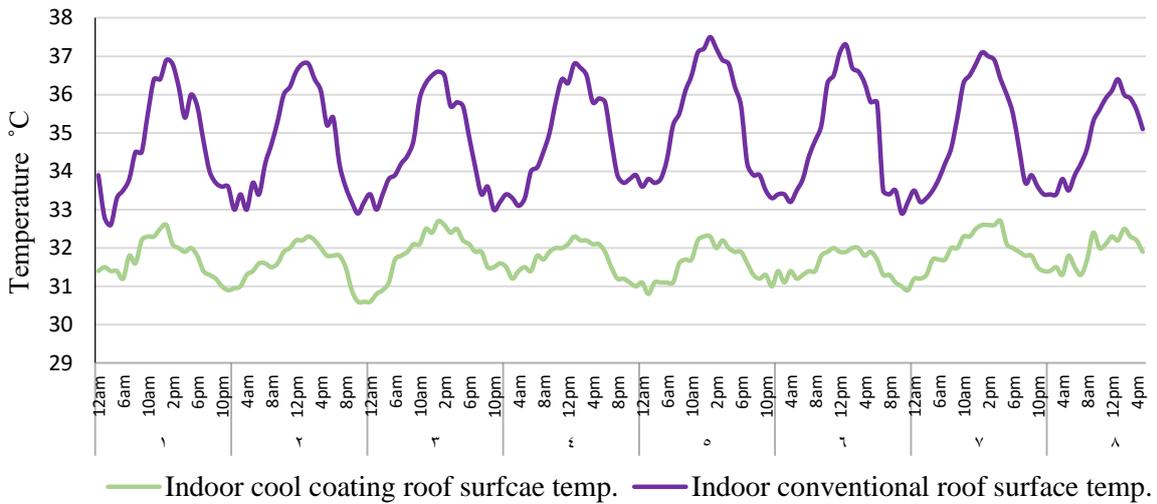


Figure 6. Indoor roof surface temperature of the cool coating roof and conventional roof

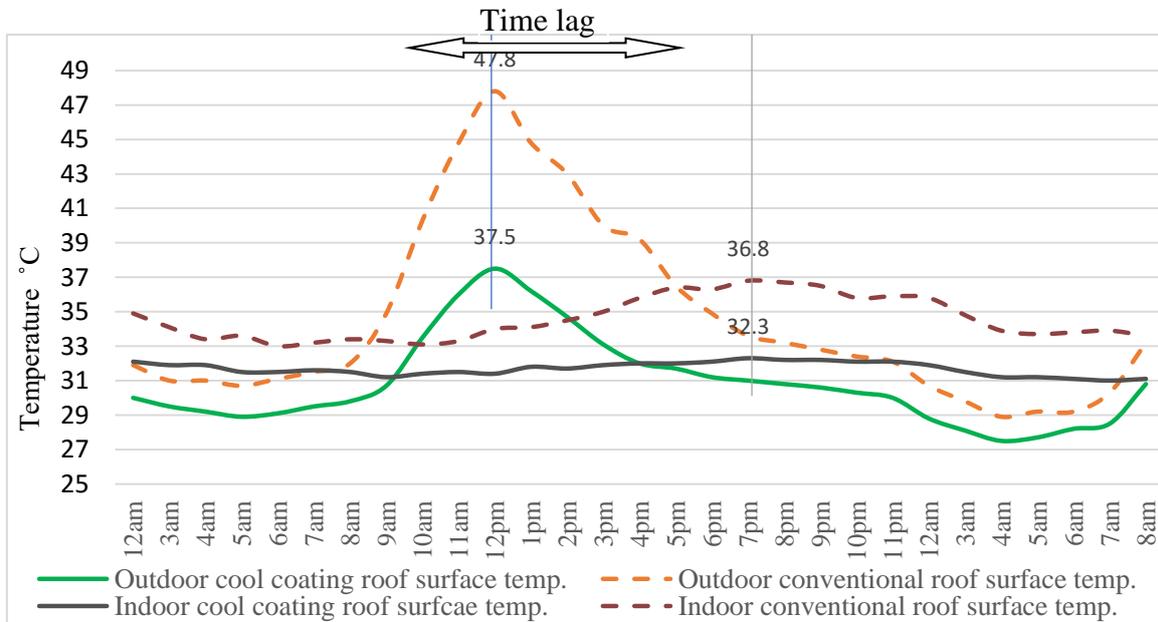


Figure 7. Time lag of maximum outdoor and indoor surface temperature

3.2 Indoor air temperature results

The comparison between the indoor air temperatures of the reference room (with a conventional roof) and the treated room (with a cool-coated roof) is presented in Figure 8. The results indicate a significant reduction in indoor air temperature within the treated room. Throughout the measurement period, the indoor air temperature of the treated room remained consistently lower than that of the reference room, with a mean temperature variation of approximately 1.2°C. The maximum difference observed was 2.4°C, while the minimum difference was 0.1°C. Specifically, the highest indoor air temperature recorded in the treated room was 33.9°C, and the lowest was 31.2°C. In contrast, the reference room exhibited a highest temperature of 34.9°C and a lowest of 32.0°C.

Further analysis comparing the difference between ambient and indoor air temperatures revealed that the treated room's

indoor air temperature was cooler than the ambient air temperature approximately 66% of the time, with an average difference of 1.7°C. During the remaining 34% of the time, the indoor air temperature exceeded the ambient air temperature by a mean of 0.95°C. Conversely, the reference room's indoor air temperature exceeded the outdoor temperature about 63.6% of the time, with an average difference of 1.7°C, and was cooler than ambient air temperature 36.4% of the time, with an average difference of 1.6°C.

These findings, alongside previous results, unequivocally demonstrate the effectiveness of cool-coated roofs in enhancing indoor thermal condition, particularly during periods of elevated outdoor air temperature characteristic of hot climates.

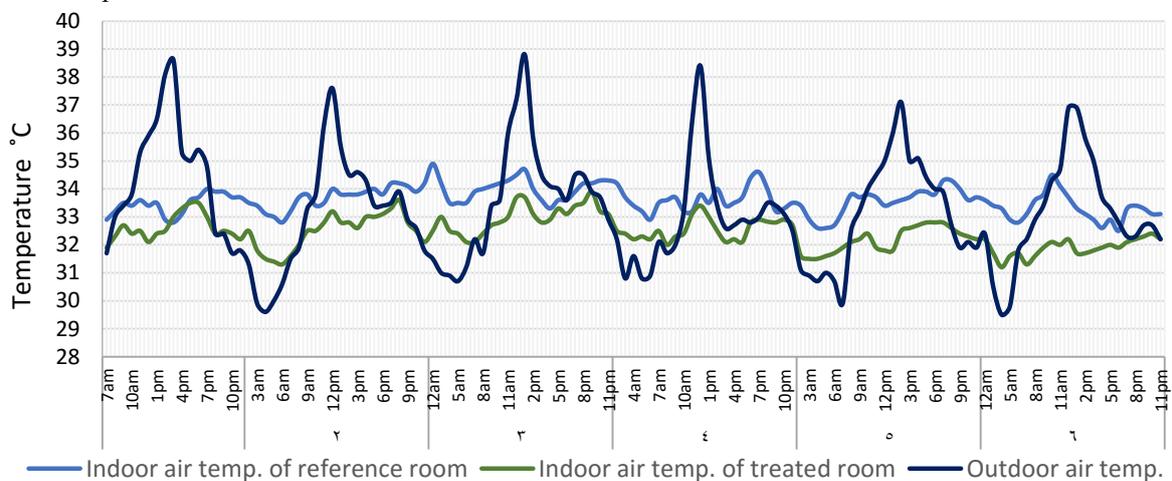


Figure 8. Outdoor air temperature and indoor air temperature of treated room and reference room

4. Discussion

Solar radiation constitutes the main source of external heat gain in buildings; therefore, controlling solar radiation is a critical strategy to reduce heat ingress. This study investigated the effect of applying a cool coating to roofs on indoor thermal condition in a hot and humid climate. The analysis revealed that roof surface temperatures reached very high levels due to direct exposure to sunlight, particularly during the hottest periods when solar intensity at noon exceeds 900 W/m². Notably, the effect of solar radiation during this period was highly concentrated, as the sun's rays were perpendicular to the roof surface, focusing the energy over a relatively small area.

A substantial reduction of approximately 13.5°C in outdoor roof surface temperature was observed for the cool-coated roof compared to the conventional roof. During daytime, the temperature difference between the two roof types reached up to 15.9°C, while only a small difference was recorded at night. This pattern can be attributed to the cool coating's enhanced ability to reflect sunlight and emit heat more efficiently than the conventional roof, as well as the influence of nocturnal radiant cooling.

Furthermore, the cool-coated roof demonstrated excellent performance in maintaining surface temperatures below ambient air temperature for approximately 90% of the time

during the hottest months. Only about 10% of the time, predominantly at noon, did the surface temperature exceed the ambient temperature by a mean of 1.3°C. In contrast, the conventional roof exhibited surface temperatures lower than ambient air temperature for only 33.5% of the time, with an average difference of 1.5°C. This represents an improvement of roughly 55% in the duration of cooler surface temperatures due to the cool coating. Such enhancement is expected to significantly reduce the heat flux into the building interior. Consequently, an average decrease of about 3.1°C was observed in the indoor roof surface temperature, which would contribute to a reduction in radiant heat transfer from the interior roof surface.

Significant reductions in indoor air temperature were also noted. The indoor air temperature in the room with the cool-coated roof was consistently lower than that in the reference room, with an average difference of approximately 1.2°C. Moreover, for 66% of the measurement period, the indoor air temperature in the treated room was cooler than the outdoor air temperature by an average of 1.7°C.

5. Conclusion

In conclusion, the application of cool roof coatings offers numerous benefits for enhancing indoor thermal condition, a finding that aligns with evidence from prior research. This

study analyzed a typical residential building located in Al Mukalla, Yemen, characterized by a hot and humid climate with high solar radiation intensity, particularly during the hot season when cooling demand is greatest.

The results demonstrated that the cool roof coating significantly reduced outdoor roof surface temperatures. The treated roof maintained surface temperatures lower than ambient air temperature approximately 90% of the time, whereas the conventional roof exceeded ambient temperature in 66.4% of measurements, with a maximum temperature difference of 15.9°C in favor of the cool-coated roof. By increasing solar reflectance and reducing heat absorption, the cool coating effectively decreased heat transfer toward the indoor environment, leading to reductions in indoor roof surface temperature ranging from 1.2°C to 5.4°C.

Furthermore, the cool coating contributed to lowering indoor air temperature by between 0.1°C and 2.4°C. It also improved indoor air conditions by increasing the proportion of time during which room temperature remained below ambient air temperature—from 36.4% to 66%—while correspondingly reducing the duration when indoor air temperature exceeded ambient temperature from 63.6% to 34%.

These findings underscore the efficacy of cool roof coatings as a passive cooling strategy for residential buildings in hot and humid climates, with significant implications for improving occupant comfort and reducing cooling energy demand.

This study has significant implications for urban planning and climate policy, highlighting the potential for incorporating cool roof coatings into building codes and sustainability initiatives to enhance energy efficiency and reduce carbon emissions in hot and humid regions.

References

[1] Y. Qin, M. Zhang, and J. E. Hiller, "Theoretical and experimental studies on the daily accumulative heat gain from cool roofs," *Energy*, vol. 129, pp. 138–147, 2017.

[2] K. Vijaykumar, P. Srinivasan, and S. Dhandapani, "A performance of hollow clay tile (HCT) laid reinforced cement concrete (RCC) roof for tropical summer climates," *Energy and Buildings*, vol. 39, pp. 886–892, 2007.

[3] B. Givoni, *Passive and Low Energy Cooling of Buildings*. New York: Van Nostrand Reinhold, 1994.

[4] G. Brown and M. Dekay, *Sun, Wind, and Light: Architectural Design Strategies*, 2nd ed. New York, NY, USA: John Wiley & Sons, Inc., 2001.

[5] C. Romeo and M. Zinzi, "Impact of a cool roof application on the energy and comfort performance in an existing non-residential building: A Sicilian case study," *Energy and Buildings*, vol. 67, pp. 647–657, 2013.

[6] A. Baniassadi, D. J. Sailor, and G. A. Ban-Weiss, "Potential energy and climate benefits of super-cool materials as a rooftop strategy," *Urban Climate*, vol. 29, p. 100495, 2019.

[7] M. Rawat and R. Singh, "A study on the comparative review of cool roof thermal performance in various regions," *Energy and Built Environment*, vol. 3, pp. 327–337, 2022

[8] L. Doulos, M. Santamouris, and I. Livada, "Passive cooling of outdoor urban spaces: The role of materials," *Solar Energy*, vol. 77, pp. 231–249, 2004.

[9] E. H. Amer, "Passive options for solar cooling of buildings in arid areas," *Energy*, vol. 31, pp. 1332–1344, 2006.

[10] M. S. Bakhlah and A. S. Hassan, "The effect of roof colour on indoor house temperature in case of Hadhramout, Yemen," *American Transactions on Engineering & Applied Sciences*, pp. 365–378, 2012.

[11] S. Tong et al., "Thermal performance of concrete-based roofs in tropical climate," *Energy and Buildings*, vol. 76, pp. 392–401, 2014.

[12] S. A. Al-Sanea, M. F. Zedan, and S. N. Al-Hussain, "Effect of masonry material and surface absorptivity on critical thermal mass in insulated building walls," *Applied Energy*, vol. 102, pp. 1063–1070, 2013.

[13] G. Kim et al., "Comparative advantage of an exterior shading device in thermal performance for residential buildings," *Energy and Buildings*, vol. 46, pp. 105–111, 2012.

[14] L. Evangelisti, C. Guattari, F. Asdrubali, and R. d. L. Vollaro, "An experimental investigation of the thermal performance of a building solar shading device," *Journal of Building Engineering*, vol. 28, 2020.

[15] M. Zinzi, "Exploring the potentialities of cool facades to improve the thermal response of Mediterranean residential buildings," *Solar Energy*, vol. 135, pp. 386–397, 2016.

[16] M. Saffari et al., "Thermal stress reduction in cool roof membranes using phase change materials (PCM)," *Energy and Buildings*, vol. 158, pp. 1097–1105, 2018.

[17] A. M. S. Bakarmom, "Design for Comfort: Design Building Envelope to Improve Thermal Comfort for Residential Buildings in Al-Mukala, Yemen," M.S. thesis, Coll. Archit., Illinois Inst. Technol., Chicago, IL, 2021.

[18] M. C. Yew et al., "Experimental analysis on the active and passive cool roof systems for industrial buildings in Malaysia," *Journal of Building Engineering*, vol. 19, pp. 134–141, 2018.

[19] B. Givoni, "Indoor temperature reduction by passive cooling systems," *Solar Energy*, vol. 85, pp. 1692–1726, 2011.

[20] R. Levinson and H. Akbari, "Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants," *Energy Efficiency*, vol. 3, pp. 53–109, 2010.

[21] M. Zinzi, "Cool materials and cool roofs: Potentialities Mediterranean buildings," *Advances in Building Energy Research*, vol. 4, no. 1, pp. 201–266, 2010.

[22] M. Kolokotroni, B. Gowreesunker, and R. Giridharan, "Cool roof technology in London: An experimental and modelling study," *Energy and Buildings*, vol. 67, pp. 658–667, 2013.

[23] T. J. Taylor and C. Hartwig, "Cool roof use in commercial buildings in the United States: An energy cost analysis," *ASHRAE Transactions*, vol. 124, pp. 88–95, 2018.

[24] B. Ashtari, M. Yeganeh, M. Bemanian, and B. V. Fakhr, "A conceptual review of the potential of cool roofs

as an effective passive solar technique: Elaboration of benefits and drawbacks,” *Frontiers in Energy Research*, vol. 9, p. 738182, 2021.

[25] M. Hosseini, F. Tardy, and B. Lee, “Cooling and heating energy performance of a building with a variety of roof designs; the effects of future weather data in a cold climate,” *Journal of Building Engineering*, vol. 17, pp. 107–114, 2018.

[26] U.S. Department of Energy, “Energy Saver - Efficient Design - Cool Roofs,” Sep. 16, 2024. [Online]. Available: <https://www.energy.gov/energysaver/cool-roofs>.

[27] Y. Gao et al., “Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments,” *Energy Policy*, 2014.

[28] A. L. Pisello, E. Fortunati, S. Mattioli, L. F. Cabeza, C. Barreneche, J. M. Kenny, and F. Cotana, “Innovative cool roofing membrane with integrated phase change materials: Experimental characterization of morphological, thermal and optic-energy behavior,” *Energy and Buildings*, vol. 112, pp. 40–48, 2016.

[29] A. Synnefa, M. Santamouris, and I. Livada, “A study of the thermal performance of reflective coatings for the urban environment,” *Solar Energy*, vol. 80, pp. 968–981, 2006.

[30] G. Xing-guo et al., “Experimental study of the thermal performance of a new type of building reflective coating in hot summer and cold winter zone of China,” *Procedia Engineering*, vol. 205, pp. 603–608, 2017.

[31] A. Synnefa, M. Santamouris, and H. Akbari, “Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions,” *Energy and Buildings*, vol. 39, pp. 1167–1174, 2007.

[32] M. Rawat and R. N. Singh, “Impact of light-colored paint materials on discomfort in a building for hot-dry climate,” *Materials Today: Proceedings*, vol. 52, no. 3, pp. 998–1005, 2022.

[33] Y. Gao, D. Shi, R. Levinson, R. Guo, C. Lin, and J. Ge, “Thermal performance and energy savings of white and sedum-tray garden roof: A case study in a Chongqing office building,” *Energy and Buildings*, vol. 156, pp. 343–359, Dec. 2017.

[34] X. Xue, J. Yang, W. Zhang, L. Jiang, J. Qu, L. Xu, H. Zhang, J. Song, R. Zhang, Y. Li, and J. Qin, “The study of an energy efficient cool white roof coating based on styrene acrylate copolymer and cement for waterproofing purpose—Part I: Optical properties, estimated cooling effect and relevant properties after irt and accelerated exposures,” *Construction and Building Materials*, vol. 98, pp. 176–184, 2015.

[35] R. K. Pal, P. Goyal, and S. Sehgal, “Thermal performance of buildings with light colored exterior materials,” *Materials Today: Proceedings*, vol. 28, pp. 1307–1313, 2020.

[36] H. Suehrcke, E. L. Peterson, and N. Selby, “Effect of roof solar reflectance on the building heat gain in a hot climate,” *Energy and Buildings*, vol. 40, pp. 2224–2235, 2008.

[37] M. Z. M. Ashhar and L. C. Haw, “Recent research and development on the use of reflective technology in building

- A review,” *Journal of Building Engineering*, vol. 45, 2022.

[38] H. H. Saber, A. E. Hajiah, and W. Maref, “Impact of reflective roofs on the overall energy savings of whole buildings,” *E3S Web of Conferences*, vol. 172, 2020.

[39] J. Quezada, A. Isalgue, and H. Coch, “Impact of solar reflectivity and infrared emissivity on the thermal performance of metal and concrete roofs in cloudy warm-humid climate,” *Frontiers of Architectural Research*, vol. 13, no. 4, pp. 842–857, 2024.

[40] K. M. Al-Obaidi, M. Ismail, and A. M. Abdul Rahman, “Passive cooling techniques through reflective and radiative roofs in tropical houses in Southeast Asia: A literature review,” *Frontiers of Architectural Research*, vol. 3, pp. 283–297, 2014.

[41] I. Hernández-Pérez, G. Álvarez, J. Xamán, I. Zavala-Guillén, J. Arce, and E. Simá, “Thermal performance of reflective materials applied to exterior building components—A review,” *Energy and Buildings*, vol. 80, pp. 81–105, 2014.

[42] C. Ferrari et al., “A composite cool colored tile for sloped roofs with high ‘equivalent’ solar reflectance,” *Energy and Buildings*, 2016. [Online]. Available: <http://dx.doi.org/10.1016/j.enbuild.2015.06.062>.

[43] H. Akbari, S. Bretz, D. M. Km-n, and J. Hanford, “Peak power and cooling energy savings of high-albedo roofs,” *Energy and Buildings*, vol. 25, pp. 117–126, 1997.

[44] H. Akbari, “Measured energy savings from the application of reflective roofs in two small non-residential buildings,” *Energy*, vol. 28, pp. 953–967, 2003.

[45] M. Kolokotroni, E. Shittu, T. Santos, L. Ramowski, A. Mollard, K. Rowe, E. Wilson, J. P. de Brito Filho, and D. Novieto, “Cool roofs: High tech low cost solution for energy efficiency and thermal comfort in low rise low income houses in high solar radiation countries,” *Energy and Buildings*, vol. 176, pp. 58–70, 2018.

[46] C. Piselli, M. Saffari, A. de Gracia, A. L. Pisello, F. Cotana, and L. F. Cabeza, “Optimization of roof solar reflectance under different climate conditions, occupancy, building configuration and energy systems,” *Energy and Buildings*, vol. 151, pp. 81–97, 2017.

[47] M. Zinzi and G. Fasano, “Properties and performance of advanced reflective paints to reduce the cooling loads in buildings and mitigate the heat island effect in urban areas,” *International Journal of Sustainable*, vol. 28, no. 1, pp. 123–139, 2009.

[48] X. Nie, R. Flores, J. Brouwer, and J. Lee, “Energy and cost savings of cool coatings for multifamily building in U.S. climate zones,” *Advances in Applied Energy*, vol. 13, 2024.

[49] P. Mold and R. Godbey, “Limewash: Compatible coverings for masonry and stucco,” in *International Building Lime Symposium*, Florida, 2005.

[50] M. Stefanidou, M. Assael, and K. D. Antoniadis, “Thermal conductivity of building materials employed in the preservation of traditional structures,” *International Journal of Thermophysics*, vol. 31, pp. 844–851, 2010.

دراسة تجريبية ميدانية لتأثير طلاء السقف البارد على درجة حرارة الهواء الداخلي في مبنى خرساني نموذجي في حضرموت، اليمن

الملخص: تعد الحرارة المكتسبة من الأسقف عاملاً حاسماً في تحديد الأداء الحراري للمباني. ومع ذلك، فإن الإستراتيجيات الرامية إلى تقليل هذا الكسب الحراري - سواءً في أثناء البناء أو بعده - غالباً ما تكون محدودة أو غير معالجة بالشكل الكافي. تستكشف هذه الدراسة تأثير طلاء السقف البارد في الظروف الحرارية الداخلية لمبنى سكني خرساني نموذجي يقع في حضرموت، اليمن. رغم الاهتمام العالمي المتزايد بتقنيات التبريد السلبي، لم تقم أي دراسة سابقة بتقييم فعالية طلاء الأسطح الباردة في هذا السياق الإقليمي والمناخي المحدد، ولم يتم التحقق تجريبياً من مدى انخفاض درجة حرارة الهواء الداخلي الناتج عن هذا التدخل. أُجريت قياسات في الموقع من خلال مسح ميداني شمل غرفتين متجاورتين متطابقتين تماماً في التصميم والحالة والمواصفات. شملت المعايير المقاسة درجات حرارة الهواء الداخلي والخارجي، بالإضافة إلى درجات حرارة أسطح الأسقف الداخلية والخارجية، كلها قبل وبعد تطبيق طلاء السقف البارد. تم جمع البيانات في أثناء الذروة في أشد الأشهر حرارة يوليو وأغسطس، أظهرت النتائج أن تطبيق طلاء السقف البارد أدى إلى انخفاض في درجة حرارة الهواء الداخلي تراوح بين 0.1 درجة مئوية و 2.4 درجة مئوية. علاوة على ذلك، انخفضت درجات حرارة السطح الداخلي بنحو 1.2 درجة مئوية إلى 5.4 درجة مئوية، بينما أظهرت درجة حرارة السطح الخارجي انخفاضاً ملحوظاً وصل إلى 15.9 درجة مئوية عند منتصف النهار. تقدم هذه النتائج دليلاً تجريبياً يدعم فعالية طلاء الأسطح الباردة كإستراتيجية تبريد سلبية فعالة وقابلة للتطبيق لتحسين الظروف الحرارية الداخلية في المباني الخرسانية في المنطق ذات المناخ الحار والرطب.