Experimental Study on Cool Roof Methods for Two Identical Portable Cabins in the State of Kuwait

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Abstract—The development of cool roof strategies in low energy buildings developments are challenging in hot climate of Kuwait. Cool roofs are the passive energy efficiency options that are aimed to lower roof temperature during the day when the sun is shining. Two portable cabins are designed with 2m × 2m × 2.8m interior dimensions, with wall and roof is made from 75mm Polyurethane sandwich panels. Each room is equipped with an air conditioner (AC) split unit of 18000BTU. Davis weather instrument is installed in each room to report real-time measurements of temperature, humidity, and indoor air quality. Emporia smart home energy monitor system was connected to the split units to report electrical energy consumption of the AC system. Initial measurements confirmed that both cabins perform near identical thermal characteristics and energy consumption. In this work, two cool roof methods are investigated including a cool roof paint, and aluminum foils. The effects of each on energy savings are discussed.

Keywords—building, climate, cool roof, energy saving, environment.

I. INTRODUCTION

There is huge potentials in developing effective energy saving methods such as cool roof, insulation, phase change material (PCM) and solar assisted AC system for hot-arid climate of Kuwait. Rawat and Singh [1] made an extensive review on energy savings of different cool roof methods in different climates. They reported that the average energy-saving of cool roofs varies from 15% to 35.7% in different climates including hot-arid climates according to literature; to be addressed in this study. Cool roofs are the passive energy efficiency options that are aimed to lower roof temperature during the day when the sun is shining [2]. Sunlight is the main factor that heats up a roof during sunny hours. Cool roofs decrease roof operating temperature and extend roof service life; cool roofs decrease indoor air conditioning demands; cool roofs increase indoor thermal comfort, and cool roofs protect environment while saving money on electricity bills.

Cool roofs use solar reflective materials to reduce roof surface temperature like white colored clothes keep you cool compared with dark clothes on a sunny day. A traditional dark roof can heat up to 74.6 °C in summer while a cool roof under same condition can only heat up to 40.5 °C, i.e., 34.1 °C cooler (see Fig.1).

Fig. 1. Cool roof versus a traditional dark roof surface temperature.

Cool roofs may reflect sunlight and emit heat more efficiently. This is attributed with two important surface properties namely solar reflectance ($\tau$) and thermal emittance ($\varepsilon$). These two parameters range on a scale from 0 to 1. The larger values close to 1, the cooler the roof will remain under sunlight. Solar Reflectance is referred to the fraction of sunlight reflected by a surface. Non-reflected sunlight is absorbed to heat. For example, a solar reflectance of 0.55 is referred to a surface which reflects 55% of sunlight. Traditional roof materials may merely reflect 5 to 20%, while cool roof materials may exceedingly reflect 55 to 90% of incoming sunlight. Solar reflectance is the important factor on keeping roof cool against the sun.

For cool roofs the SRI (solar reflectance index) will be higher, e.g., the clean white surface has SRI of 100. For a traditional roof the SRI is usually less than 20, e.g., the clean black surface has SRI of 0. According to the California Energy Commission [3] and US Green Building Council’s (USGBC) [4], for a low-sloped roof a minimum cool roof SRI value of 64 [3] or 78 [4] is required for a 3-year aged surface, and for a steep sloped roof the minimum SRI value of 16 [3] or 29 [4] is required.

Roof thermal insulation can greatly reduce heat gain/loss. Therefore, cool roofs are never a substitute to roof insulation. Insulation can reduce solar heat gain/loss in more efficient ways than reflective surface cannot. To highlight importance of thermal insulation, the readers are directed to the resources [5-8]. To make a roof cool it usually involves...
applying a coat on the roof, replacing the roof, or building another roof on the top of current roof.

Seifhashem et al. [8] have used an acrylic cool roof paint for a warehouse retail building in Australia. They used a water based acrylic coating, with a solar reflectance value of 0.878 under ASTM C1549 testing. They indicated some temperature reduction of the roof and energy saving through experimental and numerical simulations. No clear comparison was made since only one warehouse was examined before and after applying the cool roof paint. Antonaia et al. [6] have used three paints of automotive sector and performed laboratory tests on several substrates including aluminum, glass, ceramic tile, bitumen membrane and find that the white acrylic paint has better reflectance (77-80%) and thermal emissivity (92%). Applying these paints on an insulted roof in Mediterranean climate, they find that the maximum annual energy saving of 0.3-3.0% can be achieved. Bozonnet et al. [7] have studied the effects of cool roof paints on indoor operative temperature. They found that cool roofs can reduce high outdoor temperatures on some buildings in France, but the effects on indoor operative temperature are negligible. De Masi et al. [9] have studied acrylic white paint aging for application as a cool roof. They found that in-field performance testing of acrylic paint is different than laboratory tests and solar reflectance is faster degraded by around 20-25%.

Kolokotroni et al. [10] studied an office building in London, UK, by application of a cool roof paint from ABOLIN (Cool Barrier 012-CB012) with the solar reflectance of 0.7 and the infrared emittance of 0.88. The total energy saving up to 8.5% was recommended. They reported a roof reflectivity of 0.6-0.7. They also reported increase in thermal comfort by 2.5 °C. Romeo and Zinzi [11] reported a significant cooling reduction of 54% using cool roof for a non-residential building in Sicilian, Italy, compared with 44% for roof insulation, 22%-night ventilation, and 39% external shading. They reported SR value of 0.859 and thermal emittance of 0.88 for this paint. Shittu et al. [12] studied cool roof paints for two low rise houses in two islands of Sicily and Jamaica. They found significant energy saving in both locations particularly in Jamaica, which was comparable with thermal insulation savings. Yew et al. [13] used a combined passive and active cool roof lab measurements using a solar energy fan, cavity ventilation and thermal reflective coating (TRC). They found 7 °C reduction of roof temperature mainly due to the cool roof paint. They used a composite TRC with high SRI of 120 made from waste CES as renewable bio-filler and nano titanium dioxide paint as a radiant barrier.

Zingre et al. [14] studied a combined double-skin roof with a cool roof in the tropical climate of Singapore. They found that a white cool roof coating on a flat double-skin roof reduced the daily heat gain by 0.21 kWh/m2 (or 51%) which leaded to the indoor peak air temperature reduction of 2.4 °C on a sunny day. The cool roof paint selected has the solar reflectance of 0.74 and the thermal emittance 0.90. Costanzo et al. [15] investigated a low-rise office building in Catania, in southern part of Italy where summer is hot-humid Mediterranean, and winter is cold with heating demand. Due to heating demand in winter, higher solar reflectance might not be practical in this region in terms of overall annual energy saving. Sahoo [16] monitored the effects of cool roofs for 2 and ½ months in two identical houses oriented in same direction located in warm dry climate of Ahmedabad (Gujarat) in India on improving thermal comfort. They found by applying a cool roof paint with solar reflectance of 0.7, the maximum temperature reduction of 1 °C to 4.8 °C was observed. Roman et al. [17] investigated mitigation of urban heat island (UHI) using cool roof and phase change materials (PCM) within 7 climate zone in USA using EnergyPlus simulation. They found the PCM roof can save up to 54% whilst a cool roof can offer up to 40% energy-saving on rooftops. Stavrakakis et al. [18] investigated by numerical and experimental methods the effects of cool roof on thermal and energy saving of a school building located in Athens, Greece. They considered two cases of: 1. ceiling fans; and 2. split units. For the first case, they found a 25% reduction in ventilation energy and up to 3% increase of thermal comfort at the expense of a 12% increase in heating penalty in winter.

Kim et al. [19] investigated one year monitoring of cool roofs between two building with cool roof (CR) and without cool roof (NCR) in a subtropical climate in in Changwon city, South Korea. They found the effects of cool roof more pronounced in winter than summer contradiction to previous studies. He et al. [20] compared application of green roof with cool roof in climate of Shanghai, China. They concluded cool roof perform better than green roof in summer. Chen and Lu [21] developed a cool roof model and validated for 5 different cities in China. Energy saving below 10% was reported for the studied cities. Androutsopoulos et al. [22] investigated cool roof coating in a school building in Athens, Greece using both simulation and measurements. They used two methods of cooling by fans and AC. The AC energy consumption was reduced by 20%, annual heating increased by 12%, but the total annual energy reduced by 4.5%.

In this research, two identical portable cabins were constructed and effects of cool roof designs on the roof of one of the cabins were investigated. The effects of a cool roof paint and aluminum foil is discussed. There are debates on whether aluminum foil can reflect heat or it can be used as a insulation roof in scientific and public discussion forums [23, 24]. Surprisingly, there is no scientific research evidence to address the use of aluminum foils as a cool roof method. Therefore, we aimed to document and clarify effects of aluminum foil and investigate its merit as a heat reflective or cool roof. In section II, the climate of the state of Kuwait is explained. In section III, materials and methods are discussed. In section IV, results of this study are presented, and conclusions are drawn in section V.

II. CLIMATE OF KUWAIT

The State of Kuwait is a country in the West of Asia located at the northeast edge of the Arabian Peninsula and the tip of the Persian Gulf. It borders Iraq in the north and the Kingdom of Saudi Arabia in the south (see Fig. 2). Kuwait has a coastal line of 500 km and shares water borders with Iran. Kuwait is in latitudes between 28° and 31° N and longitudes between 46°, and 49° E. Kuwait includes ten islands and has flat geography with the highest elevation from sea level of 306 m.

Unlike UAE, Qatar, and Bahrain, Kuwait enjoys a colder winter season due to it being in the vicinity of Iraq and Iran and being influenced by similar weather conditions of these countries.
Although the Kuwaiti climate is classified as a subtropical desert climate according to the Köppen climate classification [25], Kuwait is less humid, particularly during the year's warm months. Kuwait has scorching summers and mild winters. The global and diffuse radiations can reach 220 and 110 kWh/m² in June and July, respectively. These values were reduced to around 100 and 40 kWh/m² in January and December. In July and August, the average monthly temperature varies from a minimum of 33 to 47 °C with absolute minimum and maximum temperatures of 28 and 50 °C, respectively.

III. MATERIALS AND METHODS

A. Portable Cabins

Two portable cabins are designed with 2m × 2m ×3m. Inside dimension is 2m × 2m, and 2.99m height with a slope height of 2.94m whilst height up to the false ceiling 2.8m (see Fig. 3).

Hence, the interior space of each room is exactly 2m width, 2m depth, and 2.8m height. The rooms are fabricated of steel frame by using 120mm I-beam at bottom and 40mm × 40mm square hollow section for frame support at bottom. Columns are made from 50mm × 50mm × 2mm (thickness) hollow sections with angles. Leg height is 300mm from the ground. Lifting lugs for lifting and handling. Purlins are used in the roof from 50mm × 50mm × 2mm (thickness) hollow sections. PVC Skirting of 3mm thick & 100mm height is used. Wall and Roof are made from 75mm Polyurethane sandwich panel.

Slope roof is covered with gypsum ceiling. Flooring is made from 18mm thick plywood finished with Vinyl sheet. One aluminum external door is used which is a single leaf of size 2m × 1m with heavy duty door closer. Door is in the middle from the floor level. One aluminum window of size 1m ×1m double leaf is used with weather proofed glass. The window is 50 cm below the roof and located in the middle of the wall. All wirings for electrical power sockets / switch sockets run through PVC conduits fixed in the wall sandwich panels. Main distribution board (MDB) is fixed. Three multiple plugs are installed in 3 sides of the room. A LED light is installed in the back wall with electric switch near door wall per the company standard. Air Conditioner is a split A/C 18000BTU. The two cabins were successfully transported to Australian University by a truck-crane (see Fig. 2) on 15 September 2022 and installed facing north (N) direction with a gap distance of 3m. Both rooms legs were levelized for suitable openings of the doors.

B. Measuring Equipment

We used Davis Instruments Airlink which is a professional air quality and temperature/humidity sensors for monitoring indoor/outdoor weather condition (www.davisinstruments.com/pages/airlink). This device provides real-time readings for every minute of AQI (air quality index), temperature, humidity, and HI (heat index). The Airlink can be placed on a desk or countertop, or mount on a wall inside or outside with an outdoor housing protection. A three feet tall wooden stand was designed and built by AU workshop to locate the Airlink at the center of the cabins. This was decided according to the South Holland Building Codes 602.5 (www.up.codes).

The Davis Airlink device measure AQI (air quality index) based on measuring 3 particle matter sizes of PM1 (1 µm), PM2.5 (2.5 µm), and PM10 (10 µm). The generated data are stored in Weather link Cloud (www.weatherlink.com) through WIFI system. Data can be accessed by purchasing annual or 3-yearly storage in Cloud. The Weather link can be opened as an app in mobile phones or accessible from computers. The accuracy of device on AQI is stated that can measures particulates as small as 0.3 microns with an accuracy of +/-10 micrograms per cubic meter in concentrations (see Table I).

For energy monitor, Emporia has developed a new device of the Vue Energy Monitor. The Vue system can monitor up to 16 home's energy appliances in real time. The Vue system can give accurately monitor how much electricity is transmitted with: A 24/7 real power consumption or generation; Real-time data is generated every 1 second; 8 to 16 individual circuit tracking Vue sensor (with 50A bundle); 3-Phase Option (with 3-phase 200A bundle). Emporia is an energy monitor device that can simultaneously monitor 8 to 16 electric consuming devices with maximum amperage of
50A for single-phase and 200A 3-phase appliances (https://www.emporiaenergy.com/). The device supports single-phase and 3-phase up to 240V/AC, it comes with 8 or 16 Vue sensors (50A) to accurately monitor every second real power consumption of air conditioner, solar energy systems, water heater, washer, dryer, and so on (see Table II).

<table>
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<th>TABLE I. TECHNICAL DETAILS OF DAVIS AIRLINK DEVICE</th>
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<td>Particulate matters</td>
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<td>Accuracy</td>
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<td>Update interval</td>
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| Indoor/outdoor relative humidity                |
| Resolution and unit                            | 0.1% |
| Range                                          | 0.1% to 100% RH |
| Accuracy                                       | ± 2% |
| Update interval                                | 1 minute |

| Indoor/outdoor temperature                     |
| Resolution and unit                            | Current data: 0.1 °C |
| Range                                          | -40 °C to +60 °C |
| Accuracy                                       | ± 0.3 °C (typical) |
| Update interval                                | 1 minute |

<table>
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<th>TABLE II. TECHNICAL DETAILS OF EMPORIA ENERGY MONITOR</th>
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The device requires 2.4 GHz WIFI with an internet connection. Energy use can be monitored in phones (iPhone / Android) and computers (Web app). Vue sensors provide 1-second energy data with accuracy of ±2%. The Vue is UL (underwriter laboratories) and CE (consumer electronics) listed for safety. The generated data is stored in the company iCloud with 1 second data is retained for 3 hours, 1 minute data is retained for 7 days, and 1 hour data is retained for indefinitely. The stored data can be exported to a registered email address whenever it is selected from the app.

C. Cool Roof Paint

A cool roof paint was applied on roof of the Right cabin and measurements conducted from 10-15 October 2022 when air-conditioning was ON and from 16-18 October 2022 when air-conditioning was OFF. Kool Seal is Kst Coating KS0063600-16 Roof Coating product [26] which is applied on roof of the Right cabin (see Fig. 4). Kool Seal® Premium Elastomeric Finish Coat (KS0063600) is formulated using a 100% acrylic polymer that provides adhesion and reflectivity. In a report on acrylic paints [27], the SRI values for different acrylic paints was determined around 100. The Kool Seal manufacturer did not provide the SRI value for their product. Two layer of paint was recommended on variety of roof surfaces such as Metal, single ply, smooth BUR, modified bitumen, polyurethane foam, concrete, existing asphaltic and elastomeric roof coatings, and other approved surfaces.

![Fig. 4. Cool roof paint applied on the roof of the Right cabin.](image)

The paint is not recommended for use on roof shingles and for EPDM rubber roofs must be primed with Kool Seal Elastomeric Base Coat Gray.

D. Aluminum Foil as a Cool Roof

There are debates on whether aluminum foil can reflect heat or it can be used as a insulation roof in scientific and public discussion forums [23, 24]. Surprisingly, there is no scientific research evidence to address the use of aluminum foils as a cool roof method. Therefore, we aimed to document and clarify effects of aluminum foil and investigate its merit as a heat reflective or cool roof. We applied a heavy-duty aluminum foil and covered the roof of the Right cabin (Fig. 5) for 19-23 October 2022 with AC OFF and from 23 October to 3 November 2022 with AC ON.

![Fig. 5. Cool roof aluminum foil applied on the roof of the Right cabin.](image)

IV. RESULTS AND DISCUSSIONS

A. Similarity Check on Thermal Characteristics

The weather instrument (Davis Airlink) was installed and connected to WIFI on 28 September. Both cabin rooms were initially disconnected with AC system to check thermal similarity of the two testing rooms for few days. Temperature and humidity are measured on 30 September 2022 and the corresponding results are shown in Fig. 6. The average difference between the two rooms was 0.48% for temperature and 1.44% for humidity on 30 September 2022. This indicates that both rooms are thermally near identical.

B. Similarity Check on Energy Consumption

For both portable cabins, the AC system was turn ON from 4 to 9 October 22 at the pre-set temperature of 22 °C.
The results of the comparison between the two rooms from 6-9 October 2022 are shown in Fig. 7. The data shows nearly identical energy consumption profiles for both rooms and reasonable cyclical energy consumption patterns that well match the ambient temperature profiles for the examined three days. The averages are identical to two decimal points and the values of 0.347 kWh for the Left cabin and 0.344 kWh for the Right cabin indicates the total difference of merely 0.865% which is below 1% error (see Fig. 7). This data clearly shows well-matched control counterparts, and we may proceed with the comparison with the application of different power-saving measures. It is obviously accuracy of building two nearly identical cabins must be praised since thermal and power consumption show nearly identical.

C. Results for Cool Roof Paint

From 10-15 October 2022 when air-conditioning was ON, the power and energy consumption are compared between the Left room (without cool roof paint) and the Right room (with cool roof paint). Figure 8 compares the AC energy consumption of the two cabins on hourly basis on 10 October 2022.

![Fig. 8. Effects of Kool Seal paint on energy consumption of the two cabins on 10 October 2022.](image)

The results from 10-15 October 2022 indicate that the total energy consumption for the Left cabin (31.84 kWh) is slightly higher than the Left cabin (31.4 kWh) and the total energy saving was merely 1.42%. The results indicate that for well insulated buildings, the effects of cool roof may be marginal. This will be also investigated during summer 2023 for better understanding of the cool roof effects.

D. Results for Aluminum Foil Roof

From 19 to 23 October 2022, the air-conditioning was turned OFF and thermal characteristics of the Left room (without cool roof) and the Right room (with aluminium foil) was investigated. As shown in Fig. 9, temperature varied from 26 to 38 °C with the average temperature for the Right cabin of 30.41 °C and for the Left cabin of 30.65 °C on 22 October 2022. Temperature of the Right cabin (with aluminium foil roof) was lower than the Left cabin in some instances by 1 °C. The average relative humidity of the Right cabin was 70.2% and for the Left cabin was 69.5% with peak value of 82% at 6:00 AM.
pronounced higher relative humidity compared with the Left cabin in the afternoon hours of 1:00 PM till midnight. Energy monitor of aluminum foil roof undergoes and will be reported in near future.

V. CONCLUSIONS

Two identical portable cabins were manufactured from insulation sandwich panels for assessing different energy savings in buildings. An indoor weather device and an energy monitor were used to measure temperature, humidity, and air conditioning energy consumption. Both cabins illustrated near identical thermal characteristics and energy consumption. Two cool roof methods applied and reported here. It is found that:

- Cool roof paint is effective on reducing energy consumption within 1-3% in winter months in Kuwait.
- Aluminum foil roof influenced the indoor thermal characteristics but not effective for energy saving.

More studies are needed on energy performance of aluminum foil roof and other cool roof techniques which is currently under. Future work will be involved with the application of phase change materials (PCMs) and solar assisted air-conditioning (AC) systems.

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