The Impact of Cool Roof on the Solar PV Applications on Building Rooftops

Experimental Case in Sharjah, UAE

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Abstract: Cool roof is the technology that delivers higher solar reflectance and higher thermal emittance than standard roofing products. In addition, It is one of the technologies that is developing in the resent years, and its fastest developing applications is in the built environment with various benefits, such as reducing the UHI effect and minimizing the air pollution and related temperatures. As a result, cool coating paint has been experimented in this research, while the impact was measured in terms of an integration with the Solar PV technology. With this, the intention was to provide guidance for both architects and building designers considering longer-term benefits. On the other hand, the aim of this research is to investigate cool roof applications on building's rooftop together with PV panels for the Middle East climatic conditions, and its impact on the electricity generation. Experimental method was considered in this study where an experiment has been conducted on the laboratories rooftop of the University of Sharjah, which is at the same time integrated within the competition housing project of the Solar Decathlon Middle East 2018 Dubai. Moreover, to record the generation of electricity and to compile the analysis report for PV modules, PV-Analysator and PROFITEST PV were used. The preliminary findings of the experimental study indicated that there is a likely impact of 5-10 % improvement with the cool roof applications. Such findings could help with significant impact on the longer-term benefits. Overall, the domestic building sector could improve and benefit through the electricity generation.

Keywords: Cool Roof, UHI Effect, Cool Coating Paint, Building Rooftop, PV Panels.

1. INTRODUCTION

Temperatures in cities are slightly a few degrees higher than that of their surrounding rural areas. This discrepancy in temperature is due to the Urban Heat Island (UHI) effect. UHI effect phenomenon happens because of replacing vegetation with structures and built-up areas, which leads to a dramatic drop in the evaporative cooling because of limited vegetation available in the surroundings. Other factors that contributes to the effect are for instance, cars and air conditioners, by releasing the heat of energy conversion into the air. This effect can be highly recognized in the city centres and downtowns.

In the United Arab Emirates (UAE), the higher urban temperature caused an increase in air-conditioning usage. Around 70% of Dubai's peak load power demand is for air conditioning. Most of the country's air-conditioners run on electricity that is generated by natural gas-fired power plants, which emit heat-trapping greenhouse gases into the atmosphere. Reducing the cooling load would decrease the country's carbon footprint (PEi, 2010). Additionally, the UAE vision 2021 is to have a low carbon, sustainable and resource efficient future, and to ensure sustainable development while preserving the environment and to achieve a good balance between economic and social development. Improving the quality of life of UAE's citizens by providing suitable housing can be achieved through minimizing the urban heat island. UHI effect can be decreased by increasing the cooling systems' efficiency, adding vegetation to buildings (like green roofs and walls), and cooling paved surfaces with highly reflective paint (Jha, M., 2017).

Cool roofs use solar reflective surfaces to decrease the roof temperatures. Cool barrier technology creates surfaces that reflect sunlight and emit heat more efficiently than dark roofs, keeping them cooler in the sun. Besides, common roofing products absorbs much solar energy than cool roofs, making them hotter. Since most dark roofs absorbs 90% or more of the solar energy, the roof can reach temperatures higher than 66°C when the weather is warm and sunny. In summertime, higher roof temperatures increase the heat flow into the building, causing the air conditioning system to use more energy. However, cool barrier technologies can create surfaces that absorb less than 10% of the solar energy, which results in reducing the roof temperature and the energy usage of air conditioning (ABOLIN Co, 2012).

Some researchers (Synnefa et al, 2007) have done a study to estimate the effect of using cool coatings on energy loads and thermal comfort in residential buildings. They performed simulations for 27 cities worldwide representing different climatic conditions, including Mediterranean, humid continental, subtropical arid, desert conditions. They used a single story house with a roof area of 100 m^2 as a base case building in the simulation. They found that the cool coating application resulted in increasing the roof solar reflectance by 0.65, and reducing cooling loads by 8-48 kWh/m^2. Moreover, another study was conducted by the University of Melbourne (UniMelb) about the cool roof paint (University of Melbourne, 2011). They installed three single room buildings at the University of Melbourne's Burnley campus in Melbourne, Australia. Two buildings were painted with cool roof paint, and the third one was left unpainted. They also did a computer simulation by TRNSYS software package. Their results show that cool roof paint products are effective at reflecting solar radiation and decreasing roof surface temperatures, when compared with a standard metal roof material. The paint reduces the indoor temperatures of the test buildings during day and night. For a typical residential building, the attic space was 18.5 degrees cooler with the use of cool paint. In terms of cooling energy reductions, a commercial building in Melbourne could benefit by approximately 3%.

The European Cool Roofs Council compared several case studies about the cool roof impact in Italy, Greece and UK (Zinzi, Michele, 2014). In Trapani, Italy, a test was carried out on 800 m2 office/laboratory block. After the cool roof application, the net cooling demand was reduced by 54%. In Athens, Greece, a white elastomeric waterproof coating was applied on 410 m2 school block. Their results show a 20% reduction in the cooling load. In London, UK, pink elastomeric coating was applied on an office building with 137 m^2. The heating and cooling demand was reduced by 3.5%.

Most studies, as previously mentioned, focused on the impact of cool roof paint on the indoor comfort in buildings, which is an important factor for building environments, however, equally, it is important to quantify the other benefits such as the benefits through other active systems, i.e. solar technologies. For this reason, the aim of this research is to test the effectiveness of the cool coating paint on PV panels through investigating cool roof applications on building's rooftop together with PV panels for the Middle East climatic conditions, and its impact on the electricity generation.

2. METHODOLOGY

Experimental method was considered in this study where an experiment has been conducted on the laboratories rooftop of the University of Sharjah (UOS), in the UAE, which is at the same time integrated within the competition housing project of the Solar Decathlon Middle East (SDME) 2018 Dubai. Moreover, to record the generation of electricity and to compile the analysis report for PV modules, PV-Analysator and PROFITEST PV were used. The preliminary findings of the experimental study indicated that there is a likely impact of 5-10% improvement with the cool roof applications. Such findings could help with significant impact on the longer-term benefits. Overall, the domestic building sector could improve and benefit through the electricity generation.

The Cool Barrier - Low Solar Absorption can be described as Two-Component Aliphatic, Polyester Polyurethane Top Coating accordingly with MIL-C-85285C (WIG, 2018). Table 1 shows the characteristic of the cool coating paint used in this study.

Table 1: The Cool Barrier paint specifications

Principal Characteristics	Recommended Substrate Conditions and Temperatures
Easy application by roller and airless spray	Surface Preparation: Sand Blasting Sa 2.5. Please prior the use of the CB 2K Top Coat Inform us about the painting and surface preparation existed specifications. Epoxy Systems or Ethyl Silicate systems are available
Unlimited recoatable	Previous coat; (epoxy or polyurethane) dry and free from any contamination and sufficiently roughened if necessary
Excellent resistance to atmospheric and sea exposure conditions	During application and curing a substrate temperature down to 0°C is acceptable provided the substrate is dry and free from ice
Non-Chalking, non-yellowing	Substrate temperature should be at least 3°C above dew point
Tough and abrasion resistant	Maximum relative humidity during application and curing is 80%
Resistant to splash of mineral and vegetable oils, paraffins, aliphatic petroleum products and mild chemicals	Premature exposure to early condensation and rain may cause gloss change
Can be recoated even after long atmospheric exposure	-
Superior Solar Reflectance: SR value: 0.91 (white)	-

In October 2017, an experiment has been conducted to test the potential improvement of PV performance by increasing the diffused radiation onto the PV surface. The location of the experiment is the rooftop of the solar PV lab, W12 building - the Central Laboratories of the University of Sharjah, as shown in Figure 1. The PV system layout and performance will be tested in real-life scenario. A tailored panel’s rack will be designed and fabricated; a nylon sheet will be coated with a special reflective paint (cool coating) and combined to the PV panels support rack. The increased solar radiation onto the PV surface will be measured with sensors and digitally stored with data-logger and workstation.

Figure 1: The experiment location; rooftop of the solar PV lab – located on top of the W12 building at the UOS campus

2.1. Setting Up the Experiment

This experiment consists of two scenarios; each scenario is with two cases. The first scenario is about comparing two cases, one case is with the cool coating paint and the other case is without the cool coating paint. The second scenario is similar to the first one but the second case is with a black carpet. The required area for each case is 5m*5m (25m^2), for both cases an area of 50m^2 is required. Table 2 presents the equipment list of the experiment.

Table 2: List of equipment

Amount	Equipment
2	Data logger - PVSYST
2	Workstation PC – PV Analysator software
2	PV panels
2	Thermal cables
2	Irradiance cables
2	Positive and negative cables
2	Wooden racks
1 bucket – 18 Litters	Cool coating paint
1	5 m * 5 m White carpet – Nylon sheet
1	5 m * 5 m Black carpet – Garbage bags

As part of the experiment, two identical PV panels were selected; on 31st October 2017, four (98cm*195cm) monocrystalline PV panels were tested on the rooftop of W12 building. All panels were connected to data loggers and PC workstations. By using PV-Analysator software, the data of each panel were collected and then analysed using Excel spread sheets. Table 3 shows the comparison of each panel results. Panels #2 and #3 were chosen due to the similarity of their generated power.

Table 3: Readings of the Four PV panels, highlighting the similar generated power

#	Voc	Isc	Vmax	Imax	Pmax	Irr	Tsens	Tmod
P1	41.150	5.728	32.472	5.314	172.564	612.945	46.276	38.664
P2	40.291	5.726	30.967	5.354	165.802	643.314	48.524	40.055
P3	39.484	5.896	30.486	5.476	166.963	672.646	53.018	46.871
P4	38.779	5.720	30.997	4.638	143.781	693.721	53.139	48.345

Two wooden racks were prepared at M12 - Civil workshop - University of Sharjah. The duration of this activity was from 9th November 2017 to 21st November 2017. The material of the racks is Plywood; each rack required 4ft*8ft Plywood panel to hold two photovoltaic panels. The type of both PV panels is Monocrystalline with dimensions of 98cm * 194cm.

2.2. Painting with Cool Coating Paint

On 26th November 2017, the Nylon carpet and Rack #1 were painted with the cool coating paint at W12 – Rooftop – UOS as shown in Figure 2. 18 litters were used to paint 25 m^2 of the Nylon carpet. The painting activity was carried out in two days, half of the bucket was used in each day.

Figure 2: The cool carpet and rack #1 painted with the cool coating

2.3. Connection for Recordings

The set of the experiment was located on the solar PV lab rooftop. Two workstations inside the solar PV lab were connected to two data loggers as shown in Figure 3. The data loggers were connected to the solar panels, which were placed on the rooftop. Connecting the data loggers to the PV panels required 8.0m cables. Through two small openings within the solar PV lab, the connection was solved.

Figure 3: Two workstations connected to two data loggers

2.4. Data Recordings

Through the test period, which was from 18th March until 12th April 2018, the research team agreed on running the data logger from 7:30 AM to 4:45 PM, and collecting the readings every 15 minutes. The total readings for each case is 38. Also, the team agreed on testing four angles: 45º, 35º, 25º, and 15º, giving one day for each angle. Ideally, it is meant to be seasonal monitoring. Figure 4 shows angle 35 under testing in the second scenario with two cases, case 1 with the cool carpet, and case 2 with the black carpet.

Figure 4: Scenario 2, testing angle 35, 19th March 2018

3. RESULTS AND ANALYSIS

By using Excel, the readings of each angle were analysed. The collected data consist of four parameters and these parameters are Power in watt, Irradiance in watt/m^2, and Temperature in °C. To understand the results clearly, a comparative analysis has been completed. There are seven parameters to compare the readings, Percentage difference of Power, Irradiance difference in w/m^2, Energy production difference assuming 16% efficiency, Power difference, Energy in WH with cool painted carpet, Energy in WH without cool painted carpet (or with black carpet), and Energy difference in WH.

In both scenarios, the PV panel that was adjusted on the cool carpet generated more power at angle 45, due to the higher amount of reflection and solar radiation. The average in power difference did not exceed 3.4% in the first scenario. But in the second scenario, where the comparison was between the cool carpet and the black carpet, the average in power deference reached 5.6% as shown in Figure 5.

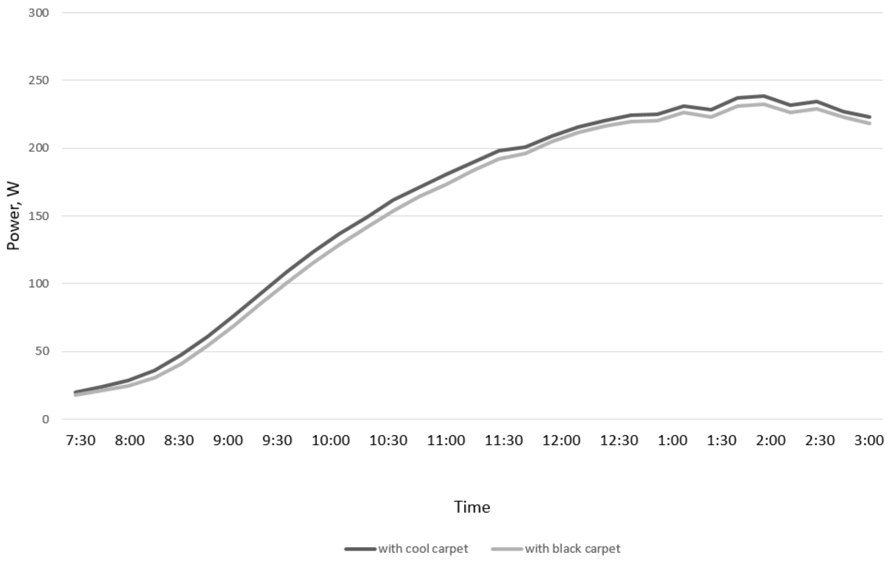

Figure 5: Power difference, angle 45, 25th March 2018

Figure 6 shows how clearly the generated power is related to the irradiation. Higher radiation leads to higher amount of power.

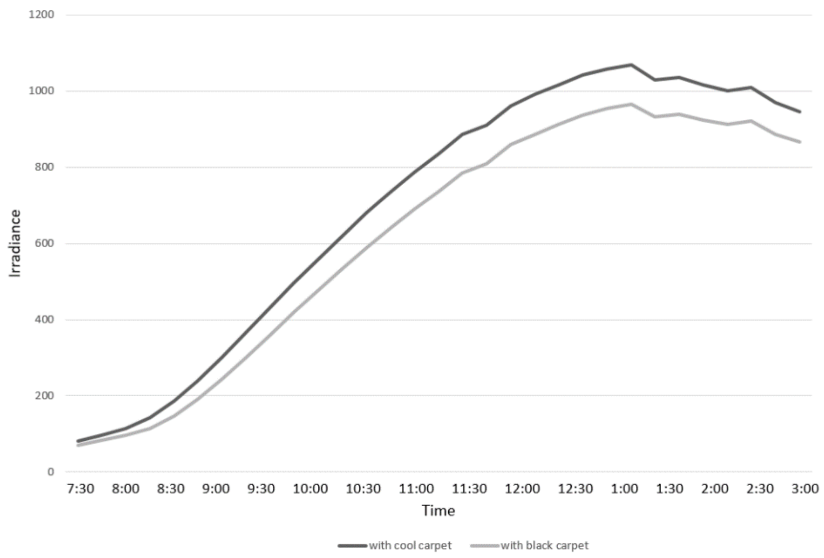

Figure 6: Irradiance difference, angle 45, 25th March 2018

4. DISCUSSION

Since most studies until now have focused on the impact of the cool coating paint on building indoor comfort and environments, it is not possible to have direct comparisons with other studies and the experimental study conducted in this paper. It is however worthwhile to discuss the potential benefits of the study and testing the effectiveness of the cool coating paint on PV panels through investigating cool roof applications on building rooftops together with the impact on electricity generation through PV panels for the climatic conditions of the Middle Eastern countries, such as the UAE.

Looking at the preliminary results from this experimental study, the applied cool coating paint demonstrated benefits with a likely impact of 5-10% improvement with the selected cool roof application. The findings could help with significant impact on the longer-term benefits, and the building sector could improve and benefit from the increasing electricity generation.

5. CONCLUSION

Case studies are significant to better understand how cool roofs work in practice and through different applications. In this paper, the experimental study helped in understanding further benefits of cool roof applications by extending knowledge to solar applications, in this case, PV panels and their electricity generation. Although the study is only presenting preliminary results, the findings have been justified through robust measurements and methodology, and the paper demonstrated somewhat significant impact of cool coating paint on the generated electrical power of the solar PV utilised panels. Further studies through experiments will be made showing seasonal variations of the results as well as different angle usage of the PV panel applications on building rooftops.

Most case studies performed in EU demonstrated that the technology is relevant to reduce the cooling demand in cooled buildings, which is also applicable for the Middle East regions, and to improve the comfort conditions. With this study, the quantified benefits have been extended to other applications creating innovative solutions for increasing energy demand in buildings. In this case, the production of energy through solar applications can be further boost with the cool coating roof paint. Moreover, the UAE Vision 2021 would welcome such innovation and technology benefitting application in rapidly growing built environment in the country and also throughout the wider region – Middle East and the North Africa (MENA).

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