*Conference Proceedings of 5th International Conference on Countermeasures to Urban Heat Islands (IC2UHI) 2019*
*December 2-4, 2019, Hyderabad, India*

https://doi.org/10.37285/bsp.ic2uhi.19

# Controlled experiment for estimating the energy-saving potential and indoor thermal comfort improvement by the use of high albedo surfaces on pitched concrete roofs

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**ABSTRACT**

Reflecting the solar radiation incident on the roof surface helps in reducing the surface temperatures. Cool roof help in reducing the cooling energy requirement of a building. There have been many studies conducted to estimate the potential of energy savings and comfort improvement using cool roof on a flat surface. However, results from these studies are not directly applicable for a sloped surface. This paper presents an experiment that was performed to identify the energy-saving potential and thermal comfort improvement for pitched/sloped cool roofs in India. Four test rooms in two locations Chennai (Warm and Humid) and Bhiwadi (Composite) were installed with Shingle-1 (initial albedo of 0.15) and Shingle-2 (initial albedo of 0.30). The difference in roof albedo between both the shingles is 0.15. The Chennai site was used for comfort monitoring and the Bhiwadi site was used for energy studies.
To assess the indoor comfort, a frequency graph has been plotted with the occurrence of indoor air temperatures. The histogram plot of temperatures recorded for Chennai displays a shift in the peak temperatures towards the comfort range in case of high albedo roof compared to roof with low albedo. There was 26% increase in overall thermal comfort by using cool roof.
The experimental results for Bhiwadi show that minimum and maximum electrical energy savings from the air conditioners are 27.1 Wh/m$^2$-day and 60.8 Wh/m$^2$-day respectively.

## Introduction

The roof of a building receives the maximum direct solar radiation compared to the other envelope components (Takebayashi and Moriyama 2007). A roof that reflects and emits the solar radiation back to the sky rather than transferring it into the building is termed as a cool roof (Cool Roof Rating Council n.d.). The cool roof helps in reducing air conditioning energy consumption in a conditioned building and improves thermal comfort in an un-conditioned building. The percentage energy savings achieved in a building from cool roofs is dependent on various parameters like the location, orientation of the building, local shading by trees or other buildings, construction type, insulation type, plenum ventilation, equipment load, occupancy and operational schedules (Konopacki and Akbari 2001). With the increase in the electricity consumption in the building sector and as the urban landscape is becoming more and more compared to the rural areas surrounding it, high albedo surfaces are employed as a geoengineering technique to delay the global carbon emissions, reduce the temperature of cities and to achieve energy savings in the buildings.
By installing high albedo roof, one can expect energy savings in the HVAC systems in conditioned buildings and increased thermal comfort in un-conditioned buildings. Early experiments to verify these results have been performed in the United States, and slowly and steadily, many countries have rigorously tested and adopted them. It is notable that the maximum

benefits of high albedo roofs can be seen in the hot and humid climatic zones. Florida Solar Energy Centre has conducted an early investigation to identify the savings that can be achieved from high albedo roofs (Parker et al. 1996). One such experiment was conducted in a commercial building in Coca Beach, Florida, for a period of two years. An annual savings of 13,000 kWh was observed from the chiller. An experiment was performed to understand the energy-saving benefits from high albedo roofs in developing countries (Akbari et al. 2011). The metropolitan area of Hyderabad was chosen for this study in which a commercial building was monitored for a period of one year. The measured annual energy savings from white roofs over black roofs ranged from 20 -22 kWh/m$^2$ of roof area and the corresponding energy use reduction of 26 % was observed. This study also concluded that over a concrete roof in commercial buildings of Hyderabad a savings of 13-14 kWh/m$^2$ of roof area which transcribes to 10% -19% of annual energy can be achieved. A study performed in rural and peri-urban areas of India shows improvement in thermal comfort with the application of cool roof (Garg et al. 2014). Study performed in Greece shows 17% reduction in annual cooling demand with the application of cool roof (Kolokotsa et al. 2018). A study (Rosado et al. 2014) performed in central California shows annual energy cost savings were \$0.886/m$^2$ (20%) with the use of high albedo roof. Another study was conducted to find the impact of high albedo roofs, and green roofs in a Mediterranean climate (Zinzi and Agnoli 2012) found that there is an improvement of indoor thermal comfort in summer using cool roofs.

In India, there is an increase in trend of having steep-sloped roofs, particularly in places with high precipitation and coastal regions. Using cool roofing solution can help in bringing down the air conditioning energy consumption and increase thermal comfort conditions. In this paper, an experimental study performed in two locations of India is demonstrated.

## Methodology

The methodology for identifying the energy-saving potential and comfort improvements involve experiment design and measurements at the site.

### Monitoring parameters

Cool roof reflects the incident solar radiation at the roof surface, thereby reducing the over deck surface temperature and heat ingress into the house. To quantify the energy-saving potential and comfort improvements due to cool roofs, it is necessary to understand the heat ingress through the roof surface. In case of a conditioned home, cool roof helps in reducing the air conditioning energy. A cool roof also reduces the mean radiant temperature inside a house, which helps in increasing the thermal comfort conditions. In the experiment outdoor roof surface temperatures, ceiling temperatures, indoor air temperatures were measured. Apart from these indoor parameters, the outdoor weather conditions such as the Global Horizontal radiation, dry bulb temperature, outdoor relative humidity, wind velocity and direction, and precipitation were measured. These parameters were logged continuously using a data logger. The sampling rate of the sensors was one data point per second, and the data has been averaged and logged for every five minutes.

## Experimental design

The study was performed on two near-identical test rooms in two cities of India - Chennai, and Bhiwadi. The experiment was performed for a roof with a slope of 30 degrees to the horizontal. The roof of one of the test rooms was coated with a dark conventional roof and another one coated with a cool roof. The test rooms in Bhiwadi were set up to run in a conditioned mode to measure the energy savings potential through high albedo shingles. The test rooms in Chennai were set up to run in an unconditioned mode to test the improvement in thermal comfort. The test rooms have been built of a brick wall and concrete roof. A schematic of the test rooms is shown in Figure 1. The test rooms were designed for two person occupancy with a carpet area of 24 $m^2$. During the day time on weekdays, only one person is considered to occupy the test hut. During weekends the house is considered to be fully occupied. The heat generation from the internal loads is considered to be 120 W.

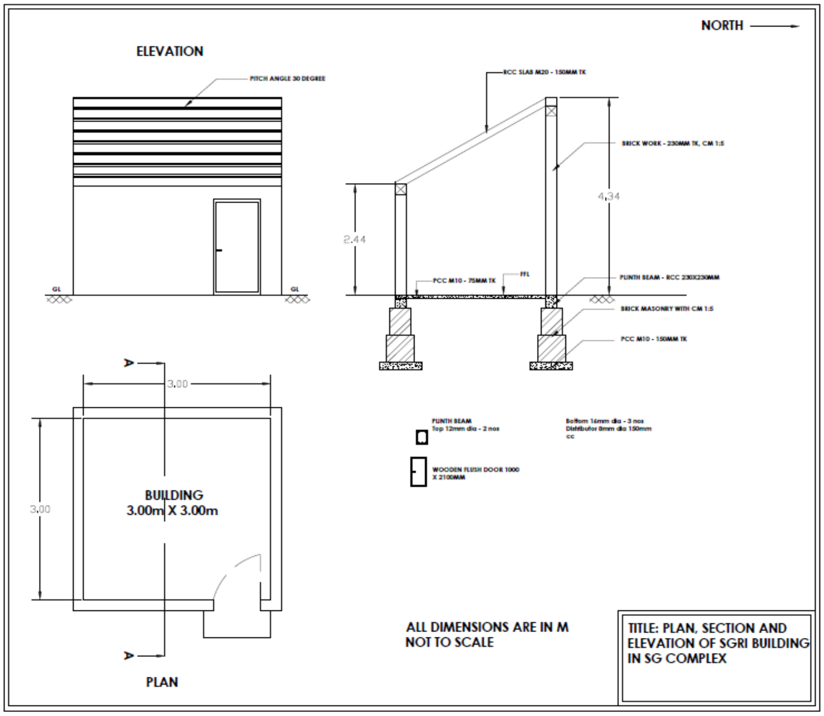


*Figure 1 Schematic of test rooms*

## Monitoring Phases

The test apparatus was monitored in two phases.

a) The first phase was when both the buildings were near identical.

b) In the second phase, the roof of one of the test apparatus (Room A) was changed to a high albedo surface and Room B was changed to a low albedo roof.

## First phase

During this phase all the monitoring parameters were matched between the two test apparatus. This phase was to ensure that both test apparatus behave in the same way before the start of the experiment.

## Chennai (Warm and Humid)

Measurements were performed in the calibration phase when roofs of both the rooms were identical. Data for outdoor roof surface temperatures, ceiling temperatures, indoor air temperatures were measured and analysed. It was observed that in unconditioned mode, the test rooms were performing identically. The Outside Roof Surface Temperature (ORST) was plotted as shown in Figure 2. Data were nearly identical for both roofs indicating the roof albedo were similar in both.

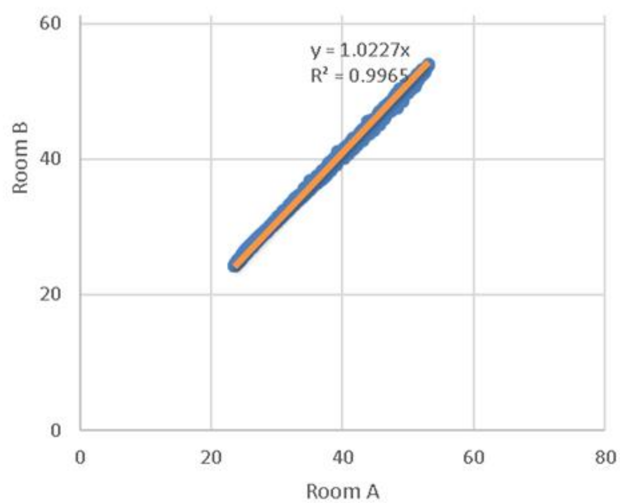


*Figure 2 Scattered Plot ORST (°C) for Room A and Room B*

## Bhiwadi (Composite)

Measurements were performed in the calibration phase when roofs of both the test rooms were identical for the Bhiwadi location. Sensor locations are shown in Figure 3. It was observed that in conditioned mode, the test rooms were performing identically as seen in Figure 4.

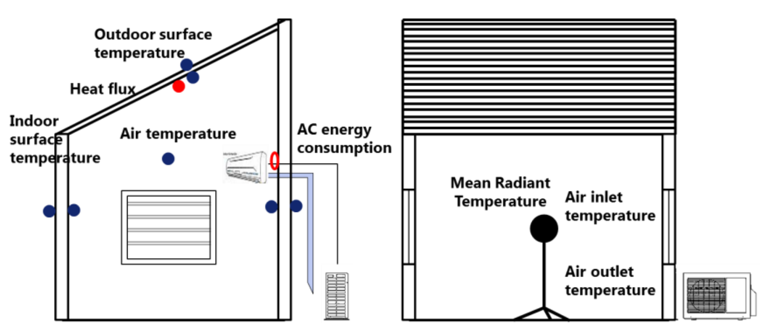


*Figure 3: Instrumentation for the test rooms*

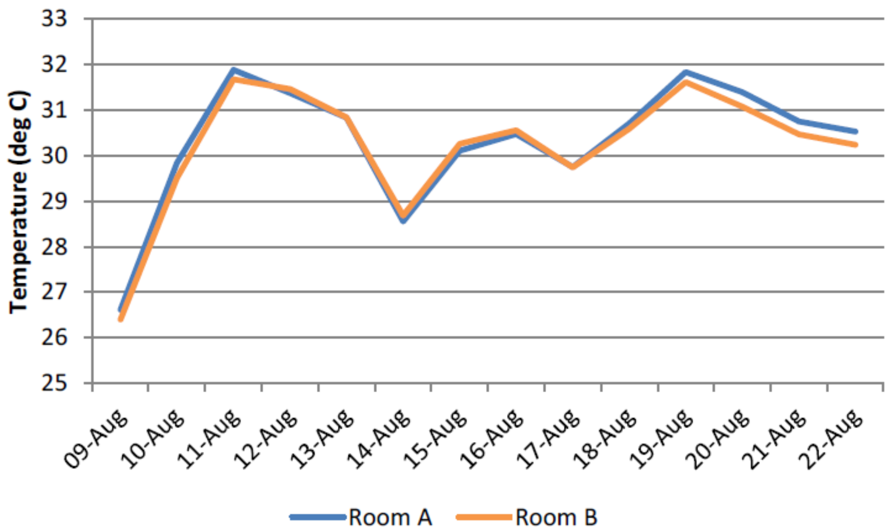


*Figure 4 Daily ORST (deg C)*

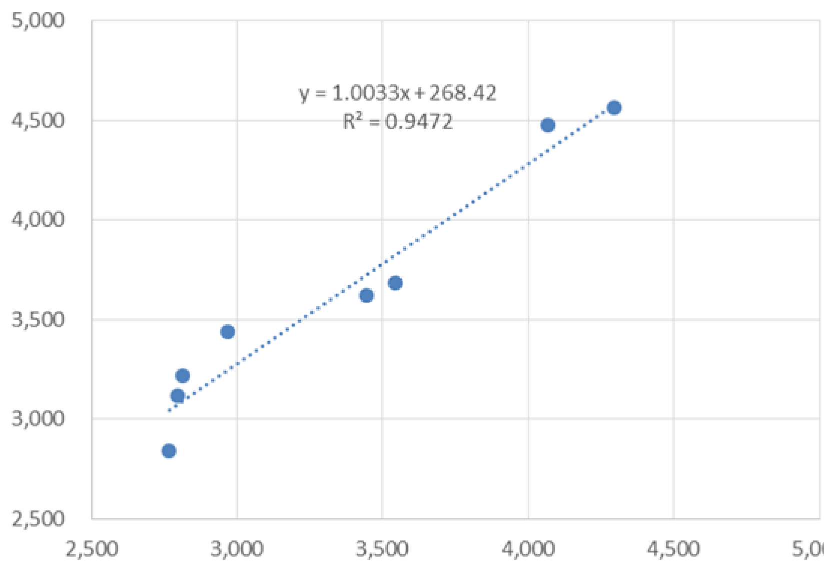


*Figure 5 Calibration phase - Daily AC electrical energy consumption (kWh) for Bhiwadi*

From Figure 5, the relation between Room A daily energy consumption $E_A$ and Room B daily energy consumption $E_B$ is as follows:

$$E_B = (E_A \times d) + c \tag{1}$$

To correct the daily cooling energy use in Room B to match that of Room A, the following correction factor is applied to the daily cooling energy of Room B:

$$E'_B = (E_B - c)/d \tag{2}$$

where
$E_A$ = daily cooling energy use of Room A
$E_B$ = daily cooling energy use of Room B
$E'_B$ = corrected daily cooling energy use of Room B
$c$ = fitted coefficient (268.4)
$d$ = fitted coefficient (1.003)

*Table 1 Measured daily cooling energy consumption for Rooms A and Room B, and corrected daily cooling energy consumption for Calibration phase*

| Date | $E_A$ (kWh) | $E_B$ (kWh) | $(E_B - E_A) / E_A$ (%) | $E'_B$ (kWh) | $(E_{B'} - E_A) / E_A$ (%) |
|---|---|---|---|---|---|
| 15-08-17 | 3,445 | 3,617 | 5.0% | 3337.6 | -3.1% |
| 16-08-17 | 2,797 | 3,115 | 11.4% | 2837.2 | 1.4% |
| 17-08-17 | 2,814 | 3,214 | 14.2% | 2935.9 | 4.3% |
| 18-08-17 | 2,972 | 3,436 | 15.6% | 3157.2 | 6.2% |
| 19-08-17 | 4,071 | 4,477 | 10.0% | 4194.7 | 3.0% |
| 20-08-17 | 4,296 | 4,565 | 6.3% | 4282.4 | -0.3% |
| 21-08-17 | 3,547 | 3,683 | 3.8% | 3403.3 | -4.0% |
| 22-08-17 | 2,769 | 2,839 | 2.5% | 2562.1 | -7.5% |

From Table 1 it can be observed that the corrected daily cooling energy use of Room B is much closer to the daily cooling energy use of Room A after the correction is applied, with a maximum difference of -7.5%. Therefore, this correction can be applied to the daily cooling energy data monitored during Phase II as well.

### Second Phase

In the second phase, the roof of one of the test apparatus (Room A) was changed to a high albedo surface and Room B was changed to a low albedo roof.

## Results and Analysis

Post calibration, Chennai site was chosen for comfort analysis. The test rooms were run in unconditioned mode and the temperature inside the rooms was used as a parameter to measure comfort.

### Temperatures

The reduction on temperatures such as the over deck surface temperatures and the under deck surface temperatures were analyzed on an hourly basis to understand the effectiveness of cool roof over the dark roof. Indoor air temperatures were measured to ensure both the test huts are conditioned to the same temperature. The histogram plot of temperatures (deg C) for Chennai Figure 6 and Figure 7 show a shift in the peak temperatures towards the comfort range in case of high albedo roof compared to roof with low albedo.

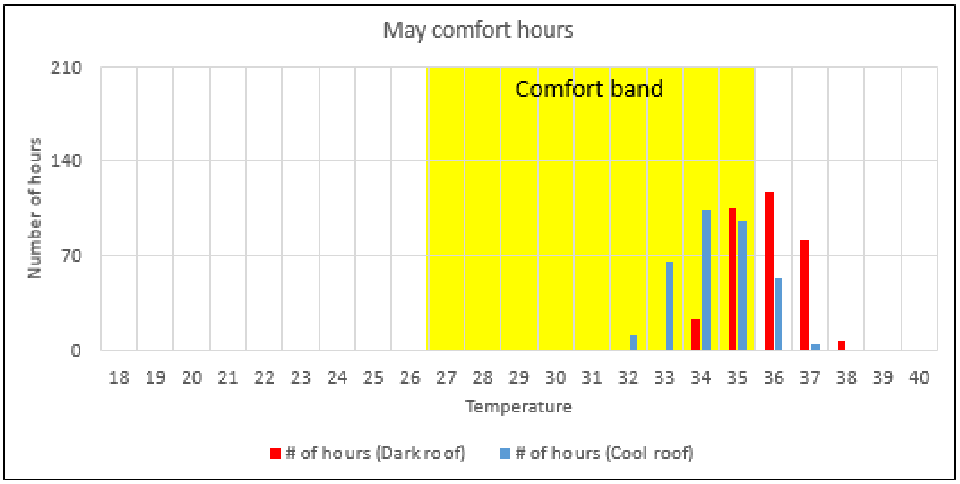


*Figure 6 Comfort analysis May*

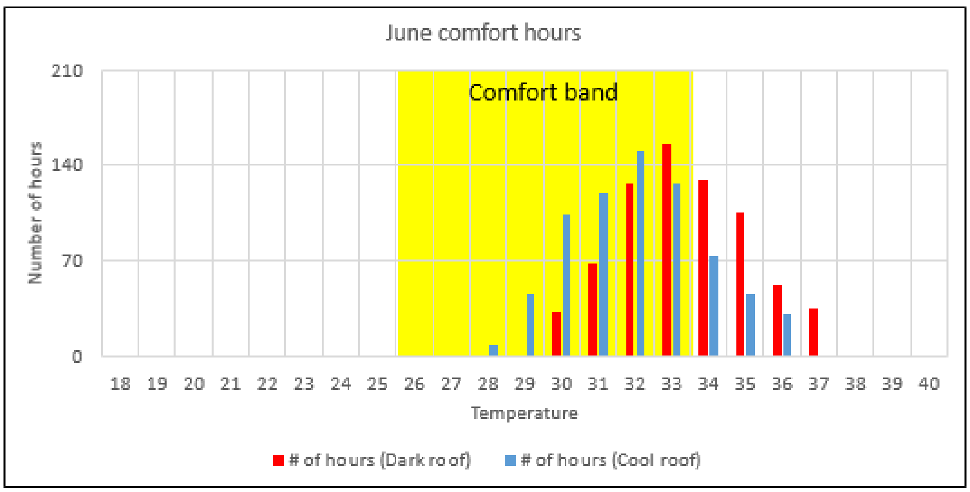


*Figure 7 Comfort analysis June*

## Energy-saving potential

After the calibration and roofing installation monitoring was started for AC electrical energy in Bhiwadi. Using the electrical power meter sensors the air conditioning energy savings achieved by using cool roofs as compared to the dark roof were calculated and normalized to the roof area. To measure the outdoor conditions, a weather station was also installed.

On examining the roof surface temperature, the difference of ORST between Rooms A & B is 3.8°C during the monitoring period with the maximum difference of 14.8°C which occurs during the peak hours. A scatter plot between the ORST of the test Rooms shown in Figure 8. The slope of the plot is less than 45 degrees, indicating the roof surface temperatures of Room B is higher than that of Room A.

The electrical AC energy savings from the experiment is shown in Figure 9, the maximum electrical AC energy savings from high albedo roof (Room A) is 397 Wh/day which accounts to 21% of the energy consumption of low albedo roof (Room B) and the minimum energy savings is 110 Wh/day which accounts to 8% of the energy consumption of Room B. These results are before applying correction from first (calibration) phase. After applying the correction, the slope of the graph has shifted from 0.82 to 0.75. In both cases, the R-square value is close to 0.98 which implies a very good fit of the model with the real data as seen in Figure 10.

Both Room A & B electrical energy consumption after the correction has been plotted in Figure 11 and the savings have been plotted in Figure 12. It was observed that minimum and maximum energy savings are 27.1 Wh/Sqm-day and 60.8 Wh/sqm-day respectively.

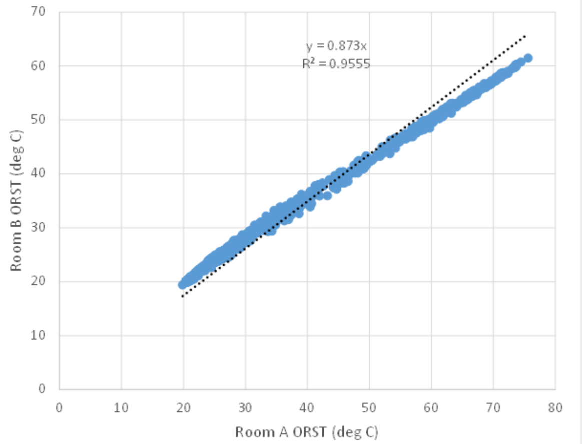


*Figure 8 Scatter plot hourly ORST for test Rooms (Bhiwadi)*


*Figure 9 Daily average AC electrical energy consumption of test Rooms (Bhiwadi)*

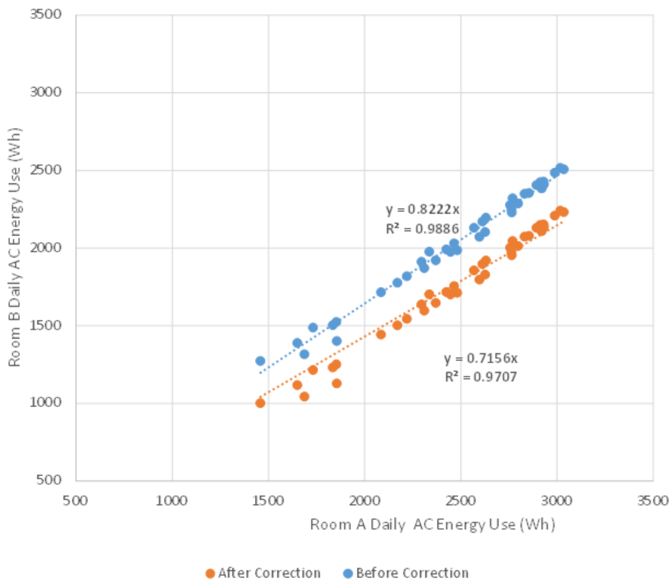


*Figure 10 Scatter plot of daily AC consumption before & after applying correction- phase II*

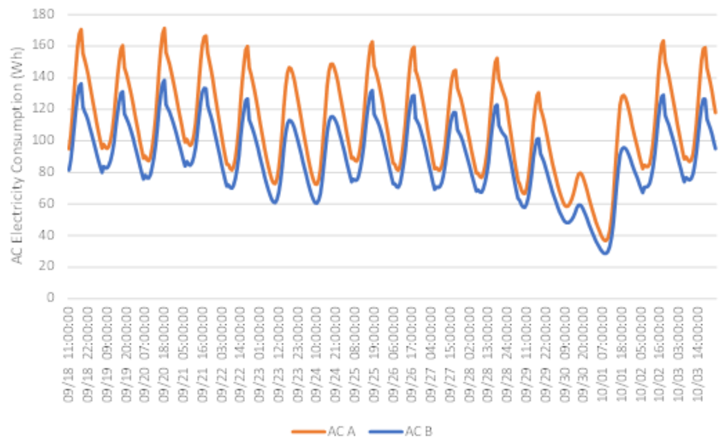


*Figure 11 Hourly AC electrical energy consumption of test Rooms (Bhiwadi)*

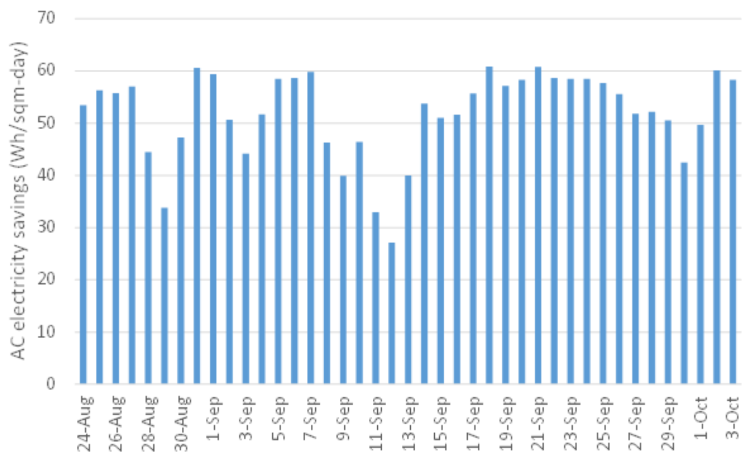


*Figure 12 AC electricity savings Bhiwadi*

## Conclusions

To assess the benefits of albedo on a sloping roof, an experiment was performed in two Indian cities situated in different climate zones. In this experiment, two experimental near identical test rooms were constructed in each city. Each test room roof is installed with shingles having different albedos. The Shingle 1 (albedo 0.15) was compared against Shingle 2 (albedo 0.30). The experimental results show that minimum and maximum electrical energy savings from the air conditioners are 27.1 Wh/m$^2$-day and 60.8 Wh/m$^2$-day respectively and the over deck roof temperatures for the rooms with Shingle 2 is 3.8°C lower on average and the maximum reduction of 14.8 deg C can be observed. The reduction in indoor temperature, which corresponds to an improvement in thermal comfort is about 1.5-2°C, which translates to 26% improvement in thermal comfort.

## Acknowledgments

The authors acknowledge the Indo-French Research Consortium (CEFIPRA) for funding this study. The authors also acknowledge the efforts of Saint-Gobain India Private Limited (Glass division) for providing the space for the experiments, support in civil construction and providing security to the test rooms.

## Abbreviations

| | |
|---|---|
| ORST | Outside Roof Surface Temperature |
| RCST | Room Ceiling Surface Temperature |
| AC | Air Conditioner |
| OAT | Outdoor Air Temperature |

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