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Assessment of the impact of cool roofs in rural buildings in India

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ABSTRACT

Increasing roof reflectance reduces absorption of solar radiation, roof surface temperature and heat ingress into the building. This leads to an increase in indoor comfort and reduction in room air temperature that in turn results in energy saving by reducing AC demand. To assess this impact of cool roofs on buildings in rural and peri-urban areas of India, a study was performed on two un-conditioned school buildings in Hyderabad (ZPH School) and Nagpur (VNHM School). Two classrooms of same size, function, and occupancy from both the school buildings were monitored for a period of ten weeks starting from March 2014 till May 2014. The data from the experiments and their analyses showed promising results. The average reduction and peak reduction in indoor air, roof underdeck and roof overdeck surface temperatures are 2.1 °C, 5.0 °C and 12.3 °C and 4.3 °C, 10.0 °C and 26.3 °C respectively for the room with white roof as opposed to grey roof in ZPH School and 1.5 °C, 4.0 °C and 9.5 °C, and 3.3 °C, 4.2 °C, and 25.2 °C respectively in VNHM School. The results from the experiment prove that white roof has a significant effect in reducing the indoor air temperatures in buildings due to reduction in outdoor and indoor roof surface temperature.

1. Introduction

Schools and other buildings in the rural and peri-urban areas in a country like India suffer from serious indoor environmental problems like heat stress, lack of comfort, and poor indoor air quality. This has a very serious impact on the quality of life and health of the occupants that includes students and teachers. In climates with high solar radiation like Hyderabad and Nagpur, reducing heat gains is essential to maintain comfortable conditions inside the building. The application of cool roofs minimizes the heat gain into the classrooms.

A cool roof is a roof that reflects most of the incident sunlight and efficiently emits some of the absorbed radiation (especially in Near Infrared (NIR) band) back into the atmosphere, instead of conducting it to the building below. A cool roof helps in reducing energy consumption in a conditioned building and improves thermal comfort in an un-conditioned building [1]. There are several benefits of cools roofs such as energy savings, increase in occupant comfort, reduction of the heat island effect, and reduction in the flow of thermal radiation into the troposphere ("negative radiative forcing") offsetting the global warming induced by emission of greenhouse gases. Since the focus of this project is to decrease indoor air temperature to increase indoor comfort, similar studies on cool roofs were reviewed.

A study by Suehrcke et al. [2] examines the effect of roof solar reflectance on a residential building's heat gain in a hot climate. The study aimed at understanding the decrease in heat gain through the roof due to the use of a highly reflective roof. Calculations were performed for a residential building in northern Australia and it was observed that a light-coloured roof reduced heat gain by 30% as compared to a dark coloured roof. Xu et al. [3] quantified the direct benefits of a cool roof in an urban setting by reporting the decrease in cooling energy use in a commercial building and the resulting greenhouse gas emissions. By converting dark roofs to white roofs, measured annual energy savings ranged from 20 to 22 kWh/m^2 of roof area in the Metropolitan Hyderabad region, corresponding to an air conditioning energy use reduction of 14–26%. Annual savings of 13–14 kWh/m^2 of roof area could be achieved by applying white coatings to uncoated concrete roofs on

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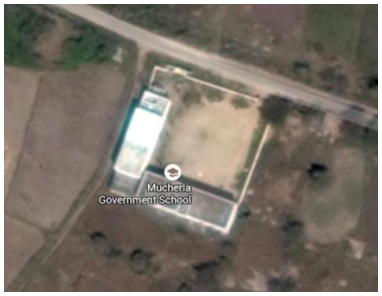
Table 1
Schools selected for cool roof experiment.

Location	Google image	Photograph
School 1: Zilla Parishad High School (ZPH School) Mucherla Village *Location*: ZPH School, Mucherla Village, Rangareddy District, AP, India (17°0′55″N, 78°30′40″E)		
School 2: Valmiki Nagar Hindi Madhyamik School (VNHM School), Nagpur *Location*: VNHM School, Gandhi Nagar, N. M. C. Nagpur, India (21°8′13.76″N, 79°03′12.10″E)		

buildings in the region, corresponding to cooling energy savings of 10–19%.

In a simulation based study by Bhatia et al. [4] a calibrated simulation model was used to demonstrate the effectiveness of the measure in five different climatic zones of India. The study demonstrated that in all climates except cold climate, the financial payback period with a cool roof could be less than 3 years. Through calibrated simulations, a building with a cool roof was noted to decrease heat flow into the building by 49%. Synnefa et al. [5] estimated the effect of cool coatings on energy loads and thermal comfort in residential building in various climatic conditions. Simulations were performed on residential buildings across 27 cities around the world. The results show that increasing the solar reflectance of the roof reduces the cooling demand by 18–93%, which is around 9–48 kWh/m^2/year.

In another study by Nahar et al. [6] the indoor thermal comfort conditions were improved by decreasing the hours of discomfort by 9–100% and the maximum temperatures in non-air-conditioned residential buildings by 1.2–3.3 °C. This study was done to experimentally determine the reduction in heat flow through a roof using white paint and glazed tiles in a hot and dry climatic zone of India. They observed up to 10 °C drop in the inside temperature of small scale models using glazed tiles and white paint. There are many studies that present results for commercial/residential buildings in urban settings or small scale models. However, there are no monitoring experiments done in actual unconditioned buildings in India. In this study, we examine the comfort benefits of cool roofs for un-conditioned school buildings in warm climates of rural India. The experiment discussed in this paper provides an important real-world evaluation of one of the cost effective solutions that serves as an important component of integrated design for sustainable living environment.

2. Methodology

The objective of this project is to monitor the roof surface (over deck and under deck) temperature and room indoor air temperature by the application of cool roof. To achieve this, two buildings were identified in the rural/peri-urban areas close to the cities of Hyderabad and Nagpur. The sites were selected because of the variations in their geographical location (see Table 1). The monitoring equipment was installed in 2 rooms in each school and was monitored for a few weeks before applying the "cool roof" coating to ensure that their performance was identical. It was important to ensure this for a reasonable side by side comparison of the results. After this, one of the roofs at each location was coated with a high albedo coating. A polymer-acrylic blended ceramic coating was selected for the coating. Ceramic coating has the ability to reflect the visible, infrared, and ultraviolet wavelengths of the sun, thereby reducing heat transfer to the building.

In this paper, the room with high albedo coating applied to its roof surface will be referred to as treated room and the room without cool coating will be referred to as untreated room. Both the rooms were monitored for a period of 10 weeks with measurements taken in 1 min intervals at ZPH School, Mucherla and 10 min intervals at VNHM School, Nagpur. A weather station was installed at each school to collect the local weather data. The difference in indoor air temperatures, over deck surface temperatures and the under deck surface temperatures were analyzed to learn the effectiveness of the application of a cool roofs in these schools.

3. Selection of buildings for experiment

The selected buildings are located in the rural area near Hyderabad and in the peri-urban area of Nagpur. The selected buildings are secured and free from external shading. Both the buildings have identical rooms with same size, similar occupancy pattern, good roof condition, proper drainage system and low height parapet walls. These school buildings are two storied structures with 300 mm plastered brick walls and 150 mm thick grey cemented concrete roof with no insulation. The rooms selected in ZPH School and in VNHM School are both located on the first floor of the building under the roof and they measure 7.3 m × 7.3 m and 5 m × 6 m