Analysis of optimal selection of energy efficient roofing material – A compartive study

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ABSTRACT

This paper presents the results of an experimental, analytical, and simulation results of an innovative cool roof system on thermal behavior and energy performance of a building. An experimental monitoring has been carried out during the year 2015 to assess both indoor and outdoor thermal conditions of the building. In Chennai which has a tropical wet and dry climate, temperature is always at a higher level except two to three months and finding out a cost effective and energy efficient roofing material is the need of the hour not only to tackle heat but to abate pollution as well. A cool roof is energy efficient roof that strongly reflects sunlight and also cools itself by efficiently emitting radiation to its surroundings. This is also known as passive cooling technique. The term 'cool roof' encompasses an extensive array of roof types, colors, textures, paints, coatings, and slope applications. In this study experiments are conducted on four different building models with different types of roofing materials and cooling load for each model was found analytically. A simulation model using the selected material is done in revit Architecture. From the study it is found that white coat roofing material is best out of the materials tested.

KEY WORDS: Cool Roof, Energy Efficient, Solar Reflectance, Thermal Performance.

1. INTRODUCTION

As the demand for energy is increasing day by day and building sector is one of the major consumers of energy, energy conservation in buildings deserve importance. Many modern buildings in India are constructed of concrete or cinder blocks and are topped with flat, tar covered roofing. Such surfaces absorb the incident sunlight, transferring it to the interiors of the building during night. Thus the hot ceiling continues to heat up the space during the day and night making the spaces unbearably hot throughout the summer season and extended to two to three winter months also. In Chennai, temperature is always at a higher level except two to three months and finding out a cost effective and energy efficient roofing material is the need of the hour not only to tackle heat but to abate pollution as well and hence this study.

A cool roof or energy efficient roof is one that strongly reflects sunlight and also cools itself by efficiently emitting radiation to its surroundings. This roof literally stays cooler and reduces the amount of heat conducted to the building below. The term, 'cool roof' refers to the outer layer or exterior surface of the roof which acts as the key reflective surface. These roofs have higher solar reflectance than an ordinary roof surface. Cool roof' encompasses an extensive array of roof types, colors, textures, paints, coatings, and slope applications. A white coloured roof strongly reflects both visible and near infrared sunlight, a white roof will typically be cooler than a colored cool roof. Thus the two basic characteristics that determine the "coolness" of a roof are Solar Reflectance (SR) and Thermal Emittance (TE). Solar reflectance is the ratio of solar energy that is reflected by a surface to the total incident solar radiation on that surface. Thermal emittance is the relative ability of a material to re-radiate the absorbed heat as invisible infrared radiation. One of the test cases involved both an increase in solar reflectance and infrared emittance (Anna Laura Pisello, 2014).

Researchers have studied the ways of reducing cooling and heating loads in a building by means of adopting cool roof concept. Synnefa (2007), studied the impact from using cool roof coatings on the cooling and heating loads and the indoor thermal comfort conditions of residential buildings for various climatic conditions. Anna Laura Pisello, Franco Cotana (2014), studied the possibility of applying an innovative "cool roof" solution, consisting of a prototyped cool clay tile, on a traditional residential building in central Italy to improve the thermal conditions of the indoor environment that is adjacent to the roof. Hashem Akbari (1997), monitored the effects of cool roofs on energy use and environmental parameters in six California buildings at three different sites. Haberl and Cho (2004), in their literature review about cool roof impact on building cooling requirement (Akbari, 1997), found that cool roof technology is able to save about 20% of cooling requirement in residential and commercial buildings. Kolokotroni (2011), found that this strategy should be included as an effective building passive retrofit solution also in temperate climates where the optimum reflectance value is around 0.6-0.7, the effect of application of cool roof paint in a naturally ventilated office building in London. Simulations of annuals building energy demand have shown that the cool roof technology has a positive impact for low insulated buildings in various climates as it reduces indoor air temperature during summer. In fact, several numerical and experimental researches showed important benefits in terms of energy saving for cooling in case of different buildings' uses, e.g. residential buildings. Their results showed that installing a cool roof reduced the daily peak roof surface temperature of each building by 33–42 K.

In this paper, performance of different energy efficient roofing materials were done and compared using analytical, experimental and simulation methods. Experiments were conducted on four physical models of 15 Sq.ft.

roof area and cooling loads for the same were compared analytically. The performance of selected material is further studied by doing a simulation study on a building model with and without the application of cool coat using the software Revit Architecture. Though the adoption of cool roofing materials is found to be costly at the initial stage, the initial cost can be compensated by the reduced monthly electricity bills.

2. MATERIALS AND METHODS

Experimental method: Four building models of area 15 Sq.ft. are experimented in this study. The latitude and longitude of the location are *Lat* (DMS), 12° 53' 52N, *Long* (DMS), 80° 2' 41E. For the building models, single wall brick same orientation is adopted as it is a comparative study. The Model 1 roof was constructed of reinforced cement concrete without any finishing material, Model 2 roof was adopted with ceramic tile, Model 3 was coated with Titanium Dioxide (white coat) and Model 4 roof was topped with Terracotta (Red clay tile). The building orientation was chosen in such a way that maximum solar intensity falls over the models and self-shading is prevented. Surface temperatures of roofing and inside temperatures of the models were measured and monitored with Non-Conduct IR Thermometer and Hygrometer respectively. Monitoring period selected in this study is the summer season with highest temperatures when cooling load required is maximum. The study is extended to winter period also. The thermal properties of the above materials are given in table (1) and fig (1) shows one of the models.

Table.1. Properties of roof materials

Properties	White coat	Ceramic tile	Red clay tile
SRI (Solar Reflective Index) %	79 - 90	73 - 85	40 - 65
Thermal Emittance	0.73 - 0.85	0.67 - 0.81	0.45 – 0.71
Price/sq.ft $)	0.527	1.05	0.602

Figure.1. Roof model 4 with red

Clay tile:

Analytical methods: A comparative study of cooling loads for all the models is done using steady state heat balance equation (1); (4) MNRE, SP 41 1987. Each heat flow values are calculated analytically and added to get the total heat flow in the models with different roofs.

Qtotal = Qc + Qs + Qi + Qv

Where, Qtotal – Total heat flow of air in the room; Qc – Heat flow due to conduction; Qs – Solar gain through transparent elements; Qv – Heat flow due to ventilation.

$$Qc = \sum_{i=0}^{Nc} A_{iU_i} \Delta T_i$$

Where, I – Building element; Nc – no. of components.

$$\Delta T = T_{so} - T_i$$

Where, T_{so} – Solar air temperature; T_i – Indoor air temperature; A – Surface area of the building component; U – Thermal transmittance; ΔT – Temperature difference between inside and outside.

$$Qs = \alpha_s \sum_{i=1}^{M} A_i S_{gi} \tau_i$$

Where, α_s= mean absorptivity of the space; Ai = area of the ith transparent element (m^2); Sgi = daily average value of solar radiation (including the effect of shading) on the ith transparent element (W/m^2); ti = transmissivity of the ith transparent element; M = number of transparent elements.

Qi- Heat flow rate due to internal heat gain

Qi = (No. of people × heat output rate) + Rated wattage of lamps + Appliance load

Qv = ρVr C ΔT

Where, ρ = density of air (kg/ m^3); Vr = ventilation rate (m^3/ s); C = specific heat of air (J/ kg-K).

ΔT = temperature difference (To – Ti) (K)

Where, To- outside temperature, Ti- inside temperature.

Simulation study: A simulation study for the selected material is conducted for residential building of 2067sq.ft. Plinth area with and without the cool roof to check the thermal performance. AutoCAD Revit Architecture is used for simulation study.

3. RESULTS & DISCUSSIONS

From the analytical and experimental methods it is found that white coat is best out of the four models tested. The Thermal profiles of internal & external surface temperature and indoor and outdoor temperatures of the experimental models are shown in fig.2 and tabulated in table.2. Average rate of change of roof surface temperature, thermal performance index and thermal damping of the models are depicted in Figures.3, 4 and 5. From Figure.3, it obvious that the variation in temperature over time is less for model coated with white coat. The % reduction in the monthly cooling load requirement for the models from analytical calculation is represented in table.3.The cooling load requirement for model with white coat is less compared to the other models. The monthly electricity consumption of the simulated building before and after the coat is shown in Figures.6 and 7. The simulated models are shown in Figure.8.

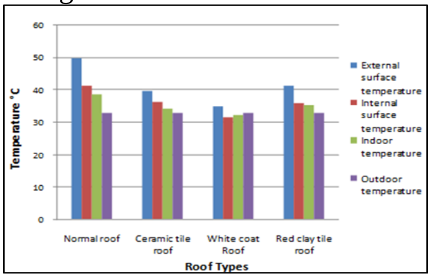

Figure.2. Thermal profiles of internal & external surface temperature and Indoor and outdoor temperature

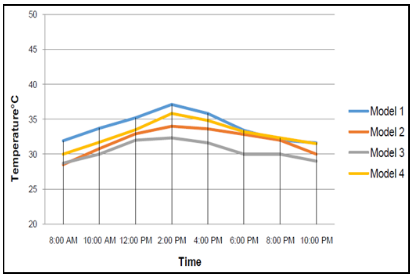

Figure.3. Average rate of change of roof surface temperature

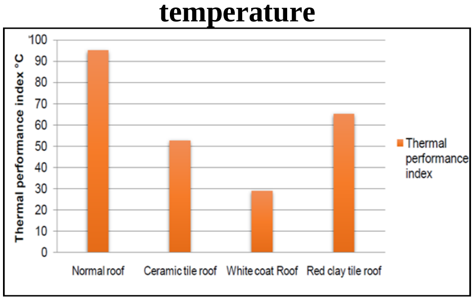

Figure.4. Thermal performance index of study materials

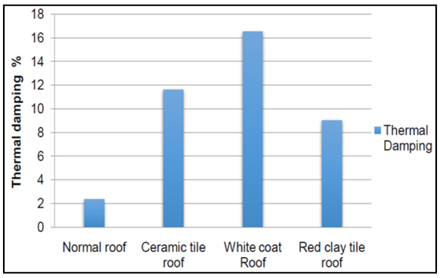

Figure.5. Thermal damping of study materials

Table.2. Thermal performance of model materials

Type of roof	Temperature			
	External surface temperature	Internal surface temperature	Indoor ambient temperature	Outdoor ambient temperature
Normal roof	49.8°C	41.5°C	37.6°C	38.7°C
Ceramic tile roof	39.7°C	36.3°C	34.2°C	38.7°C
White coat roof	35°C	33.7°C	32.3°C	38.7°C
Red clay tile roof	41.2°C	36°C	35.2°C	38.7°C

Table.3. % reduction in the monthly cooling load requirement

Sl. No	Models	% reduction in cooling load compared to the normal roof
1	Model 1	-
2	Model 2	7.24
3	Model 3	21
4	Model 4	5.37

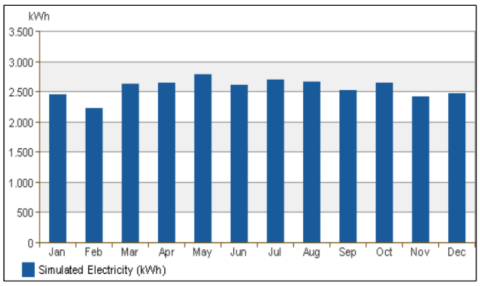

Figure.6. Monthly electricity consumption before application of coat

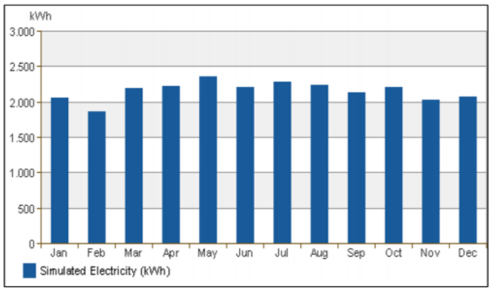

Figure.7. Monthly electricity consumption after application of coat

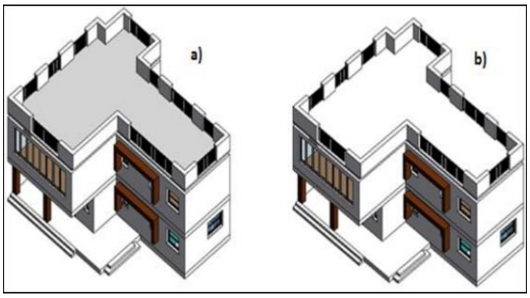

Figure.8. Simulated building in Revit Architecture, a) is building without coat and b) with coat

4. CONCLUSIONS

The temperature analysis of results of white coat shows that, compared to normal roof there is a reduction of 14.8ºC in the case of external roof surface temperature and 8.4ºC in the case of internal roof surface temperature. The inside air temperature shows a reduction of 5.3ºC. The white roof coating is also able to reduce temperature variations over the roof and from this study it is found that white coat gives more occupancy comfort and compared to the other two materials it is found to be cheap as well. Compared to the normal roof the initial increase in cost can be compensated by the reduction in monthly electricity bills. The analytical and simulation results support this fact. Hence white coat can be used for new buildings or for roof retrofitting cost effectively to get better thermal comfort.

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