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Experimental Investigation of Passive Cooling using Solar Reflective Paint (SRP) coating.

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ABSTRACT

The present study is focused to analyze the effect of applying a solar reflective paint on the exterior surface and compare the experimental values of the study with theoretical data. This analysis is restricted to a location like Chennai city, where there is no heating requirement. Based on the ECBC guidelines, white colour solar reflective paint with a solar reflectance of 80% is used in this study. The average temperature observed inside the test structure without and with SRP coating is 35.75°C and 31.59°C. The heat gain into the building is drastically reduced from 0.426083 kWh/day to 0.015228 kWh/day thereby reducing the cooling energy required to achieve the comfort within the test structure by 96.48% for the occupants within the test structure situated in tropical hot climatic conditions.
Keywords: Solar reflective paint, passive cooling, indoor environment, thermal comfort, energy consumption.

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INTRODUCTION

Need for human comfort necessitated cooling and heating techniques for building which has increased the use of cooling and heating systems thereby increasing the consumption and demand of conventional energy based on fossil fuels. Building architecture of yesteryears used a variety of passive techniques to minimize the flow of heat into as well as from a building. In contemporary times, these have been forgotten. For tropical country like India where the Tropic of Cancer is running through almost the middle of the country, the climate is hot and temperatures is generally quite high especially in southern peninsular India with solar radiation intensity around 800 – 950 W/m^2 [1]. India's 2011 census provided an interesting data. As per the census, one Indian out of three live in an urbanized areas. Compared to the population growth in larger Indian cities with ten lakh and more population, the growth in smaller cities was rapid. With miminal impact on the environment and sustainably using the available natural resources, the basic needs of every people in this country has to be met. This is a challenging task but can be achieved by taking simple, effective, locally sustainable modifications in the design and construction of urban houses thereby reducing the resource consumption.

The existing already constructed buildings need cooling and with availability of electrical energy crisis prevailing in India along with high electricity energy cost, the lone alternative is to adopt low-cost passive cooling techniques. Passive cooling is a technique of restricting / removing the heat from / to the environment of a building using the natural heat rejecting process to the ambiance by radiation, convection and conduction. Apart from economic benefits, India, as a signatory of Kyoto protocol, is obliged to reduce green house gases. By adopting this passive cooling techniques, thermal behaviour of existing already constructed buildings can be improved thereby increasing the comfort of the inhabitants.

In general, the heat is transferred though a roof by conductive, convective and radiative mode of heat transfer. Figure 1(a) shows the different sources for heat gain within the building. Proper selection of roof materials can minimize the heat transfer. Heat transfer through conduction can be restricted by using insulated materials in the ceiling. The convective heat transfer depends upon the wind, its velocity and incidence. Using reflective materials on the exterior surface, the radiative mode of heat transfer is lessened by minimizing the solar energy absorption. The emissive property of the reflective paint applied on the external surface cools the roofs by irradiating absorbed energy in the reverse manner. Also, quantity of long wave thermal energy radiated into the inner of a building can be decreased by using low emissivity materials on the interior surface of the roof. Fiber cement tile is highly emissive and with highly reflective paint applied on the exterior surface, it reduces the exterior surface temperature and restricts the heat transfer to the interior of a building. Recently, as seen in Fig. 1(b), cool paint is widely used in which the pigment of the conventional paint is replaced with a "cool" pigment, which restricts the absorption of infra red radiations.

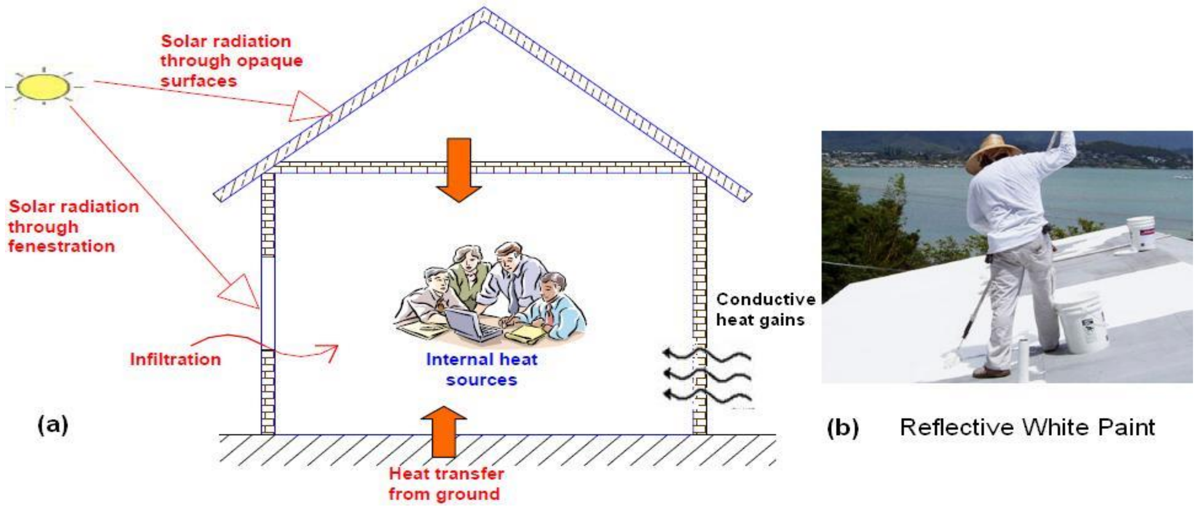

Fig. 1 (a) Different sources for heat gain within a building (b) Applying reflective white paint on the roof surface

Several researchers especially from European Union countries, USA, Australia, New Zealand, Japan, Brazil, GCC countries have carried out studies on the cooling potential of the building with the application of reflective coatings on it. Presently in India, the importance of application of reflective coating is recently taken in a serious manner. Earlier, the thermal behaviour of a building to the external surface colour was studied by Bansal *et al*. [3]. The performance of white colored coating improved compared to aluminum pigment based coating. Commercially available white paints contains carbonates and oxides of zinc, calcium, aluminum and titanium and it possess high reflectivity in the visible region. Harrison and Walton [4] used a white paint that contained 35% titanium dioxide on the exterior of the buildings under certain conditions and a significant radiation cooling with 15^{o}C below ambient temperature was obtained. A detailed review on paints and its capabilities, coating techniques and technologies to control surface thermal radiation was presented by Wijewardane and Goswami [5]. Cool paints and its impact on the thermal behaviour and energy demand of residential buildings both old and newly constructed were studied numerically and experimentally by Diana Dias *et al* [6]. The study showed that there was 43% decrease in cooling needs with reduction in temperature by around 5^{o}C thereby providing a cheap solution to thermal comfort in existing buildings.

Studies by Guo *et al*. [7] showed that by applying heat reflective insulation coating on exterior surfaces, the air conditioning electricity savings annually was about 5.8 kWh/m^2 month. Givoni and Hoffman [8] studied the interior temperatures of different unventilated building and observed a 3^o C lesser temperature in the summer for a building painted with white compared to a one painted with grey. Synnefa *et al*. [9] mentioned the cool materials for urban habitats. They reported that white concrete tile painted with reflective coatings reduced the surface temperature by 4^{o}C. Harry Suehrcke *et al*. [10] performed studies in hot climates to understand the impact of roof solar reflectance on building heat gain. They highlighted the difference in heat gain between dark and light coloured roof surfaces and suggested that light coloured roof had 30% lesser heat gain than the latter. Uemoto *et al.* [11] compared the thermal performance of cool coloured acrylic paints having infra red reflective pigments with conventional coloured acrylic paints of similar colours (yellow, white and brown).

The prevalence of Urban Heat Island (UHI), phenomena created due to elimination of natural vegetation and replacing it with paved surfaces and buildings [12], is rising day by day in large metropolitan cities causing the temperatures to exceed by 10^{o}C than above those in the adjoining neighbor areas [13]. Roofs of the building is an important absorber of heat from solar radiation and temperature of such areas (e.g. roofs, pavements) reaches around 30 to 45^{o}C whereas the temperatures were between 16 to and 26^{o}C for the surrounding areas with vegetation with a difference of around 20 degree C [14]. The application of highly reflective cool coating on the exterior surface reduces the temperature of roof and building facade thereby increasing the indoor thermal comfort during the hot season by reducing the necessity for cooling. Passive cooling technique [15] is a low-cost, easy to apply, effective, energy efficient and helps in reducing the phenomena of Urban Heat Island [12]. Due to aesthetic reasons, the heat absorbing darker colour which contribute to UHI were preferred. So, cool non-white colours were developed [16]. Still these cool paints of darker colours reflected solar radiation [12]. Urban climatic change and heat island effect caused enhanced used of air conditioners thereby increasing the electricity demand. Passive cooling techniques provide comfort in non air conditioned buildings as well as reducing cooling loads in thermostatically controlled buildings, improve outdoor urban environment and control heat island effects. A detailed summary on the state of art of passive cooling dissipation techniques for buildings and other structures were discussed by several authors [2, 17].

Based on the literature review it is established that applying solar reflective coating improves the human comfort inside the building and thereby reducing energy demands for cooling. Even though wide-ranging studies were carried out in especially in European Union countries and U.S.A extensive research is not carried out in India which predominately has a hot climate. Presently in India, all the air conditioned and naturally ventilated spaces has to comply with ECBC 2007 requirements [18]. This present paper focuses on the effect of applying solar reflective paint (SRP) on the exterior surface and compares the experimental values of the study with theoretical data.

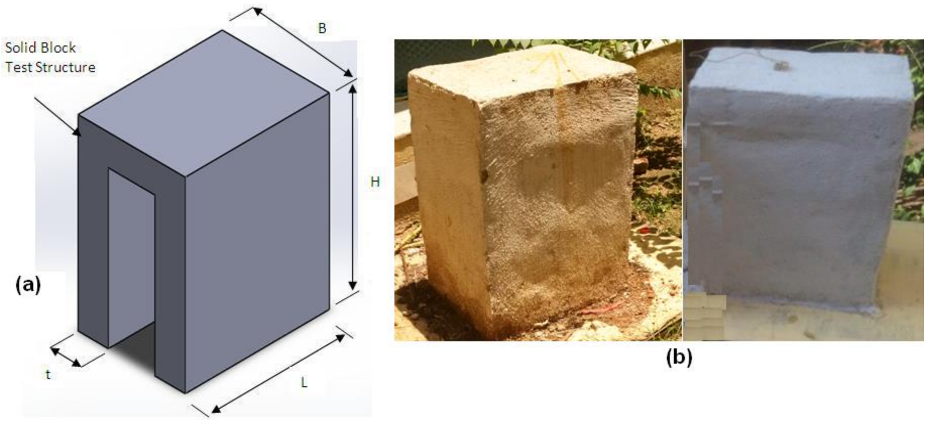

Fig. 2. (a) Schematic model of the test structure (b) Experimental setup of the test structure with reflective paint coating

Experimentation

ECBC presently mandates a minimum solar reflective index (SRI) of 0.70 [19]. Table 1 shows the details of the materials and design inputs used in the study. Based on the measurements as given in Table 1, a room made with concrete solid block is made. Initially, the experiment is conducted without any coating and later with a coating of solar reflective paint (SRP) of thickness 200 microns. K type thermocouple is used to measure the temperature on the inside the test structure. Similar thermocouple is used to measure the ambient temperature. The trials are conducted from 10:00 am to 16:00 pm and the readings are measured a time interval of 30 minutes. Figure 2(a) and 2(b) shows the schematic diagram and experimental setup of the test structure with reflective paint used in the present study.

Table 1. Technical details of the experimental setup

Solar reflective paint – Technical details		Colour of the solar reflective paint	White
		Reflectance of the solar reflective paint	80%
		Emmitance of the solar reflective paint	90%
		Coating thickness of the solar reflective paint	200 microns
		Thermal transmittance (U) of the solar reflective paint coating [20]	0.040 W/m^{2}K
		Building material used for making wall	125 mm thick brick wall
		Thermal resistance (R) of the solar reflective paint coating [20]	25 m^{2}K/W
Test structure – Dimensional details	Without SRP coating	Thermal transmittance (U) of the 125 mm (0.41 feet) thickness brick wall + 12 mm plaster on both sides [1]	4.347 W/m^{2}K
		Thermal resistance (R) of the wall assembly -- 125 mm (0.41 feet) thickness brick wall + 12 mm plaster on both sides [1]	0.23 m^{2}K/W
	With SRP coating	Thermal transmittance (U) of the 125 mm (0.41 feet) thickness brick wall + 12 mm plaster on both sides + Solar reflective paint coating on the exterior surface	0.0396 W/m^{2}K
		Thermal resistance (R) of the 125 mm (0.41 feet) thickness brick wall + 12 mm plaster on both sides + Solar reflective paint coating on the exterior surface	25.23 m^{2}K/W
	Length of the test structure (L)		594.36 mm (1.95 feet)
	Width of the test structure (B)		441.96 mm (1.45 feet)
	Height of the test structure (H)		762 mm (2.50 feet)
	Thickness of the wall (t)		124.96 mm (0.41 feet)

RESULT AND DISCUSSIONS

This analysis is restricted to a location like Chennai city, where there is no heating requirement and it is carried out at the campus of Hindustan Institute of Technology and Science, Padur,near Chennai. Figure 3 shows the average of the daily high and low temperatures of the Chennai city throughout the year. The peak temperature varied between 35°C to 42°C with average peak temperature around 38°C (311 K) which is considered as the ambient temperature for the analytical studies. The temperature for human comfort for the present study is assumed to be 300 K (27°C).

Theoretical Analysis

As seen in Fig. 1(a), the conductive heat gain through opaque surfaces (walls, roofs, etc.) which is a sensible heat transfer process for every month is calculated by the equation.

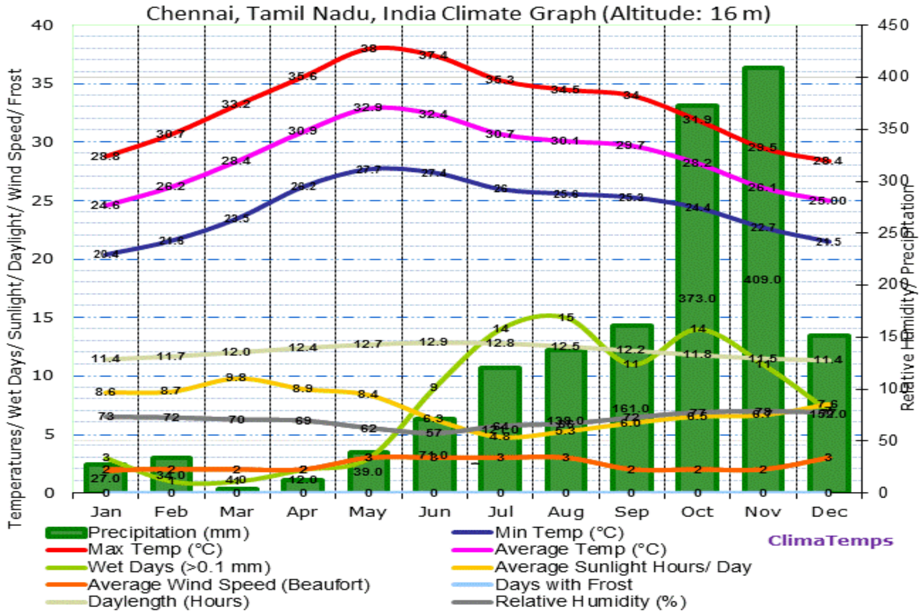

Fig. 3. Average temperature of the Chennai city throughout the year

$$Q_{opaque} = U\,A\,(T_{ambient} - T_{inside}). \quad (1)$$

where Q_{opaque} is the heat transfer through opaque surfaces (kWh), U is overall heat transfer coefficient, (W/m^{2}K), A is heat transfer area of the surface (m^2), T_{inside} is the indoor dry bulb temperature (K), $T_{ambient}$ is the outdoor dry bulb temperature (K) and n is number of hours per month. Average temperature of the city of Chennai, based on Fig. 3, $T_{ambient}$ is assumed to be 311 K (38°C) and the temperature for human comfort, T_{inside} is assumed to be 300 K (27°C).

The heat transfer due to infiltration by sensible component is calculated by the expression as

$$Q_{inf,\,sensible} = m\,C_p\,(T_{ambient} - T_{inside}) = Q\,\rho\,C_p\,(T_{ambient} - T_{inside}). \quad (2)$$

where T_{inside} is the indoor dry bulb temperature (K), $T_{ambient}$ is the outdoor dry bulb temperature (K), Q is the infiltration rate (m^3/s), ρ is the density of the infiltrated air (kg/m^3) and C_p is the specific heat of the infiltrated air (J/kgK).

Using air change method approach, the infiltration rate (Q) is expressed as

$$Q = (ACH)\,V / 3600. \quad (3)$$

where V is the gross volume of the space in m^3 and ACH is the number of air changes per hour. The value of ACH is nearly 2.0 for poorly and loosely sealed building whereas it is 0.50 for well sealed and tight building. The ACH value is very low as 0.20 for the modern building built now-a-days. Infiltration rate (Q) value for different design arrangements of walls, doors, windows, etc are mentioned in air conditioning design handbook [21].

The ventilation heat loss can also be calculated based on the equation

$$Q_{inf} = 0.33\ N\ V\ (T_{ambient} - T_{inside}). \quad (4)$$

where Q_{inf} is the ventilation loss (W), N is the number of fresh air changes per hour of the building (ac/h) and V is the volume of the inside space of the building (m^3).
Heat gain through fenestration is given as

$$Q_s = \Sigma A_{unshaded}\ S\ SHGF_{max}\ CLF. \quad (5)$$

where Q_s is the heat transfer through fenestration (kWh), ΣA is the glass area of the window which is exposed to solar radiaton (m^2), S is the shading coefficient, $SHGF_{max}$ is the maximum solar heat gain factor and CLF is the cooling load factor. Based on the window location, its orientation, month of the year, internal shading device as well as type of glass material, the values of CLF, S and $SHGF_{max}$ is estimated.

The total heat gain by the building is

$$Q = Q_{inf} + Q_{opaque} + Q_s. \quad (6)$$

In this present study, internal loads due to products stored or processes performed, due to appliances and equipments, due to lightings and due to occupants are not considered. Table 2 list the values obtained based on the theoretical study.

Experimental Study

The study was carried out on 16th October 2015 and Table 3 shows the readings of the prevailing ambient temperature and the temperature inside the test room structure with coating of solar reflective paint and uncoated test structure. Figure 4 and 5 shows the temperature distribution inside the room with and without solar reflective paint coating. As the solar radiation increases by the day and reaches the peak value around noon, peak temperature inside the room without coating is reached around 13:00 pm and afterwards, as the sun falls, the solar radiation gradually decreases and similar distribution of temperature inside the room is observed without coating. As seen in Fig. 6 for a room with solar reflective paint coating, the temperature is lesser than without coating and a difference in temperature of around 3 to 7 degrees is observed. Figure 6 shows the comparative temperature distribution of the ambient temperature with temperatures inside the test structure with and without SRP coating.

Table 2. Heat gain by the building by theoretical analysis and experimental approach

Heat gain components within the building	Theoretical Analysis (kWh/day)		Experimental Study (kWh/day)	
	Without SRP Coating	With SRP Coating	Without SRP Coating	With SRP Coating
Conductive heat gain through opaque surfaces (Q_{opaque})	1.7274	0.01589	0.424	9.9274×10^{-3}
Heat transfer due to infiltration by sensible component ($Q_{inf,\ sensible}$)	8.4999×10^{-3}	8.4999×10^{-3}	2.0832×10^{-3}	5.3006×10^{-3}
Total heat gain by the building ($Q = Q_{inf} + Q_{opaque}$)	1.73589	0.0243899	0.426083	0.015228
Cooling Energy required	1.73589	0.0243899	0.426083	0.015228

Table 3. Temperature observed at atmosphere and inside the building

Outside ambient Temperature [°C]	Inside Room Temperature-with SRP coating [°C]	Inside Room Temperature - without SRP coating [°C]	Time [in hours]
35.1	29	32.2	10:00 am
36.4	29.2	33.4	10:30 am
37.8	31	34.9	11:00am
39.2	30	36.3	11:30am
41.3	32	38.3	12:00pm
41.8	32.4	38.4	12:30pm
41.9	32.5	38.8	13:00pm
39.4	32.5	36.4	13:30pm
40.2	33.2	37.1	14:00pm
37.5	32.5	34.5	14:30pm
36	32.4	34.5	15:00pm
35	32.4	34.3	15:30pm

The average ambient temperature, temperature observed inside the test structure without and with SRP coating is found to be 38.46 °C, 35.75 °C and 31.59°C respectively. The fall in temperature observed for test structure inside is around 4.16°C for solar reflectance of 80%. Based on the theoretical study, the total heat gain is estimated to be 1.73589 kWh/day without SRP coating whereas it is 0.0243899 kWh/day with SRP coating. On the other hand, based on experimental investigations, total heat gain is found be 0.426083 kWh/day without applying SRP coating and 0.015228 kWh/day on application of SRP coating on the test structure. On applying the SRP coating to the test structure, the heat gain is drastically reduced by 96.48%. The cooling energy required to achieve comfort within the test structure too is reduced from 0.426083 kWh/day to 0.015228 kWh/day by 96.48%.

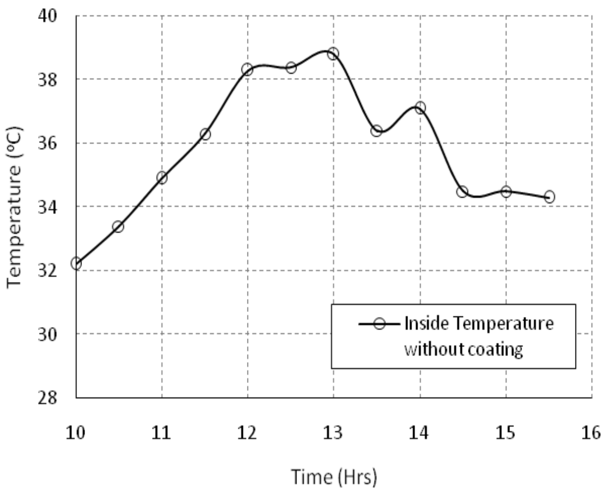

Fig. 4. Inside temperature without coating of reflective paint on the exterior surface

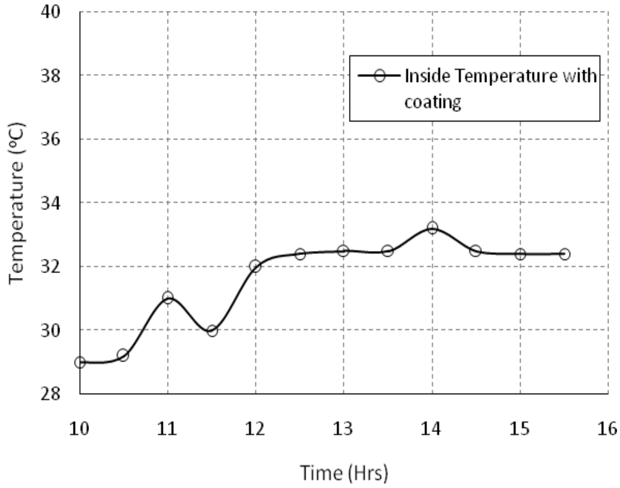

Fig. 5. Inside temperature with coating of reflective paint on the exterior surface

The results demonstrated that applying the SRP coating on the exterior surface of test structure resulted in efficient reduction of heat gain within the test structure and also reducing the energy consumption for cooling the buildings offering comfort conditions for the occupants within the buildings located in tropical hot climate.

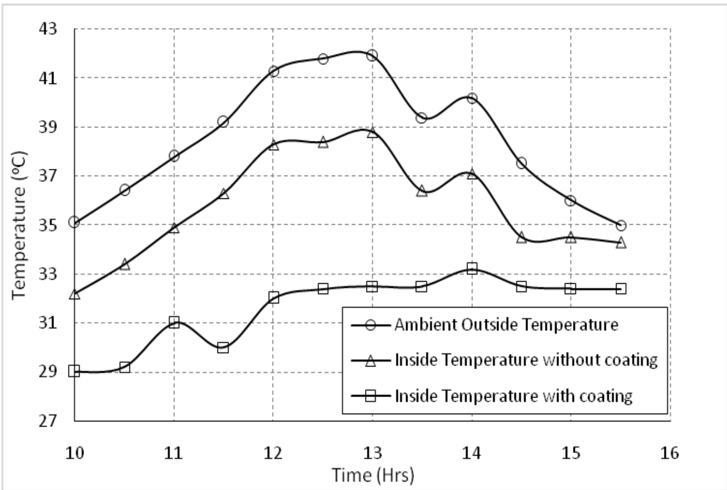

Fig. 6. Comparison of ambient temperature, inside temperature with and without coating

CONCLUSION

Based on the theoretical and experimental investigations, it is shown that white solar reflective paint coating with solar reflectance of 80% is able to reduce the heat gain into the building thereby reducing the cooling energy required to achieve the comfort within the test structure by 96.48% from 0.426083 kWh/day to 0.015228 kWh/day. The average temperature observed inside the test structure without and with SRP coating is 35.75°C and 31.59°C respectively and by this means, providing a comfort conditions for the occupants within the test structure situated in tropical hot climatic conditions.

REFERENCES

[1] Integrated Green Design for Urban and Rural Buildings in Hot-Dry Climate Zone, Central Public Works Department, Government of India, New Delhi, February 2013.

[2] D.G. Leo Samuel, S.M. Shiva Nagendra and M.P. Maiya, Passive alternatives to mechanical air conditioning of building: a review, Building and Environment. 66 (2013) 54-64.

[3] N.K.Bansal, S.N. Garg and S.S. Kothari, Effect of exterior surface colour on the thermal performance of buildings, Building and Environment. 27 (1) (1992) 31-37.
[4] A.W. Harrison, M.R. Walton, Radiative cooling of TiO2 white paint, Solar Energy. 20 (1978) 185-188.
[5] S. Wijewardane, D. Y. Goswami, A review on surface control of thermal radiation by paints and coatings for new energy applications, Renewable and Sustainable Energy Reviews. 16 (2012) 1863-1873.
[6] Diana Dias, Joao Machado, Vitor Leal and Adelio Mendes, Impact of using cool paints on energy demand and thermal comfort of a residential building, Applied Thermal Engineering. 65 (2014) 273-281.
[7] W. Guo, X. Qiao, Y. Huang, M. Fang and X. Han, Study on energy saving effect of heat-reflective insulation coating on envelopes in the hot summer and cold winter zone, Energy and Buildings. 50 (2012) 196-203.
[8] B. Givoni, M.E. Hoffiman, Effect of building materials on internal temperatures, Research Report, Building Research Station, Technion Haifa, 1968.
[9] A.Synnefa, M. Santamouris and I. Livada, A Study on the thermal performance of reflective coatings for urban environment, Solar Energy. 80 (2006) 968-981.
[10] Harry Suehrcke, Eric L Peterson and Neville Selby, Effect of roof solar reflectance on the building heat gain in a hot climate, Energy and Buildings. 40 (2008) 2224-2235.
[11] Kai L Uemoto, Neide M.N Sato and Vanderley M. John, Estimating thermal performance of cool colored paints, Energy and Buildings. 42 (2010) 17-22.
[12] A. Synnefa, M. Santamouris and K. Apostolakis, On the development, optical properties and thermal performance of cool colored coatings for urban environments, Solar Energy. 81 (2007) 488-497.
[13] Soares, Ilhas de Calor Fazem temperatura variar até 12 graus dentro de São Paulo, O Estado de São Paulo, São Paulo, 09 de setembro de 2007-Caderno Metrópole C4, 2007.
[14] L.L. Andrade, L.H. Souza, H. Sakuragi and R.M. Castro, Estudo de ilhas de calor na cidade de São José dos Campos utilizando o canal infravermelho termal do Landsat-5 e o aerotransportado HSS, in: Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, INPE, 2007, pp. 473-480.
[15] M. Santamouris, K. Pavlou, A. Seneca, K. Niachou and D. Kolokotsa, Recent progress on passive cooling techniques: advanced technological developments to improve survivability levels in low-income households, Energy and Buildings 39 (2007) 859–866.
[16] M. Ryan, Introduction to IR-reflective pigments, Shepherd Color Company, 2005, Available in http://www.shepherdcolor.com.
[17] Mattheos Santamouris, Dionysia Kolokotsa, Passive cooling dissipation techniques for buildings and other structures: the state of the art, Energy and Buildings. 57 (2013) 74-94.
[18] TERI (The Energy and Resources Institute), New Delhi, http://www.teriin.org
[19] Information on http://www.eco3.org/ecbc/
[20] Information on http://www.energysaving-coatings.com
[21] Shan K. Wang, Handbook of air conditioning and refrigeration, Second Edition, McGraw- Hill Publications, New York, USA, 2000.