



Analysis of Cool Roof Passive Techniques for Residential Buildings in a Subtropical Humid Climate

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Abstract. The objective of this study was to provide the thermal comfort by means of passive cool solar reflective materials which have a high solar reflectance and high thermal emittance on the existing roof and thereby reducing the consumption of electrical energy. Experiments were performed by using locally available solar reflective materials to insulate the roofs. In this work, the thermal performance of concrete roof and asbestos sheet roof with and without insulation has been analyzed by performing experiments to existing buildings. The results are verified by computer simulation using Computational Fluid Dynamics tools with FLUENT software. The result of using solar reflective paint with high reflective coating shows a fall of 4.8°C in peak hours and saves 303 kWh when considering an energy load with an air conditioner in the summer season, in comparison to non-insulated pitched and flat roof energy loads of residential buildings in Bhopal. An optimum solution of an insulator for both types of roofs is presented. The application is intended for low-rise or medium-rise residential buildings in a subtropical climate like Bhopal.

Keywords. *passive cooling, cool roof, thermal comfort, insulators, subtropical climate*

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Introduction

Despite the declaration of various schemes, the residential buildings in India have been experiencing an unusual increase in the frequency of power outage. Figures available with the Central Electricity Authority (CEA, 2016) show that during the summer of 2016, the peak demand in India was 159,542 megawatt (MW), but only 156,934 MW of it was met. Thus, during last summer, there was a peak deficit of 1.6%. This growth in demand for electricity in the summer is due to the increased use of mechanical equipment for thermal comfort (Yeretzian and Visser, 2013).

It is concluded in many research papers that one of the ways of reducing energy generation is to reduce the demand for air conditioning (Akbari et al., 1998; Ferreira and Prado, 2005; Yeretzian and Visser, 2013). Engineers and architects should investigate more in researching different passive and active strategies to reach the best possible solution for thermal comfort. This can

be done by using less energy and by natural climatic control for their buildings instead of relying on machines for cooling which are electricity dependent, and take part in ruining the environment (Yeretzian and Visser, 2013).

Mainly in summer, thermal comfort is always the main concern in subtropical climate regions like Bhopal. Passive cooling and natural ventilation have traditionally been two important features in the city of nawabs. To achieve thermal indoor comfort, vernacular architecture can be seen in old monuments of Bhopal.

Using insulators with good thermal resistance for roofs, either during the designing and construction of the building, or during renovation, are usually more cost-effective and can reduce a considerable amount of the energy that is consumed in cooling (Boixo et al., 2012; Synnefa et al., 2007; and Synnefa et al., 2010). Cool roofs by applying insulators in the form of solar reflective

materials are one of the cost-effective passive strategies that install easily, reduce heat gain, and improve thermal comfort in warm climates (Synnefa, et al., 2010; Uemoto et al., 2010). From the above studies, it can be said that in building regulations, it should be mandatory in every country (having a hot climate) to install cool roofs, for this being the least expensive option to achieve the energy conservation and thermal comfort. From here, the objective of research comes out: to reduce the amount of energy used to reduce cooling energy demands during the summer by focusing on the cool roof as a solution.

The main idea for this study is to enhance the implementation of passive cool solar reflective material on the existing roof through an investigation of several possibilities and alternatives which are easily available in the city. In this paper, we have investigated the two types of roofs by comparing the results of before and after of applying four different types of insulators to achieve thermal comfort and energy saving. The cool roof is one of the passive cooling strategies; Implementation of this plan will be able to conserve the energy needs of the building. This scheme can economize the required energy expenditure, to make a comfortable space condition, and attempt to lower the cooling load drastically. Thus, this present research evaluates a range of possible varieties of roof insulation which are easily available and simple in use, in terms of cost and availability.

The experimental study in this research covers solutions for reducing the inside temperature by applying the passive strategy in the form of insulators on the roof for low-rise and medium-rise residential buildings in Bhopal, India. The research is divided into two parts; in the first part, experiments were performed with and without using insulators and observed data for ambient temperature and surface temperature. In the second stage, the results are verified using simulation tool Computational Fluid Dynamics tools with FLUENT software. The results of this research on existing residential buildings show a significant reduction in thermal load and energy consumption. The recommendations given for further research consists of combining cool roof

techniques with wall insulation, and window insulation as a way of reducing cooling loads.

The Concept of Cooling through Roofs

Synnefa et al. (2010) stated that the technology of a cool roof is an energy efficient, sustainable, and financially viable solution for reducing building energy consumption for cooling and mitigating heat islands. Parker et al. (1995) concluded that cooling through roofs on a building's envelope for reducing the thermal loads and energy demands is considered as a passive solution depending on different types of building. Many experimental studies proved that the roof surface can reach up to 37°C above the ambient temperature on a normal sunny day in warm climates (Borge-Diez et al., 2013). The actual advantage of a cool roof on any particular building will depend on several factors in which the most important is the climatic zone, including building type and load. In spite of this, there are many environmental benefits of cool roofs. In urban areas, as the quantity of heat transferred from roofs decreases, heat in the urban environment also reduces. Hence, using the cool roofs technique reduces urban air temperatures as proved by Zinzi and Fasano (2009). This can be achieved very efficiently by using reflective coatings and materials of good thermal resistance (Rossi et al., 2014). Parker et al. (1995) proved in their study that a cool roof improves indoor thermal comfort. Consequently, dependency on mechanical systems for cooling increases electricity bills. (Pisello et al., 2013) Applying a cool roof will achieve a reduction of about 10% to 40% in air conditioning energy (Akbari et al., 2005; (Pisello et al., 2013; Synnefa et al., 2007). Granja and Labaki (2003) studied, in the case of a low thermal resistance or thickness of roof, there is a reduction in heat flux up to 74 W/m² while the color changes from gray to white.

Rossi et al. (2014) presented a review study on cool roofs and heat island mitigation showing that during the peak period in hot climates, in comparison to the green roof, reflective cool roofs with high solar reflectance present much higher heat island mitigation potential.



Figure 1: Photograph of Room 1 & 2

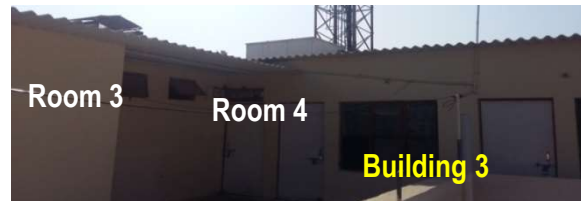


Figure 2: Photograph of Room 3 & 4

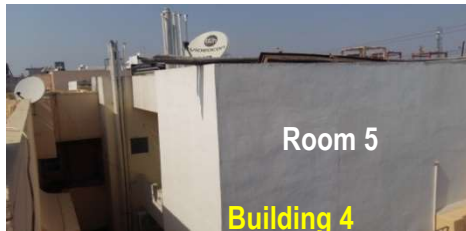


Figure 3: Photograph of room 5

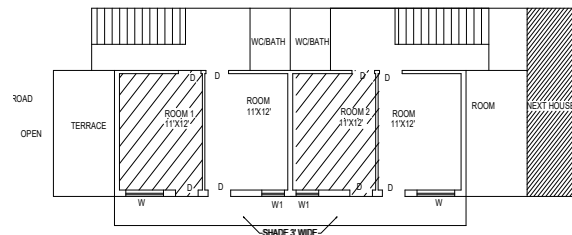


Figure 4: Plan of room 1 & 2

Table 1

Tools used for taking data

Data taken	Ambient Temperature	Humidity	Surface temperature
Tools used	Hygrometer	Hygrometer	Infrared thermometer
Specifications	Humidity Accuracy: $\pm 6\%$ in the 25 to 80% range and from 0 to 50°C (32 to 122°F) Temperature Accuracy: $\pm 1^\circ\text{C}$ from -10 to 50°C and $\pm 1.8^\circ\text{F}$ from 14 to 122°F		Temperature Range - -40°C to 50°C Accuracy: $< 0^\circ\text{C}$ (32°F): $\pm(1.0^\circ\text{C} (\pm 2.0^\circ\text{F}) + 0.1^\circ/1^\circ\text{C}$ or $^\circ\text{F}$); $> 0^\circ\text{C}$ (32°F): $\pm 1\%$ or $\pm 1.0^\circ\text{C}$ ($\pm 2.0^\circ\text{F}$), whichever is greater

In the following sections, types of building, typology, and the weather of the city with the performance of insulation material which is relevant and applicable in the Bhopal context will be discussed.

Building Typology and Weather Analysis

The aim of the study was to select a building type which was in a conventional pattern of the construction techniques used in Bhopal. Most of the residential buildings in Bhopal are low-rise duplexes, and the flat system is still not very common in Bhopal. The selected buildings are low-rise buildings and are very common residential buildings in Bhopal. These are located in one of the main residential areas. The buildings are constructed from framed structures made of concrete with brick masonry, and with a concrete flat roof and asbestos sheet roof having a

false ceiling below it. The details of the selected buildings are shown in Table 2. Bhopal has an average elevation of 500 meters. The average annual high temperature in Bhopal during summer ranges from 38°C to 43°C and average annual low temperature during winter ranges from 19°C to 22°C . Due to the urban heat island, sometimes temperatures can reach 45°C inside the city during summer time (Bhopal Weather, 2017). Humidity always remains high during summer time and hence the atmosphere remains sweaty. Monsoons usually start from July and last until September ends.

After the literature review on the insulating material, a search was done for the availability of locally available material. The materials used were Solar Reflective Paint (SRP), hydrated lime, tiles, and aluminum paint. Thermal properties and other details of insulators are given in Table 3.

Table 2

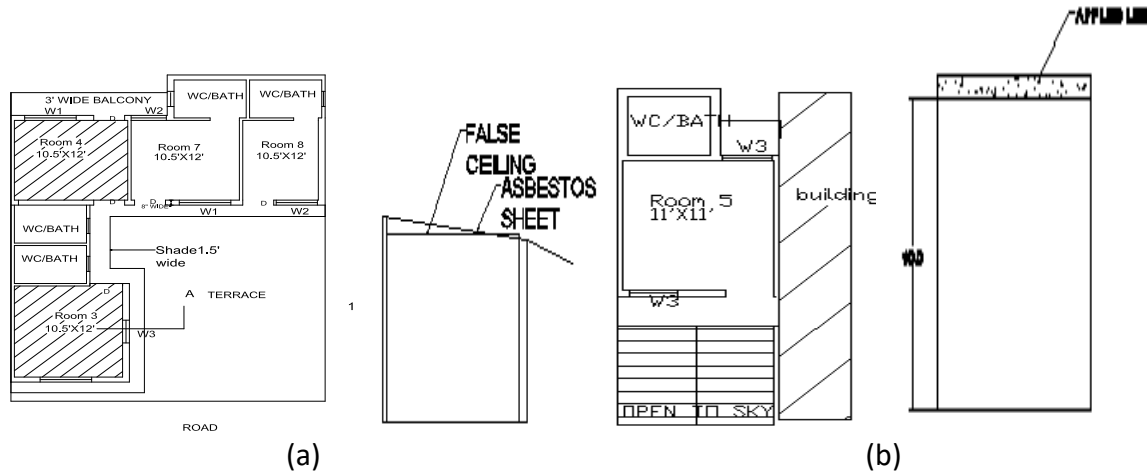
Detail of the case buildings

Building no.	Room no.	Floor	Floor area	Orien-tation	Flanked Side	Roof Type	Roof finishing	Wall Type	Openings %	Shades	Purpose /Occupancy
Building 1	Room 1	First /top	3.66mx 3.35m	South	South, west	Concrete	Cement	Brick Wall	15%	South Wall Is Shaded With Extended Roof	Bedroom /2 person
Building 2	Room 2	First /top	3.66mx 3.35m	South	South	Concrete	Cement	Brick Wall	15%	South Wall Is Shaded With Extended Roof	Bed room/2 person
Building 3	Room 3	Second /top	3.05mx 3.35m	North	South(Parti ally), West	Asbestos with false ceiling	-	Brick Wall	18%	North /South Wall is Shaded With Extended Roof	Rented /one person
Building 3	Room 4	Second /top	3.35mx 3.35m	North	South	Asbestos with false ceiling	-	Brick Wall	15%	North Wall Is Shaded With Extended Roof	Rented /one person
Building 4	Room 5	Second /top	3.35mx 3.05m	North	South(parti ally), West	Concrete	Cement	Brick Wall	20%	North Wall Is Shaded With Extended Roof	Rented /one person

Table 3

Details of insulators

Room	Case number	Insulators	K -value W/ m ² °C	Reflective index	Emissivity	Thickness	Cost /m ² (Rs).	Durability	Scheduled Date (To-From)
1	Case 1.1(No Insulator) Case 1.2 (With Insulator)	Solar reflective paint on co	0.09	0.88	0.913	2 coats	100	5yeras	24/4/16-26/4/16 29/4/16-1/5/16
2	Case 2.1(No Insulator) Case 2.2 (With Insulator)	Ceramic Tiles	1.3	0.6	0.9	10mm	300	10years	29/4/16-31/5/16 3/5/16-9/5/16
3	Case 3.1(No Insulator) Case 3.2 (With Insulator)	Aluminum paint	0.72	0.61	0.45	2 coats	80	5 years	4/5/16-6/5/16 10/5/16-18/5/16
4	Case 4.1(No Insulator) Case 4.2 (With Insulator)	Solar reflective paint	0.09	0.88	0.913	2 coats	100	5yeras	10/5/16-14/5/16 18/5/16-25/5/16
5	Case 5.1(No Insulator) Case 5.2 (With Insulator)	Lime	0.83		0.913	2 coats	10	1yeras	27/5/16-30/5/16 2/6/16-8/6/16

**Figure 5:** (a) Plan and cross section of room 3 & 4, (b) Plan and cross section of room 3 & 4

Salient features of the above treatment are: Environmental Friendly, Energy Saving, Dead Weight Reduction, and Long Lasting and Zero Heat Transmission to Surroundings.

Methodology Applied

The methodology implemented in this paper is based on an experimental study and simulation work of different types of insulators applied to two types of roofs: concrete and asbestos sheet roof. For the experimental study, five rooms in four typical residential apartments given in Figure 5(a) and (b) are chosen to represent the common type of housing in Bhopal. Parameters observed and equipment used in the present study are given in Table 1.

Methodology Adopted for Observations

The following procedure is adopted for taking observations:

1. Continuously at least 3 days' readings of temperature and humidity in extreme summer in the month of May;
2. Applying the scheduled insulator;
3. Readings after applying insulators (observing in almost similar climatic conditions as at the time of no insulator).

Methodology Adopted for Analysis of Data

Analysis is done by two methods:

1. First method is to determine the exact reduction in inside temperature. The readings were observed keeping similar temperatures as in no insulation in all the cases.
2. In the second part, the results observed in the experimental study at 3 pm would be compared with the results of Computational Fluid Dynamics (CFD), and return on investment determined by heat transferred. The cooling load of air conditioners with and without insulators is obtained to calculate the reduction in load.

Since the numbers of observation tables were large (more than 15 case tables; one for each case, hence by taking at least three readings per

case) a total of 10 observations taken in 48 days were selected for analysis, in which 5 cases were without applying insulators and 5 cases were with an insulator in each room.

The room selected for the experiments are shown in Figure 1. The main two variables were selected for the roof: type of roof (concrete and asbestos sheet) and insulation material. These resulted in five different possibilities for roof insulation in two different type of roofs by consecutive alteration. The aim was to evaluate the best insulator with the optimum solution for each type of roof capable of taking out the most suitable and cost-effective energy efficient solutions in order to minimize heat transfer from the roof in the summer season. The experiments on the five proposed roofs were performed for the actual residential building chosen for the study and compared them with non-insulator conditions for the summer season (between April 21 and June 22).



Figure 6: Building photographs after applying insulator - SRP at Roofs



Figure 7: Building photographs after applying insulator - Lime at roof



Figure 8: Building photographs after applying insulator - Tiles at Roof and Wall



Figure 9: Building photographs after applying insulator - Aluminum Paint at Roof

As maximum cooling load is during the summer, maximum reduction in cooling loads after applying the insulators is found in the summer, so the measurements were taken from last April to mid-June. Since the winter season is very short (November–February) in the subtropical humid climatic zone, in this study we neglect the effect of winters. Observations in each room for all conditions were taken 3 days before application of insulators and for 6–7 continuous days until the outside conditions matched with no insulator conditions. The observations were taken five times in a day to view the time lag effect properly. The times selected were 9 am, 12 pm, 3 pm, 6 pm, and 9 pm, i.e. from 9 to 9. For analyzing

the thermal condition of rooms, the data observed are ambient temperature, surface temperature, and relative humidity. Suggestions and labors for implementing insulators were taken from an architect. The drawing shown below (Figures 6 to 9) clearly indicates the implementation of insulators.

Results Obtained through Experiments

1st Method: Temperatures Observed when Outside Conditions are Similar in all the Cases

Approximately similar weather data is observed in no insulator (case 1.1, case 2.1, and so on) and with insulators (case 1.2, case 2.2, and similar in other rooms). Ambient air temperature in all cases at different timings is shown in Figures 10–14. The temperature differences, decrease in temperature, and net percentage decrease in temperature are tabulated in Tables 4–8.

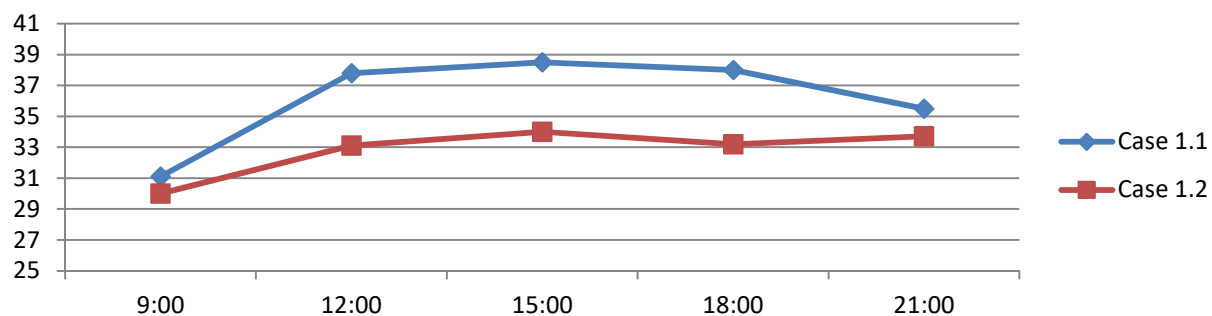


Figure 10: Inside temperatures (T_i) of room no.1 in all cases

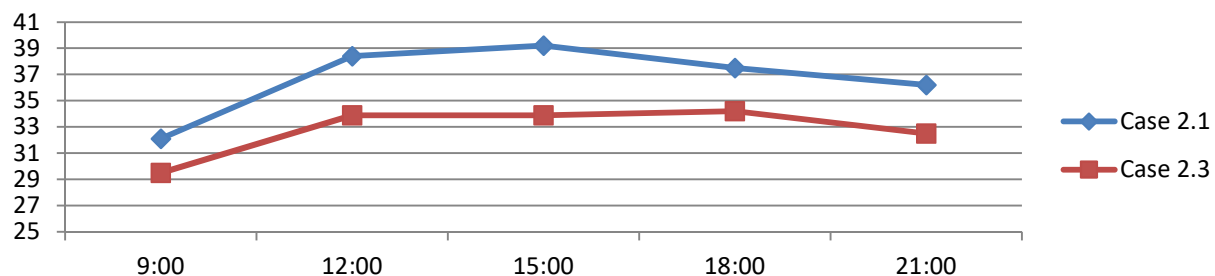


Figure 11: Inside temperatures (T_i) of room no. 2 in all cases

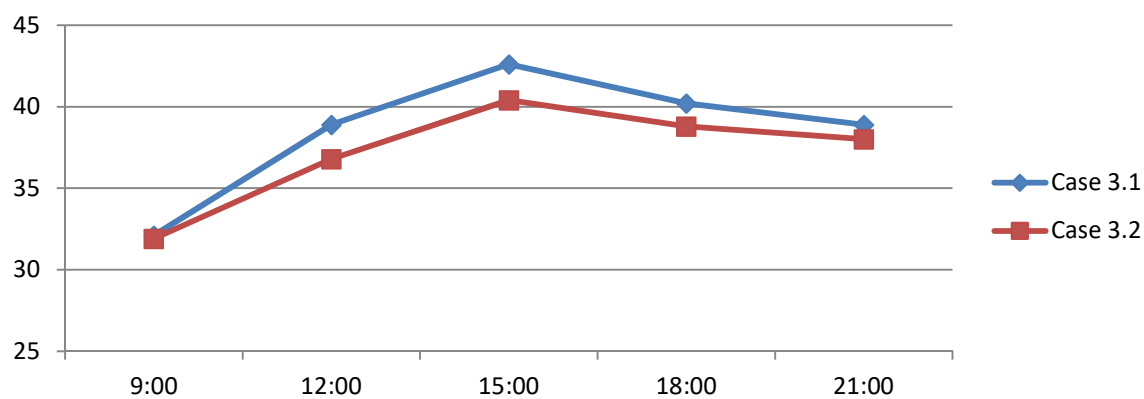


Figure 12: Inside temperatures (T_i) of room no. 3 in all cases

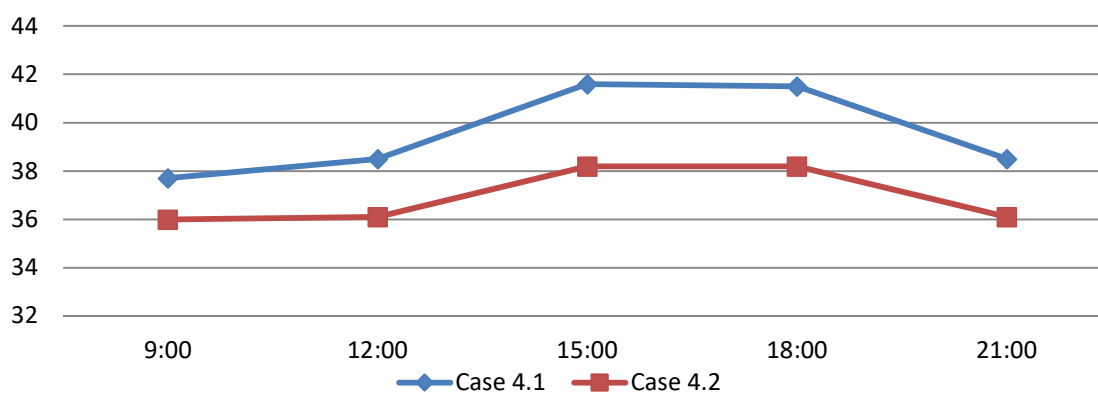


Figure 13: Inside temperatures of room no. 4 in all cases

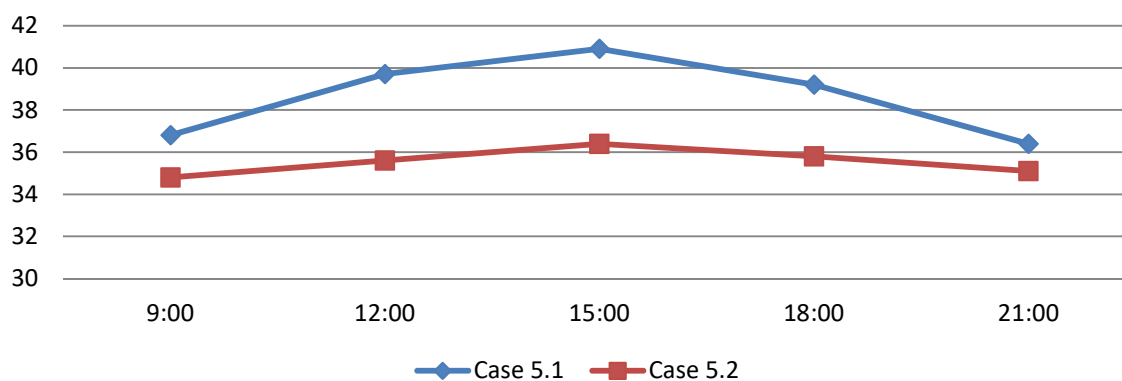


Figure 14: Inside temperatures of room no. 5 in all cases

Table 4Decrease in room temperature of room no. 1 (T_i) in $^{\circ}\text{C}$ & in percentage

Time	Observed temperatures		Reduction in temperatures from Case 1.1 to 1.2	
	Case 1.1	Case 1.2	$^{\circ}\text{C}$	%
9:00	31.1	30	1.1	3.5%
12:00	37.8	33.1	4.7	12.4%
15:00	38.5	34	4.5	11.7%
18:00	38	33.2	4.8	12.6%
21:00	35.5	33.7	1.8	5.1%

Table 5Decrease in room temperature (T_i) of room no. 2 in $^{\circ}\text{C}$ & in percentage

Time	Observed temperatures		Reduction in temperatures from Case 2.1 to 2.2	
	Case 2.1	Case 2.2	$^{\circ}\text{C}$	%
9:00	32.1	29.5	1.4	4.4%
12:00	38.4	33.9	3.3	8.6%
15:00	39.2	33.9	3.5	8.9%
18:00	37.5	34.2	2.2	5.9%
21:00	36.2	32.5	2.2	6.1%

Table 6Decrease in room temperature (T_i) of room no. 3 in $^{\circ}\text{C}$ & in percentage

Time	Observed temperatures		Reduction in temperatures from Case 3.1 to 3.2	
	Case 3.1	Case 3.2	$^{\circ}\text{C}$	%
9:00	32.1	31.9	0.2	8.1%
12:00	38.9	36.8	2.1	11.4%
15:00	42.6	40.4	2.2	8.9%
18:00	40.2	38.8	1.4	5.8%
21:00	38.9	38	0.9	6.0%

Table 7Decrease in room temperature (T_i) of room no. 4 in $^{\circ}\text{C}$ & in percentage

Time	Observed temperatures		Reduction in temperatures from Case 4.1 to 4.2	
	Case 4.1	Case 4.2	$^{\circ}\text{C}$	%
9:00	37.7	36	1.7	4.5%
12:00	38.5	36.1	2.4	6.2%
15:00	41.6	38.2	3.4	8.2%
18:00	41.5	38.2	3.3	8.0%
21:00	38.5	36.1	2.4	6.2%

Table 8Decrease in room temperature (T_i) of room no. 5 in $^{\circ}\text{C}$ & in percentage

Time	Observed temperatures		Reduction in temperatures from Case 5.1 to 5.2	
	Case 5.1	Case 5.2	$^{\circ}\text{C}$	%
9:00	36.8	34.80	2.0	5.4%
12:00	39.7	35.60	4.1	10.3%
15:00	40.9	36.40	4.5	11.0%
18:00	39.2	35.80	3.40	8.7%
21:00	36.4	35.10	1.30	3.6%

From above observations, it is seen that there is a maximum decrease in temperature by 12.6% or 4.8°C at 6 pm which is significant. The decrease in temperature is observed at all timings, but at 9 am and 9 pm, it is less in comparison to 12 pm, 3 pm, and 6 pm.

From the above tables and graphs, it is observed that the maximum reduction in temperature was observed by the tiling on the roof by 8.9% or 3.5°C at 3 pm followed by 8.6% at 12 pm. Again, net minimum reduction is at 9 am by 4.4%. Hence, by applying tiles on roof, reduction can be up to 3.5°C .

In this case, the roof is of asbestos sheet. Initially the rooms were too hot and temperatures were always much higher than concrete roof rooms, although a false ceiling is provided, even the temperatures were high, since the thermal mass of the asbestos sheet is less, hence, the heat does not store in mass and the temperatures directly change with the change in outer temperatures.

Temperatures were also reduced but were less in comparison to the concrete roof. Maximum reduction by applying aluminum paint on the roof is by 2.2°C or 5.2% and 2.1°C or 5.4% at 3 pm and 12 pm respectively. Hence, aluminum paint is less effective in comparison to SRP on roofs.

In this room, the SRP at roof shows the maximum effect at 3 pm and 6 pm. Since the roof is of an asbestos sheet, the time lag is less. But it was observed that the temperatures are always high in these rooms. The minimum reduction is seen at 9 am. Initially, the outside temperatures are either found equal or less than the internal temperature—after applying insulators, the temperature reduces; hence giving thermal comfort to occupants.

From the observations, the effect of hydrated lime is significant throughout the day, but at 9 pm its effect is less. Lime is a good thermal insulator but it is required to be reapplied almost every year; however, an advanced form of lime insulator is now available on the market with an improved life. A maximum temperature difference is observed at 12 pm and 3 pm of 4.1°C and 4.5°C respectively. However, a remarkable change in temperature is observed at 9 am as other insulators (on different test rooms) do not give a significant effect at this timing.

Results of CFD Analysis

Computer simulation is performed at 3 pm only, as maximum temperatures are observed at this time. Steps followed for CFD Analysis of rooms using Ansys Fluent are prepossessing, solver, and post-processing.

Preprocessing

CAD Model: A 3D CAD model is generated by using Unigraphics, then import the CAD model into Ansys Design modeler in Parasolid format (.xsl or .xsl). CAD models of all the rooms are shown in Figure 15.

Mesh: Generate the mesh of rooms in the Ansys Mesh software. Mesh Type is Hybrid. Taking Element Edge Length = 2.5 mm, Mesh generated and 1 No. of Nodes and No. of Element are given in Figure 15.

After mesh generation, the following setup is followed in the Ansys Fluent.

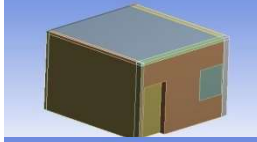
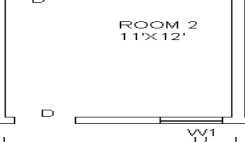
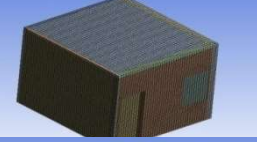
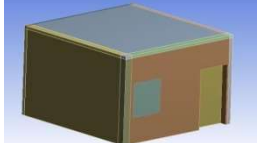
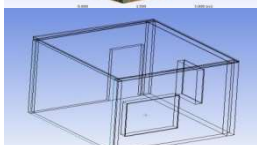
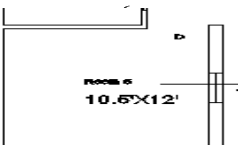
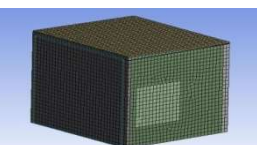
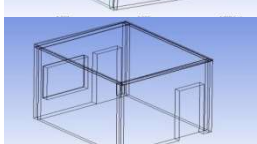
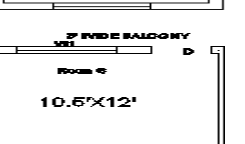
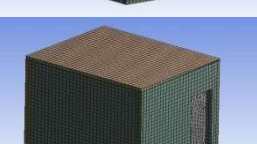
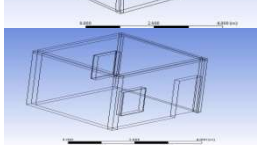
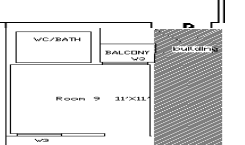
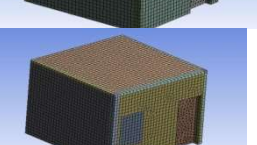
Room	CAD Images	Plan of room	Mesh images	Nodes	Elements
Room 1				108795	87288
Room 2				108049	86340
Room 3				44107	163976
Room 4				43040	163123
Room 5				39126	156711

Figure 15: CAD images, mesh images, and plan of all the rooms

Table 9

Outside ambient and surface temperatures

Case	Outside Temperature at 3 pm		Roof			
	Temperature		Wall N	S	E	W
Case 1.1	40.5	56.5	-	38.8	-	-
Case 1.1	40.6	42.6	-	39.8	-	-
Case 2.1	40.5	52.5	-	42.5	-	-
Case 2.2	39.5	40.4	-	34.8	-	-
Case 3.1	43	67.4	43.9	45.7	--	46.7
Case 3.2	43	53.9	42.4	46.6	-	47.8
Case 4.1	43	64.6	45.4	43.3	-	-
Case 4.2	43	56.1	45.1	44.7	-	-
Case 5.1	43	53.8	41	40	40.3	-
Case 5.2	42.2	49	40.7	43	44.2	-

Problem Type: 3 Dimensional; **Type of Solver:** Pressure-based solver. **Physical model:** Viscous: laminar, Energy; **Material Property:** Flowing fluid is air; Density of air = 1.225 kg/m³; **Boundary Condition:** Outside Ambient Temperature and Surface (exposed) Temperature at 3 pm given in Table 9.

Post Processing

The graphical representation of results is shown in Figure 16 and results obtained are shown in Table 10.

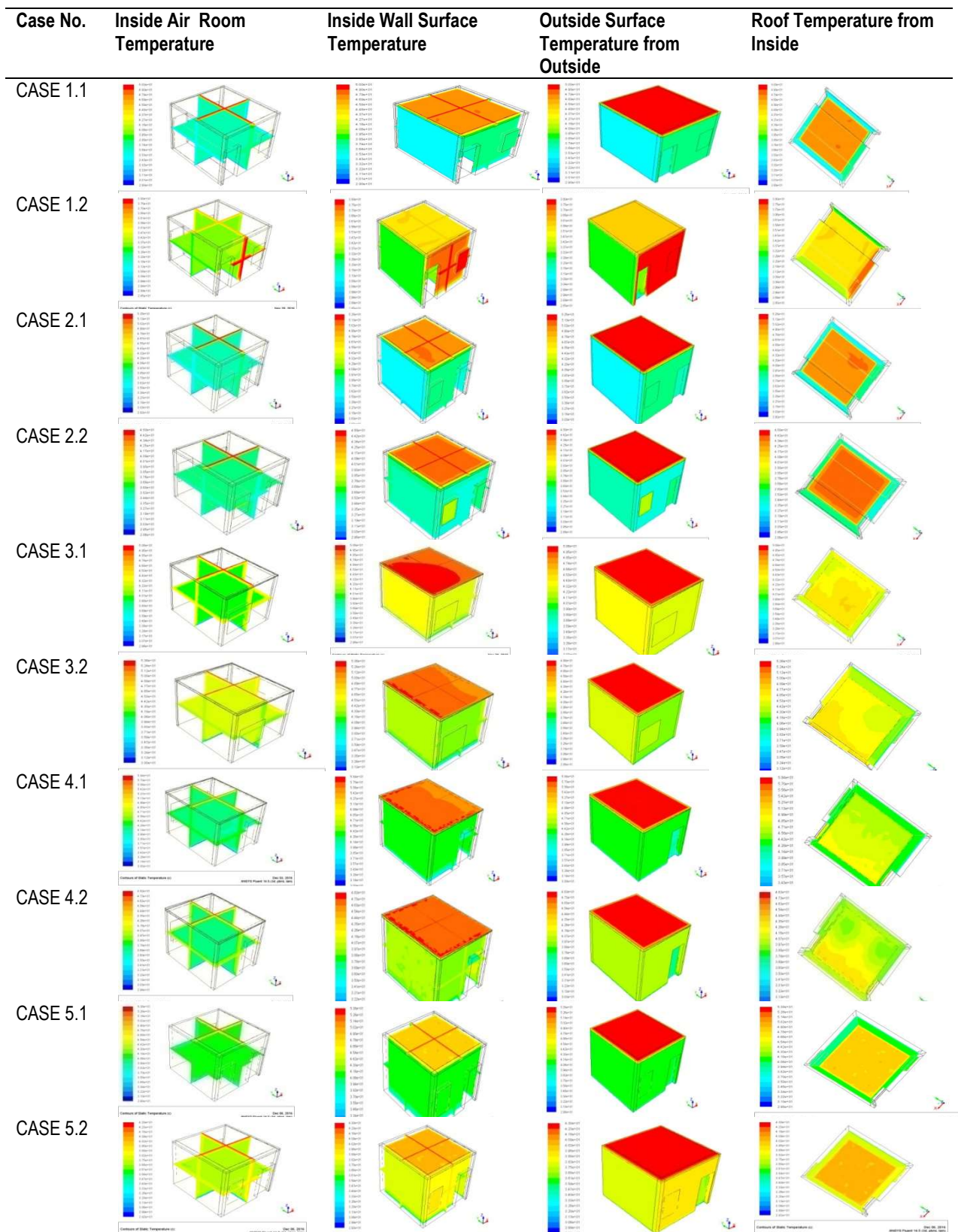


Figure16: Images of temperature variation in rooms in all cases

Table 10

Results obtained by computer modeling

Case	Inside Temperature				Temperature	Roof	Heat transfer kWatts
	Wall N	S	E	W			
Case 1.1	37.1	38.7	35.7	35.3	37.6	49.4	86.6
Case 1.2	34.8	36.9	33.9	33.1	33.6	35.6	61.7
Case 2.1	37.2	39.1	36.3	36.7	38.6	52.0	82.3
Case 2.2	35.0	34.5	35.0	34.3	35.3	43.2	61.7
Case 3.1	43.1	42.8	42.8	43.2	41.4	49.3	126.0
Case 3.2	41.2	40.8	40.8	42.0	39.4	43.7	116.6
Case 4.1	42.4	42.5	41.0	42.7	40.9	47.9	117.3
Case 4.2	39.5	39.5	39.8	39.8	38.1	41.3	100.3
Case 5.1	40.8	40.0	40.8	40.9	40.7	48.2	115.7
Case 5.2	38.4	37.7	37.7	37.8	36.9	40.4	100.6

Table 11

Comparison of results of CFD with experimental results (at 3 pm)

The temperature difference in between cases.	Temperature difference observed in CFD	Temperature difference observed in field experiments	Difference	Comments
Case 1.1 To 1.2	3.99	4.5	-0.5048	Almost similar results observed
Case 2.1 To 2.2	3.2742	3.5	-0.2258	Almost similar results observed
Case 3.1 To 3.2	2.0196	2.2	-0.1804	Almost similar results observed
Case 4.1 To 4.2	2.7539	3.4	-0.6461	Almost similar results observed
Case 5.1 To 5.2	3.7902	4.5	-0.7098	Almost similar results observed

Comparison of Experimental Results with CFD Results:

The decrease in the inside temperatures computed from field experiments and computer simulation are compared in this section and presented in Table 11.

Results found are almost similar, experimental results are found little higher, which may be due to other conditions which are neglected such as activity in the room, the opening of windows, etc.

Calculation of Return on Investment (ROI)

For computing optimum solution in this research, we calculate ROI.

Return on Investment: It is a profitability ratio that calculates the profits of an investment as a percentage of the original cost. It measures the percentage of the purchase price on how much money was made on the investment. It shows in-

vestors how efficiently money invested in a project is producing a profit. Investors also use this ratio to compare the performance of different investments of all types and sizes.

$$\text{ROI} = (\text{Net Profit} / \text{Cost of Investment}) \times 100 \quad [1]$$

For calculating reduction in the electricity bill, few assumptions are made which are given below.

Reduction in the electricity bill is computed by taking a load of air conditioner of 1.5 tones (2.0 kW), for 3 peak months in the concrete roof and 5 months in the asbestos sheet roof (using 8 hours per day).

Taking electricity charges @5Rs. per unit.

Electricity consumption of AC in concrete room per year = $2.0 \times 8 \times 30 \times 3 = 1440$ kWh,

Electricity consumption of AC in asbestos sheet roof per year = $2.0 \times 8 \times 30 \times 5 = 2400$ kWh.

Since the life of cool coating is not much, reduction in load considering for whole life is computed for every solar passive strategy we adopted. Calculations of reduction in electricity bills, cooling load, and ROI for each room are given in Table 12.

Results and Discussion of Findings

In this paper, a method is proposed, evaluated, and simulated for the cool roof as a way to improve thermal conditions indoors. Our proposed solution depends mainly on protecting the roof surface from direct solar radiation so to reduce heat gain.

Several studies on insulators indicate that by installing the solar reflectance, the temperature of the surface lowers. This is because solar radiation is reflected rather than absorbed and hence the heat penetrating into the building decreases. During the summer, in air-conditioned or non-air-conditioned buildings, insulation helps in lowering energy consumption and improves thermal comfort. Hence, the use of cool materials in an urban area at large scale leads to significant energy savings due to the high solar reflectivity of insulators used. This results in the reduction of the air temperature because of surface heat balance at the urban level (Synnefa et al., 2007). Insulation on roofs proves much more effective

than wall insulation (inside temperature about 6°C–7°C reduces). For a climate like Bhopal, the solar reflective material on roofs give sufficient reduction in inside temperature. This research concludes that by applying solar reflective material, one can achieve the best result at very low rates.

From the results, it is clearly seen that the optimum solution through insulation used either on the roof or wall, is by applying Solar Reflective Paint, which is cost-effective and durable. Although, it is observed that the white paint becomes dimmer as the days pass. Tiles are costly but give good results for a long time. The effect of aluminum paint was found to be less. Maximum reduction is shown in Figure 17.

Using computer modeling, the results obtained are almost similar with experimental results. It is proved that for any type of roofs, SRP is the optimum solution.

Hence from above results, the conclusions derived are discussed below:

SRP as an insulator on the roof is the most economical and effective solution in places of hot climatic conditions like Bhopal.

Lime is the best solution, but its maintenance is required almost every year.

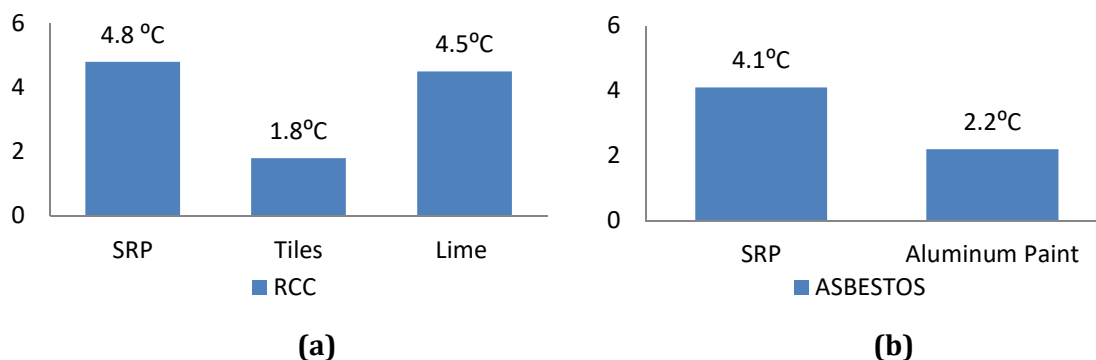


Figure 17: Decrease in inside temperature (max.) by applying insulators on a) concrete roof
b) asbestos sheet roof

Table 12

Calculation of cooling load reduction and ROI.

Insulator	Room Type	Appli- cation at	Area Sqm	Cost Of Insulator Per Sqm (Rs)	Total Cost Of insulation	Life In Year	Electricity Consumption Without Insulator (kWh)	Reduction in Cooling Load After Applying Insulator (%)	Reduction In Electricity Bill Kwh (Rs)	ROI (%)
SRP	Concrete	Roof	12.26	130	1594	3	4320	16	2010.3	216.8
Tiles	Concrete	Roof	12.26	350	4291	10	14400	21	29548.0	352.4
AL.P	ASB	Roof	13.27	120	1593	3	7200	9	2036.3	542.4
SRP	ASB	Roof	11.57	130	1504	3	7200	17	3686.1	837.7
Lime	ASB	Roof	10.22	20	204	1	1440	17	241.6	387.5

Conclusion and Recommendations for Further Research

As global warming is arising, a rise in energy consumption used for cooling in cities of warm climates is likely to continue unless more passive energy efficient and cost-effective measures are introduced. As a roof is the most exposed part of the building envelope which receives direct sun rays, it is most challenging to protect it. The performance of the roof depends mainly on its type, shape, construction, and materials. This study proposes an affordable technique to reduce energy consumption by applying passive cool insulators through roofs, which has been validated using simulation. Solar reflective paints can increase thermal comfort for the inhabitants with no energy burdens from HV/AC systems on existing roof and can be used in effective forms as passive cooling techniques. The maximum reduction in temperature is found by applying SRP on the roof (4.8°C). Also, it is the optimum solution for such types of roof.

This study is performed for achieving indoor thermal comfort as well as reducing energy consumption for low/medium-rise residential buildings in subtropical humid climates. The results obtained from this study can be applied in similar climates to Bhopal's and the methodol-

ogy applied can be applied to other climatic conditions. With this proposed cool roof, other passive strategies are recommended for use, such as wall insulation and solar shading for façades, together with double or triple glazing for windows with low U value (Marwa et al., 2015). The proper window-to-wall ratio is also important for proper ventilation and lighting. The results of the simulations also provide an optimal solution of insulators for both types of roofs on central Indian weather conditions. The cost of insulators is affordable for middle-class people and is very low in comparison to other building cooling systems. Also, the installation of insulators in existing buildings does not disturb the occupants, as they are easy to install. Recommended for future work, it should also include passive cooling strategies, and their efficiency measured against the cool roof with wall and window solution to reduce the cooling hours. It is also recommended that in the Indian code for residential buildings, energy efficiency applying cool roofs should be a mandatory item.

We can conclude that in most of India, energy consumed in cooling is larger in summer, and effective passive cooling solutions should be introduced, otherwise the load on our energy resources to satisfy future cooling demands, especially in urban areas, will be increased, which will directly degrade the environment.

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