Assessment of cool roof technology for its energy performance in buildings

A thesis submitted in partial fulfilment
of the requirements for the degree of

Master of Science (by Research)
in
IT in Building Science

by

Surekha Tetali
200850025
surekha.tetali@research.iiit.ac.in

Centre for IT in Building Science

International Institute of Information Technology
Hyderabad-500032, India

April 2011

INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY

Hyderabad, India

CERTIFICATE

It is certified that the work contained in this thesis, titled **"Assessment of cool roof technology for its energy performance in buildings"** by *Surekha Tetali* (200850025), has been carried out under my supervision and is not submitted elsewhere for degree.

Date

Advisor: Prof. Vishal Garg
Centre for IT in Building Science
IIIT Hyderabad

Preface

A roof can bring lot of heat into buildings during summers especially when there is high amount of solar radiation. A roof that decreases heat ingress into the buildings by reflecting and emitting the sun's heat back into the sky is said to be a cool roof. Solar reflectivity (SR) and infrared emissivity (IE) are two main properties of the roof surface which determine the performance of the cool roof. Some commonly available cool roofing materials in India are: white cement, white elastomeric coating, reinforced aluminium foil, white ceramic tiles, etc. All these material have different SR and IE values and their performance would degrade with aging. India being a country with hot tropical climate, in most of its states there exist a yearlong cooling requirement, and hence cool roof promises to be a worthy technology in decreasing the cooling energy consumption. There are several direct and indirect benefits of cool roof. Looking into the advantages of cool roof in decreasing the energy consumption, from an experimental demonstration project conducted in an office building located in a city (Hyderabad) with composite climate, it has been observed that cool roof with solar reflectivity of 0.7 has a potential of saving 19% of cooling energy consumption for the top floor of the building as compared to a conventional concrete grey roof. For common man to analyse this advantage of cool roof and select appropriate roofing material, an online cool roof calculator has been developed which generates the resultant savings due to cool roof in terms of energy savings and cost. It also generates the payback of the selected cool roof material, and calculates the comfort achieved due to the specified cool roof if the space is unconditioned. Further, an experimental observation showed that, out of various cool roof materials such as: different kinds of coatings, ceramic tiles, and reinforced aluminium foil, ceramic tiles might provide a better payback due to their extended life period compared to other materials. Further, there are more advantages of cool roof. Through energy simulations it has been observed that use of cool roof would decrease the insulation required for the roof, especially in day time use office buildings located in all major climatic zones of India, except cold. High SR of the roof decreases the heat ingress and hence reduces the insulation requirement. Hence, all these studies together, show the advantages of cool roof, especially in decreasing the cooling energy consumption in buildings, and reducing requirement of roof insulation.

Abstract

A roof with an ability to reflect and emit the sun's heat back to the sky instead of transferring it to the buildings is said to be a cool roof. It has high solar reflectance and thermal emittance values. Cool roofs are one of the important energy conservation measures in buildings in countries like India. This thesis presents an assessment of the energy savings potential of cool roof through the analysis of experimental results, and through simulations. Further, a tool has been developed to calculate energy savings, payback and thermal comfort due to cool roof. The work also includes a survey of cool roof in historical and present day context of India, and a field study of performance of various cool roof materials.

A survey of various cool roof technologies available across India was done. The study shows the importance of cool roof in historical architecture of India, the current trends, and its relevance in codes and rating systems. Further, several cool roof materials were installed on field, and were tested for performance over a year. From this, it has been observed that ceramic tiles though provide lesser savings compared to the white elastomeric coatings; they tend to have longer life providing a good payback over time. The work includes analysis of the raw data of a parallel experiment conducted in two typical buildings in Hyderabad by IIIT Hyderabad in collaboration with LBNL- USA. The collected data has been analysed based on the operating hours of the building, and the calculated average savings ranged between 0.066-0.072 kWh/m^2/day. The work also includes the development of an online cool roof calculator. This cool roof calculator provides the energy savings, payback and thermal comfort achieved due to cool roof for the user specified building parameters and for the specified city. The calculator can be accessed at: http://coolroof.cbs.iiit.ac.in/index.html . This is the first of its kind tool, which performs online simulation using EnergyPlus for all available Indian weather files. Lastly, cool roof was analysed in combination with roof insulation. The impact of cool roof on requirement of roof insulation in office buildings was understood through simulations. Results showed that the savings achieved by increasing the thickness of insulation, has diminishing returns, and the insulation has negligible effect on cooling electrical energy consumption in case of roof with high solar reflectivity. Especially, roofs with very high solar reflectivity values of 0.7 and 0.8, adding roof insulation might increase the cooling energy consumption. This study also suggests that the recommendation by the Energy Conservation Building Code of India for the prescriptive method is to be revisited.

To my parents

Dr. T.L.Rambabu and Jyothi Tetali

Acknowledgments

To start with, I would like to thank, wholeheartedly, one and all, whether I name them below or not, who have helped and supported me throughout this endeavour, of mine, at IIIT Hyderabad, which has been a thoroughly enjoyable combination of academic, professional and personal experiences, which have constantly put me in the right frame of mind.

I owe my deepest gratitude to my teacher and Advisor, Prof. Vishal Garg, who has been the driving force behind this Thesis. His highly informative teaching, patience, guidance, and, above all, the invaluable encouragement he constantly gave me, have made this possible for me. He guided me at several crucial junctures, both on academic and professional fronts, and introduced me to a research community that inspired me and made me realise my interests. I sincerely thank him for the numerous opportunities he has opened up, through various challenging research projects, for me to explore the concerned field, and for his relentless support, in general, throughout my time at IIIT H.

I also thank Prof. Jyotirmay Mathur, who has been like a co-advisor to me, in providing several research inputs, and in providing a structure to my thought process. I sincerely thank him for critically reviewing all the work, and helping me in correctly presenting the work I did.

I am grateful to Mr. Prabhakar for helping me in the field installation of the cool roof products, and for being a good colleague to work with at the research centre. I thank Kshitij and Akshey for helping me in, and contributing to, the development of the cool roof calculator.

All my friends, and lab mates at IIIT H and MNIT Jaipur, with whom I shared space and good times, will always be remembered, and those times will be cherished.

I truly appreciate the really useful insights on several things, academic and otherwise, my best friend Hema Sree and my brother Ravitheja provided me with, during the numerous fruitful discussions I had with them. I also thank my fiancé Sivom for the guidance and support he has kindly extended towards the final and crucial stages of my Thesis completion.

I am always indebted to the constant blessings and encouragement that I receive from my parents. I cannot thank them enough for the belief they had in me, and letting me pursue my interests and dreams. My family and friends have been a great support at every stage of my life.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

.idf	EnergyPlus Input Data File
AC	Air Conditioner
COP	Co-efficient of Performance
EP	EnergyPlus
EPD	Equipment Power Density
GHG	Green House Gases
HVAC	Heating Ventilation Air Conditioning
LCC	Life Cycle Cost
LPD	Lighting Power Density
OD	Occupancy density
ORNL	Oak Ridge National Laboratory
RCC	Reinforced Cement Concrete
RSC	Roof Savings Calculator
SHGC	Solar Heat Gain Coefficient
SLC	Satyam Learning Centre
SR	Solar Reflectivity
SRI	Solar Reflective Index
STAR	Simplified Transient Analysis of Roofs
WWR	Window wall ratio

Chapter 1: Introduction

1.1: Cool roof and its relevance

India is a tropical subcontinent stretching between 8°4' and 37°6' north latitude, with cooling requirement in most of its states. It's the seventh largest country in the world, with more than a billon population. In the country, the construction industry plays a major role in its economy contributing on an average 6.5% of the GDP. India produces around 660 billion kWh of electricity, and over 600 million Indians, still have no access to electricity [1]. This alarms the need of electricity and its savings in a developing country like India. With a near consistent 8% rise in annual energy consumption in the residential and commercial sectors, building energy consumption has seen an increase from 14% in the 1970s to nearly 33% in 2004-05 [2]. With increasing temperatures, in already hot climates of India, the space cooling demands for all the building types is increasing. Insufficient electricity production, increased electrical energy consumption, extreme climates leading to human discomfort, are some major reasons which drive today's construction industry in search of some energy conservation and building performance, methods and means, that help in overcoming this situation. Traditionally, white washing the roofs using lime and chalk is one common practice, and act to reduce heat gain from roofs, among other energy conservation strategies that are prevalent in India [3]. Such roofs are called as cool roofs.

1.1.1 A cool roof and its properties

As defined by the Cool Roof Rating Council [4], a cool roof reflects and emits the sun's heat back to the sky instead of transferring it to the building. The coolness of the roof is measure of two properties: solar reflectance and thermal emittance. Both the properties are measured from 0 to 1 and the higher the value, the cooler the roof. Figure 1.1 shows the working of cool roof as explain by CRRC.

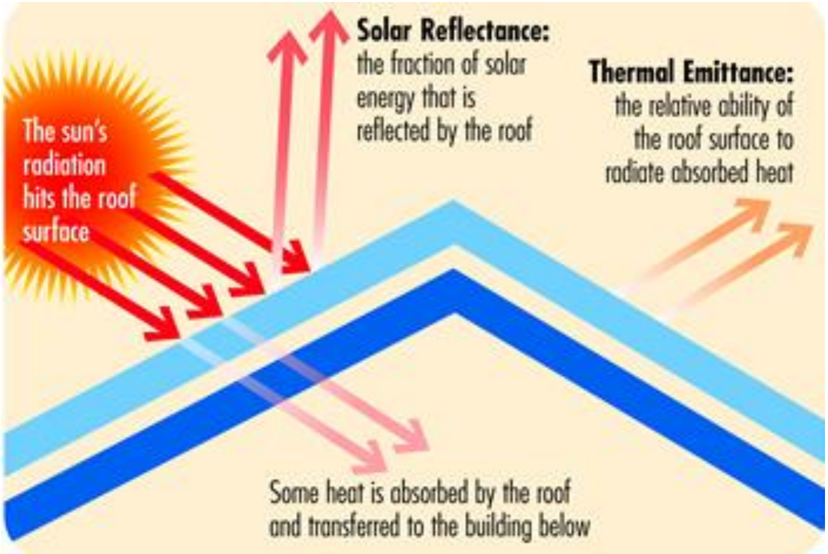


Figure 1.1: Working of a cool roof (Source: http://www.coolroofs.org/)

Roof reflectivity:

A reflective roof is typically light in colour and absorbs less sunlight than a conventional dark-colour roof. Less absorption of sunlight lowers the roof's surface temperature, reducing the heat transfer through the roof. This property of the roof makes it a "Cool Roof"

When the roof surface is painted white or treated white, the surface temperature of the roof decreases. This further decreases the effective temperature difference between the outdoor and the indoor thereby reducing the heat gain into the rooms through the process of conduction which can be measured using the formula:

$$Q = UA(\text{delta } t)$$

Where,

Q= heat transfer rate (W)

U= Coefficient of heat transfer/Conductance of the roof (W/m^2 K)

A= Surface area (m^2)

delta t= temperature difference between the outdoor and indoor (K)

Roof Emissivity:

Emissivity of the roof material defines the ability of the material to radiate out the absorbed heat. All the roof materials except metals generally are having an emissivity of 0.9. Emissivity of the metal roof is around 0.5 due to which the rooms with metal roof have less possibility to get cooled naturally. Roofing materials with less emissivity are appropriate in cold climates.

How to measure:

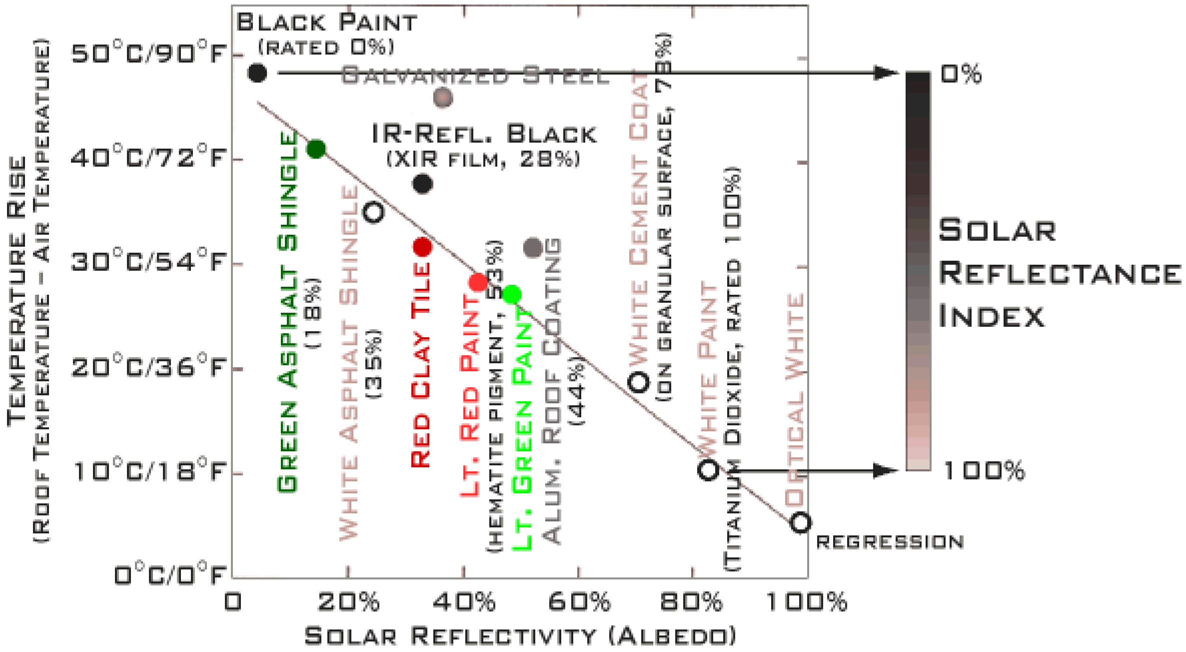


Figure 1.2: Measuring solar reflectivity

Solar reflectivity is measured according to ASTM E903. Traditional roofing materials have an SRI of between 5% (brown shingles) and 20% (green shingles). White shingles with SRI's around 35% were popular in the 1960s, but they lost favour because they get dirty easily. The current trend is to make white shingles more reflective. (Source: http://heatisland.lbl.gov/CoolRoofs/HeatTransfer/#Sunlight)

Materials specialist Paul Berdahl is developed a new rating system called the solar reflectance index (SRI) to measure how hot materials are in the sun. The extremes of white and black paint (on the graph above) define the solar reflectance index (SRI).

However, as stated in CRRC [4], a cool roof need not necessarily be white. There are many “cool colour” products use darker-colour pigments that are highly reflective in the near infrared (non-visible) portion of the solar spectrum. With “cool colour” technologies there are roofs that come in a wide variety of colours and still maintain a high solar reflectance. Research and development of these cool coloured roof products is being conducted by LBNL and ORNL [5]

1.1.2 Benefits of cool roof

Benefits of cool roof include but are not limited to the decrease in heat gain into buildings through roof because of the increase in roof solar reflectance, which thereby decreases the cooling energy consumption, and mitigates global warming. Advantages of a cool roof in different applications are discussed below.

In Unconditioned spaces:

- Decrease in indoor temperatures and increase in comfort conditions.

In Conditioned spaces:

- Decrease in heat gain, which reduces the energy consumption by the cooling system. This saving in consumption of the air conditioning system under a cool roof is about 5% when compared with the normal grey roof.

Reduces Heat Island effect:

- Cities generally are around 2° to 8°C warmer than surrounding areas due to dark materials, including roofs, which absorb the sun's light energy as heat during the day and release it at night as heat. This phenomenon removes the opportunity for air to cool down at night and results in higher temperatures being maintained longer. By immediately reflecting solar radiation back into the atmosphere and reemitting some portion of it as infrared radiation, cool roofs result in cooler air temperatures for the surrounding urban environment during hot summer months, thereby reducing the heat island effect caused.

Reduces Global warming:

Cool roof also help in decreasing the rate of global warming. Cool roofs result in conservation of electrical energy which in turn reduces the production of electricity. Decrease in electricity production results in decrease of green house gas emissions. As a direct benefit, cool roofs also cool the world independently by reflecting the sun's energy as light back to the atmosphere, thereby mitigating global warming. **Decreases roof maintenance costs due to longer roof life.** Treating the roof white also helps in increase the roof of the life by decreasing the heat transfer through the roof surfaces which effect in thermal expansion and contraction of the material. The properties of the material are prevented from the harsh weather effect of the sun, thereby increasing the life of the overall roof.

1.2: Related work

There are several research laboratories throughout the globe which emphasize and experiment in this field of cool roof. Some of the noted ones are LBNL and the ORNL. At national level, Centre for IT in Building Science, IIIT Hyderabad, is one of the main labs which works on cool roof and related fields. As mentioned earlier, there are several direct and indirect benefits of cool roof, over which an extensive research is going on throughout the world. Some related work which shows the advantages of cool roof has been documented in the following paragraphs:

Cool roofs also are said to mitigate global warming by offsetting CO_2 emissions. In a study performed by H.Akbari et al [6], on a global basis, increasing the world wide albedos of urban roofs and paved surfaces will induce a negative radiative force on the earth equivalent to offsetting about 44 Gt of CO_2 emissions.

Ronnen Levinson and Hashem Akabari [7] studied the potential benefits of cool roofs on commercial buildings. The annual heating and cooling energy uses of four commercial building prototypes—new office (1980+), old office (pre-1980), new retail (1980+), and old retail (pre-1980)—were simulated in 236 US cities. The simulations showed that substituting a weathered cool white roof (solar reflectance 0.55) for a weathered conventional gray roof (solar reflectance 0.20) yielded annually a cooling energy saving per unit conditioned roof area of 5.02 kWh/m^2 nationwide, and a heating energy penalty of 0.065 $therm/m^2$ nationwide.

Harry Suehrcke et al [8] studied the effect of roof solar reflectance on the building heat gain in a hot climate. This study aims in understanding the decrease in heat gain through roof due to the use of high reflective roofs. Calculations were performed for north Australia and it has been observed that a light-coloured roof has about 30% lower total heat gain than a dark coloured roof. Further the heat flow through roof for three different roof construction types was observed. Hence, this study shows that the increased thermal mass can decrease the night cooling that can happen through the roof of a building.

A. Synnefa et al [9] had estimated the effect of cool coatings on energy loads and thermal comfort in residential building in various climatic conditions. Simulations where performed for a residential building for 27 cities around the world. The results show that increasing the solar reflectance of the roof reduces the cooling loads by 18-93%, which is around 9-48 kWh/m^2 years. The study explains that the two major factors affecting the energy savings resulting from cool coatings in residential building are the climate and U value of the roof.

It has been found by Berdahl et al [10] that outer surfaces of dark roofs can be even 50 degree hotter than the surroundings, whereas the temperature difference in case of light colour roofs is of the order of 10 degrees only.

Konopacki et al.[11] measured daily summer air conditioning savings of 6.3, 3.6, and 0.4 kWh/1000 ft^2 (18, 13, and 2%) for three California commercial buildings—two medical offices in Davis and Gilroy and a retail store in San Jose. Corresponding demand reductions were 0.31, 0.22, and 0.15 kW/1000 ft^2 (12, 8, and 9%). Estimated annualized air conditioner savings were 590, 340, and 60 kWh/1000 ft^2, assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.35.

Hildebrandt et al.[12] measured daily air conditioner savings (annual savings / number of cooling days per year) of 2.1, 4.1, and 2.3 kWh/1000 ft^2 (17, 26, and 39%) in an office, a museum and a hospice in Sacramento. Estimated annualized air conditioner savings were 120, 240, and 200 kWh/1000 ft2, assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.35.

Konopacki and Akbari [13] estimated daily cooling energy savings of 3.6 kWh/1000ft2 (11%) and peak power reduction of 0.35kW/1000ft2 (14%) in a large retail store in Austin, TX. Estimated annualized air conditioner savings were 630 kWh/1000 ft2, assuming an increase in the aged solar reflectance (post-retrofit minus pre-retrofit) of about 0.45.

Parker et al [14] measured daily energy savings of 4.1kWh/1000ft2 (25%) and a peak power reduction of 0.56kW/1000ft2 (30%) for a school building in Florida. Estimated annualized air conditioner savings were 440 kWh/1000 ft2 for an estimated 0.35 to 0.40 increase in the solar reflectance of the roofs.

Hence, extensive research is going on in this field to estimate the advantages due to cool roofs. In a literature review by Jeff S. Haberl [15], study of 72 different research papers related to cool roof has been performed. This study states that the cooling energy savings can be averaged to about 20%, due to cool roofs. However, most of these studies are not for Indian cities. Further, the savings due to cool roof widely depend on various factors such as: the climate, roof type, roof solar reflectivity and type of building. Studies [16][17] pertaining to evaluation of cool roof material and its aging also exist but not in the Indian context. Hence, there is very less amount of prior study that analyses the prospects, performance, relevance and the savings that can be achieved due to cool roof technology in India. There are cool roof calculators [18] [19] which calculate the total energy savings due to cool roof, for all most all the US cities, and a similar tool does not exist for the Indian cities, which therefore demands one such for India.

1.3: Thesis Statement

In this work, an assessment of the energy savings potential of cool roof has been done through the analysis of experimental results and simulations. Further, a tool has been developed to calculate energy savings, payback and thermal comfort enhancement due to cool roof. It also presents analysis of performance of roof insulation when the roof of a building is coated white, and examines the ECBC recommendations in this regard. The work also includes a survey of cool roof in historical and present day context of India, and a field study of performance of various cool roof materials. With no or very less studies related to cool roof in this direction, in India, the work is an attempt to fill-in the gap.

1.4: Main Contributions

The main contributions in this work include:

1. Assessment of energy savings potential of cool roof technology in various climates of India
2. Field performance of various cool roof materials at IIIT H hostel
3. Analysis of raw data for a cool roof demonstration project at SLC, Hyderabad, to calculate the energy savings by the application of cool roof

4. Analyse the effect of cool roof on requirement of roof insulation thickness in office building of India through energy simulation. Comparing the results with the prescriptive recommendations of Energy Conservation Building Code of India.
5. Development of an online energy savings, payback and thermal comfort calculator for cool roofs

1.5: Overview of the thesis

The complete thesis has been divided into six chapters.

Chapter 1: Introduction: provides an introduction to the cool roof technology, the relevance of the study and summary of the related published work in this field. It further provides an overview of the complete thesis.

Chapter 2: Potential of cool roof technology in India shows a survey of various cool roof technologies available across India. The importance of cool roof in historical architecture of India, the current trends, and its relevance in codes and rating systems is documented as part of this chapter. Further, several cool roof materials were applied on hostel building at IIIT Hyderabad, and were tested for performance over a year. The materials include: simple white cement coating, ceramic tiles, aluminium sheet, and the white coatings specifically manufactured for cool roof applications. The details of this field test and the performance of the materials has been documented in this chapter.

Chapter 3: Analysis of raw data of a cool roof demonstration project- In this chapter an estimation of the energy savings due to cool roof has been performed for a parallel experiment conducted in two typical buildings in Hyderabad by IIIT Hyderabad in collaboration with LBNL- USA. The related literature, collected data in the experiment has been analysed to calculate the energy savings that are resulted due the cool roof on the building. The experimental setup, analysis of data and the results achieved through this experiment are presented in this chapter.

Chapter 4: Development of an online cool roof calculator: In this chapter the development process of an online cool roof calculator is a project that has been funded by the ClimateWorks Foundation, USA, has been explained. The chapter also contains the related literature, and explains the details of the tool – such as the backend, interface and the output.

The details of the simulation inputs, the database of materials and the proposed testing of the tool has been documented.

Chapter 5: Effect of cool roof on requirement of roof insulation thickness in office building in India: To understand the impact of cool roof on requirement of roof insulation in office buildings, simulations were performed for varying roof insulation thickness and roof solar reflectivity The related literature, methodology and the results achieved from the simulations where discussed in this chapter. This chapter further suggests that the recommendation by the Energy Conservation Building Code of India, for the prescriptive method is to be revisited.

Chapter 6: Conclusion and Future Study: This provides an overall summary of the thesis results and the knowledge that has been gained through the work. The work done also provides a platform for future work in this field, especially related to the policy level initiatives for cool roof in India.

1.6: Related Publications

Publications related to the work presented in this thesis are:

Books

- Energy Conservation Building Code User Guide. Published By: Bureau of Energy Efficiency, New Delhi. Developed by: USAID ECO-III Project, IRG, New Delhi. Member of Development team. Accessible at: http://www.bee-india.nic.in/schemes/documents/ecbc/eco3/ecbc/ECBC-User-Guide(Public).pdf

Papers in International Conferences:

- Vishal Garg, Surekha Tetali, Kshitij Chandrasen, Jyotirmay Mathur. “Online Energy Savings Calculator for Cool Roof”. Clima 2010 - REHVA World Congress, Antalya, Turkey, 2010.
- Surekha Tetali, Jyotirmay Mathur, Vishal Garg. “Effect of Cool Roof and Roof Insulation on HVAC Energy Consumption in Office Buildings in Tropical Climate”.

(Abstract Accepted for Building Simulation 2011. Sydney, Australia. November 2011)

Technical Report:

- Hashem Akbari, Tengfang Xu, Haider Taha, Craig Wray, and Jayant Sathaye from LBNL. Vishal Garg, Surekha Tetali, M. Hari Babu and K. Niranjan Reddy from IIIT Hyderabad. "Using Cool Roofs to Reduce Energy Use, Greenhouse Gas Emissions, and Urban Heat-island Effects: Findings from an India Experiment". (To be published).

Online tool developed:

- Cool roof calculator. Accessible at: http://coolroof.cbs.iiit.ac.in/
  The site has been hosted on 20 December 2010.

Contributed to:

- Cool Roofs for Cool Delhi: A Design Manual for Bureau of Energy Efficiency (BEE), Government of Power, India (member of the review team)

References

[1]. "India: Addressing Energy Security and Climate Change". The Ministry of Environment & Forests and Bureau of Energy Efficiency, Ministry of Power. Government of Indiapublication.

[2]. "Background paper for Sustainable Buildings and Construction for India: Policies, Practices and Performance". A UNEP SBCI (Sustainable Building & Construction Initiative) and TERI publication.

[3]. Annexure 3 – "Passive Architecture Design Systems". Eco-housing Assessment Criteria-Version-II. August 2009.

[4]. Cool Roof Rating Council. Accessible at: http://www.coolroofs.org/

[5]. The Cool Colors project. Accessible at: http://coolcolors.lbl.gov/

[6]. Hashem Akbari · Surabi Menon · Arthur Rosenfeld. "Global cooling: increasing world-wide urban albedos to offset CO_2" Climatic Change (2009) 94:275–286. DOI 10.1007/s10584-008-9515-9

[7]. Ronnen Levinson, Hashem Akbari. Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency (2010) 3.53-109.

[8]. Harry Suehrcke, Eric L. Peterson, Neville Selby. Effect of roof solar reflectance on the building heat gain in a hot climate. Energy and Buildings 40 (2008) 2224-2235.

[9]. A. Synnefa , M. Santamouris a, H. Akbari. Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings 39 (2007) 1167-1174.

[10]. Berdahl, P. and S. Bretz. 1997. "Preliminary Survey of the Solar Reflectance of Cool Roofing Materials," Energy and Buildings - Special Issue on Urban Heat Islands and Cool Communities, 25(2):149-158.

[11]. Konopacki, S., L. Gartland, H. Akbari, and L. Rainer. 1998. "Demonstration of Energy Savings of Cool Roofs," Lawrence Berkeley National Laboratory Report No. LBNL-40673, Berkeley, CA.

[12]. Hildebrandt, E., W. Bos, and R. Moore. 1998. "Assessing the Impacts of White Roofs on Building Energy Loads." ASHRAE Technical Data Bulletin 14(2).

[13]. Konopacki, S. and H. Akbari. 2001. “Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin.” Lawrence Berkeley National Laboratory Report LBNL-47149. Berkeley, CA

[14]. Parker, D., J. Sherwin, and J. Sonne. 1998b. “Measured Performance of a Reflective Roofing System in a Florida Commercial Building.” ASHRAE Technical Data Bulletin 14(2).

[15]. Haberl, J. S.; Cho, S. “Literature Review of Uncertainty of Analysis Methods (Cool Roofs)”. October 2004. Published by: Energy Systems Laboratory (http://esl.tamu.edu), Texax A & M University. Accessible at: http://hdl.handle.net/1969.1/2071

[16]. Ronnen Levinsona, Paul Berdahla, Asmeret Asefaw Berheb, Hashem Akbari. “Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane”. Atmospheric Environment 39 (2005) 7807–7824

[17]. Sarah E. Bretz, Hashem Akbari. “Long-term performance of high-albedo roof coatings”. Energy and Buildings 25 (1997) 1599167

[18]. Roof Savings Calculator. Accessible at: http://www.roofcalc.com/

[19]. DOE Cool Roof Calculator. Accessible at: http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm

Chapter 2: Relevance of cool roofs in India

2.1: Historical relevance of cool roofs in India

Energy and Environment are the two key words of today's Architecture. When buildings of today go in search of methods and means to decrease their impact on energy and environment, culturally rich countries like India, have a history of being energy efficient and environmentally friendly in their construction activities. Many vernacular technologies are energy efficient and sustainable, though some of them are no longer implementable because of the changed cultural, ecological, and economic situations of the country. In this regard, the key challenge is to understand the benefits of those techniques and find ways to integrate them to today's buildings. In hot climates, most of the buildings of this century tend to depend on air conditioning systems and electricity, and are unable to adapt to the present day climate. Most of these modern building are very poorly designed to withstand the prevailing climatic conditions. This resulted on dependency of cooling system which in turn consume large amount of electricity. Buildings of modern day tend to behave like boxes created out of glass and RCC. Lack of proper shading, over glazing, thin skin, inefficient air conditioning systems are some prominent features of the energy consuming ghost buildings. In contrast to the modern building the vernacular building are more adaptable to the local climate and environment. Use of thick walls, wind catches, ponds, courtyards, are some design principle which include physical functionality, beauty, low-energy use, comfort , durability and affordability. Many of these vernacular buildings tend to use local material, passive cooling and heating, and renewable energy systems. Hence, taking a step back into the future, will be the need for a sustainable earth.

Building roofs have a major share in adding to the head load in the buildings. Being exposed to direct solar radiation all through the day, with maximum surface area exposure, roofs act as paths of heat gain into the interior spaces. Traditionally, in India, building roofs which are flat act as multipurpose spaces. Flat roofs of house in India are gathering grounds for many activities. During the day, they act as drying yards, and during the night they turn to sleeping platforms. Especially in a multi family culture that was once very much prevalent in India, terraces are the spaces for kids to play, and families to gather. In North Western India, in states such as Gujurat and Rajasthan, it's a common practice to coat the roofs white, using lime and chalk. China mosaic also is another popular practice in which women arrange the broken tiles (mostly white) in a spider web pattern. Based on the local climate of the place, and availability of the material, the roof finishes use to vary. The white coating always helped to keep the terrace surface cool, and emit less radiation during the cooler parts of the day, when the roofs are occupied for other activities. This in turn restricted the heat flow into the building all through the day.

In an Annexure developed by the Eco Housing group [1] several passive architectural design systems are that prevalent in India are discussed. Amongst many other technologies specified, reflective surfaces, paints and coatings – cool roof is one major strategy to decrease heat ingress in buildings through roof. Paul Gut et al [2] list several passive and climate responsive design strategies for different climates of tropical and subtropical regions. As per this book, reflective paint over roof, roof ponds, vegetation over roof, and roof insulation are some of the important features of a climate responsive building in all the climates of this region, except cold.

Therefore, cool roof is one the most import passive strategy that existed in practice since long. The 'bring back' of the technology is need for India to save energy and environment. Methods to increase awareness, present trends and the related research in this field have been further discussed in various sections of this chapter.

2.2: Current relevance of cool roofs in India

With rapid urbanization and increasing cooling needs, today's India is looking into various heat reduction and energy conservation measures. Cool roofs being the most accessible, economical, and beneficial measure, tends to attain popularity among the builders, Architects, house owners and researchers of this field.

The trend of cool roofs in the five major climates of India, through some satellite images are as shown from Figure 2.1 - Figure 2.5. From these images it's clear that, Ahmedabad and Bangalore are two cities which practice the cool roof technology better, compared to the other cities. Shillong being a cold climate has least need of a cool roof. Mumbai and New Delhi are cities which need to adapt the technology for better urban environment.

Figure 2.1: Bird's eye view of a locality in Ahmedabad showing use of cool roof

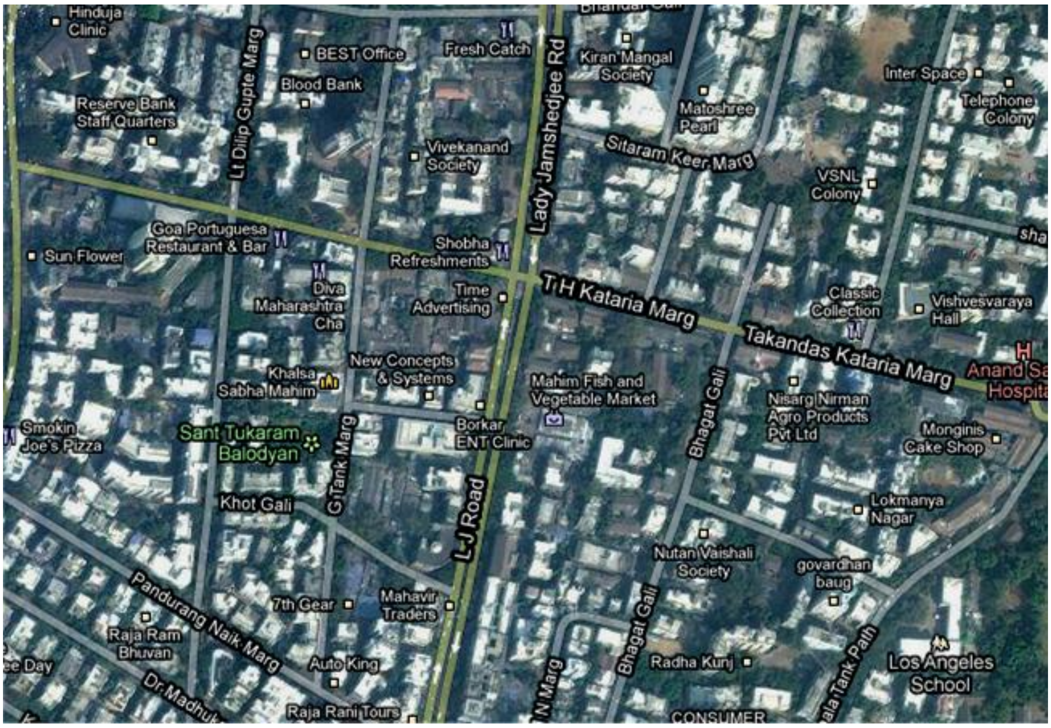


Figure 2.2: Bird's eye view of a locality in Mumbai showing less use of cool roof

Figure 2.3: Bird's eye view of a locality in NewDelhi showing very little use of cool roof

Figure 2.4: Bird's eye view of a locality in Bangalore showing use of cool roof

Figure 2.5: Bird's eye view of a locality in Shillong showing very little use of cool roof

2.2.1 Codes, Voluntary and Mandatory programs related to cool roof in India

Cool roof has been given importance in several building energy codes and rating systems that have been launched in the country in the recent past. For any building which aims to be energy efficient or green, cool roof is one of the measures that are considered by the project for its roof. Therefore, an overview of the codes and the existing ratings systems, in relevance with cool roofs has been discussed further.

Codes

There is an energy code in India which is the Energy Conservation Building Code [3]. In this code, there is mention of cool roof and its testing standard. When the project follows the prescriptive method, it is necessary for the project to use a high reflective roof. The code allows using high reflectivity in energy simulation when the project takes the whole building performance method. The code doesn't specify the cool roof requirements based on the climatic region but as whole specifies the requirements of a cool roof.

Specifications regarding the cool roof as in the code:

Section: 4.3.1.1 -Cool roofs (Page No: 7) of ECBC 2007 under Prescriptive Requirements for Building Envelope:

"Roofs with slopes less than 20 degrees shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75. Solar reflectance shall be determined in accordance with ASTM E903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996)."

Further a User Guide of the Energy Conservation Building Code [5] has been developed, in which Appendix B: The whole building performance methodology illustrates an example for calculating energy savings through this approach. Cool roof has been considered as one of the energy conservation strategies in this method. However, as per the code, for this method, the aged reflectivity of the roof is to be considered as 0.45, and the same is to be simulated to show the energy savings

Another national code which is related to buildings is the National Building Code [4]. This code provides standards for building construction, materials and services. However, the code is silent in defining the requirement of cool roof for a building. It specifies the details, guidelines and standards related to the structure, design, fire, structural details, design details, fire service, construction practices and landscaping, which are to be met by the building of the country. Hence, if cool roofs become a part of the codes requirement, then a wide scope exists for this technology within the country.

Both the codes are not mandatory as of now.

Along with these codes, there are several policy making bodies within the country which are important decision makes in fields related to environment and buildings. The country has a number of policy initiatives to mainstream energy efficiency and green buildings as control and regulatory instruments, including appliance standards, mandatory labeling and certification, energy efficiency obligations, and utility DSM(Demand side management) programs; economic and market-based instruments; fiscal instruments and incentives; support, information and voluntary action. Some of these that have a potential include cool roof concept are briefly explained below:

Energy Conservation Building Code 2007

The Energy Conservation Act 2001 provides for the establishment of state energy conservation agencies to plan and execute programs. The Act led to the formation of Bureau of Energy Efficiency (BEE) that formulated the Energy Conservation Building Code

(ECBC). It targets building energy efficiency and was introduced in the year 2007. This is the nation's first building energy code and aims to have a major impact on energy-efficiency in buildings. It is a voluntary code for all buildings with a connected load of 100 kW and most likely to become a mandatory code. It covers minimum requirements for building envelope performance as well as for mechanical systems and equipment, including heating, ventilation and air conditioning (HVAC) system, interior and exterior lighting system, service hot water, electrical power and motors in order to achieve energy efficiency in different climatic zones of India. As mentioned in the earlier section, the code states requirements for cool roofs, for all Indian climatic zones.

The Ministry of Environment and Forests (MoEF), Environmental Impact Assessment (EIA) and Clearance:

This is a mandatory requirement for all buildings with a built up area above 20,000 sq. m and such projects have to be apprised by the MoEF's Environmental Appraisal Committees (EACs) and the State Environmental Appraisal Committees (SEACs). MoEF has a potential to develop policies related to cool roofs and buildings, however, this isn't a part of the ministry's agenda yet.

The Ministry of New and Renewable Energy:

This has initiated several programs focusing on the utilization of renewable energy sources in buildings. MNRE keeps working on several awareness programs and funds several projects to various schools and research centres. Hence, this is one ministry which can encourage the demonstration of cool roof nationwide in form of various field and laboratory studies.

Sustainable Habitat Mission under the National Action Plan on Climate Change National Action Plan on Climate change was launched by the Honorable Prime Minister, Dr. Manmohan Singh on June 30, 2008. It encompasses a broad and extensive range of measures, and focuses on eight missions, which will be pursued as key components of the strategy for sustainable development. These include missions on solar energy, enhanced energy efficiency, sustainable habitat, conserving water, sustaining the Himalayan ecosystem, creating a "Green India," sustainable agriculture and, finally, establishing a strategic knowledge platform for climate change. For the habitat mission, the strategies proposed aim at promoting efficiency in residential and commercial sector through various measures such as, change in building bye laws, capacity building, research and development in new technologies, education and awareness, etc., management of municipal solid wastes, and promotion of urban public transport. Hence, the energy efficiency of buildings which is a part of the mission, leads to the implementation measures such as cool roofs. A aim towards greener India leads the country towards more green buildings which meet the requirements of energy efficiency codes and rating systems, and thus would proposed cool roofs for reducing energy consumption.

Voluntary and Mandatory Programs

There are various building rating systems within India which include the cool roof as one of the suggested measures for energy efficiency. They categorize cool roof as a credit for buildings which are going to be certified green.

Some of the rating systems and the specifications or requirements related to cool roof as provided by them are:

IGBC Green homes [6]

Site Credit 3.0

Heat Island effect: Roof (Page No: 29)

Goal:

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate.

Compliance Options:

Use material with high solar reflectance and thermal emittance (such as, white china mosaic or white cement tiles or any other highly reflective materials) and/or provide vegetation to cover at least 50% of the exposed roof areas.

Note:

Exposed roof area does not include areas occupied by equipment such as HVAC, solar water heater, photovoltaic etc.

Approach and Methodologies:

Consider providing green roofs or using highly reflective materials over roof to reduce the heat island effect. Typical materials with high reflective properties include china mosaic, white cement tiles, paints with high Solar Reflective Index (SRI) values etc.

IGBC Green Factory [7]

SE Credit 6.0

Heat Island Effect on Factory Roof and Parking area (Page No: 24)

Goal

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on the microclimate.

Compliance Options

Roof

Use high albedo roofing material or heat resistant paint or china mosaic or white cement tiles or any other highly reflective materials over the roof to cover atleast 50% of the exposed roof area.

Parking Areas

Plant shade-giving trees to cover at least 75% of the open parking areas (or) install permanent roof to cover 75% of the parking areas. In the event of installing a permanent roof, it should meet the requirements for mitigation on the roof.

Approach and Methodologies

Consider installing heat resistant paint and vegetated roofs to reduce the heat island effect. Typical materials with high reflective properties include china mosaic, white cement tiles, paints with high Solar Reflective Index (SRI) values etc.

<u>LEED India CS & LEED India NC [8][9]</u>

Credit 7.2

Heat Island effect: Roof (CS- Page: 80; NC-Page: 44)

Intent:

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Requirements:

Option 1:

Use roofing materials having a Solar Reflective Index (SRI) equal to or greater than the values in the table below for minimum of 75% of the roof surface.

Roof type	**Slope**	**SRI**
Low sloped roof	<=2:12	78
Steep-sloped roof	>=2:12	29

Potential technologies & strategies:

Consider installing high albedo and vegetated roofs to reduce heat absorption. Product information is available from the cool roof rating council website, at www.coolroofs.org.

GRIHA[10]

Criterion 5

Reduce hard paving on-site and/or provide shaded hard pave surfaces (Page No: 23)

Objective:

To reduce hard paving on-site (open areas surrounding building premises) and/or provide shade on hard-paved surfaces to minimize the heat island effect and imperviousness of the site.

- Use light colored, reflective roofs having an SRI (solar reflectance index) of 50% or more. The dark colored, traditional roofing finishes have SRI varying from 5% to 20%. A fine example of higher SRI is the use of broken china mosaic and light colored tiles as roof finish, which reflects heat off the surface because of high solar reflectivity, and infrared emittance, which prevents heat gain.
- Use commercially available, high solar reflective (albedo) roof coatings or heat reflective paints on roofs that shade paved areas. Do not use stone mulches such as fine gravel, crushed granite or pebbles in unplanted area immediately adjacent to buildings, as they can heat up, reflect solar radiation inside, and also cause glare.
- Use high albedo or reflective pavements to keep parking lots, pavements, and the inside roads cool, because an increase in albedo of 0.1 decreases the pavement temperature approximately by 8 deg F.
- Use light colored aggregates or 'white top' the pavements with a layer of cement concrete, 50 mm thick. Stabilize the pavements with porous or permeable materials such as sand, crushed bricks, broken mosaic tiles or stones where the soil is stable or the traffic load is quite low. Recycled materials such as demolished concrete (rubble), broken china, and mosaic tiles could also be used.

Eco-Housing, Pune

Site Planning, S.No: 1.14

Site should be properly planned to mitigate the 'heat island effect' (thermal gradient difference between developed and undeveloped areas) by the following –

- Provide shade on at least 40% of non-roof impervious surfaces on the site, including parking lots, walkways, plazas etc.

- Place a minimum of 50% of parking space underground OR plan covered parking with a reflective roof (net impervious area of less than 50%) for a minimum of 50% of the parking area.
- Use light colored (Solar Reflectance index >0.5) for pavements, walkways etc.
- Exception: Mandatory side space as per fire regulation and PMC byelaws shall be exempt for the calculation of impervious areas.

City level regulations

A city has a final set of building guidelines in the form of building bye laws which are finally implemented at town and city level by the respective Development Authorities and Municipal Corporations/Municipalities. These byelaws however, currently have not been able to integrate the ECBC provisions and other sustainability parameters.

Other rating systems which are also responsible in forming the standards for the green buildings are:

- Leadership in Energy and Environmental Design (LEED), IGBC
- Green Rating for Integrated Habitat Assessment (GRIHA)

One of the most remarkable changes that attributed to positive investor sentiment and increasing transparency in the sector is because of proactive government policies both central and state level. The reforms taken up by the government have been accepted by the developers and investors alike.

Urban government reforms: energizing real estate [11]

Launched in December 2005, Jawaharlal Nehru Nation Urban Renewal Mission (JNNURM) continues to ensure the integrated development of urban infrastructure and an effective inter-linkage between assest development and management. In 2007-08, central assistance of INR54.82 billion (USD1,330 million) was proposed as per the Eleventh Five year plan

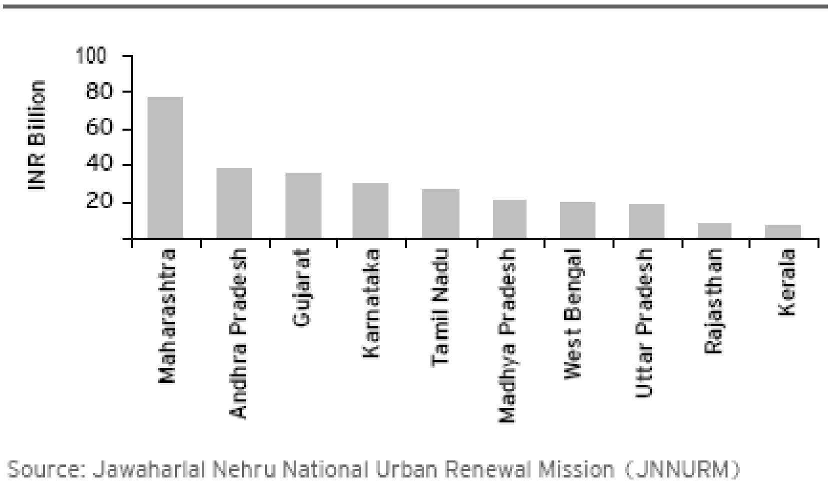


Figure 2.6: State-wise (top 10 states) sectioned project cost (as on August 2008)

2.2.2 Key participants and Infrastructure

India being a democratic country, and academically rich country, has provided an opportunity to various government, non government, and academic agencies and associations to play their part initiating and increase the use of cool roof technology implementation, research and development. A survey of such agencies, institutions and organization has been done.

Key agencies

National Level:

Government:

- Ministry of environment and forests, Government of India
- Ministry of Power, Government of India
- Central Public Works Department (CPWD)
- Ministry of New and Renewable Energy- Government of India

Associations:

- Confederation of Indian Industry
- Building Material and Technology Promotion Council (BMPTC)
- Solar Energy Society of India (SESI)
- Indian Society of Heating Refrigeration and Air Conditioning Engineers -ISHRAE

- American Society of Heating Refrigeration and Air Conditioning Engineers-ASHRAE
- Builders association of India (BAI)
- Confederation of Construction Products and Services (CCPS)
- Council of Architects (COA)
- Indian Building Congress (IBC)
- Indian Institute of Architects (IIA)
- Indian Green Building Council (IGBC)
- Institute of town planners
- National Council for Cement and Building Materials (NCCB)
- International Building Performance Simulation Association India Chapter (IBPSA (I))

Institutes:

- Central Building Research Institute (CBRI), Roorkee
- Devi Ahilya Vishwa Vidyalaya, Indore
- IIT, New Delhi
- IIT, Mumbai
- IIT, Roorkee
- IIIT, Hyderabad
- MNIT, Jaipur
- SAP, Chennai
- SPA, New Delhi
- School of Building Science and Technology, CEPT, Ahmedabad
- Sri Matha Vishno Devi University, Jammu

Organizations:

- The Energy and Resources Institute (TERI)
- Housing and Urban Development Corporation Limited (HUDCO), India

Regional Level:

- Municipal development authorities
- Urban development authorities

- State Energy Development Agencies
- State Housing Corporation Limited/ Housing Boards
- Public Works Department

Lot of governments at regional level are taking initiatives for promoting cool roofs, one of the recent ones is Delhi Government evaluating cool roof technology for Delhi. One news article [12] states that Delhi will paint roofs white to save power, and a plan to build cool roofs was finalized in meeting held in July 2009.

Laboratories

The fact that currently there is no laboratory which is offering cool roof testing services in India becomes both a limitation and an opportunity. However, India does have potential at National level and regional level in form of the private laboratories as listed in Appendix A: Potential Testing Laboratories. As specified in the IGBC green building rating system and ECBC, ASTM standards are suggested for testing cool roof products.

List of labs which have potential to test and certify cool roof and the current services that they offer is given in Appendix A: Potential Testing Laboratories.

2.2.3 Awareness and Education

Traditional Indian Architects do have the awareness and knowledge related to the advantages of a cool roof. Since traditional Indian buildings are low rise buildings, it was a practice by the Architects to treat the roof in such a way that less heat enters inside during the peak summers. Due to the quick urbanization happening in this century, the increase in multi-storeyed buildings, increase in the number of AC users, the traditional impact of the cool roof is being decreased.

In states such as Gujarat and Rajasthan it is a common practice of white roof coating or white tiles over the roof. Some of the traditional ways of treating the roof for reducing the heat ingress in India are:

- Cool roof coating using white cement

- White ceramic tiles
- Use of China mosaic
- Inverted earthen pots
- Lime coating
- Roof ponds

All the rating systems in India address cool roof hence Architects and project teams of this projects are aware of cool roof. Various seminars and conferences have been conducted in the Nation in creating awareness among these topics of Cool Roof.

Two of such documents which mention cool roof technology are given below:

<u>Ministry of Environment and Forests, Government of India</u>
<u>Manual on norms and standards for environment clearance of large construction projects</u>
Mitigation measures to reduce heat island effect
(Page No: 55)
Planting trees, bushes, or a properly planned landscaping can help reduce the heat island effect by reducing ambient temperatures through evapotranspiration. Plant vegetation around the building to intercept solar radiation and to shade the walls and windows of buildings (with S, SW or SE exposure) to prevent heat gain. This would also help in reducing air-conditioning load/use. Use light colored, reflective roofs having an SRI (solar reflectance index) of 50% or more. The dark colored, traditional roofing finishes have SRI varying from 5% to 20%. The fine example of higher SRI is the use of broken china mosaic, light colored tiles as roof finish, which reflects the heat off the surface because of high solar reflectivity, and infrared emittance which prevents heat gain.
Use commercially available, high solar reflective (albedo) roof coatings or heat reflective paints on roofs used to shade paved areas. Don't use stone mulches such as fine gravel, crushed granite or pebbles in unplanted areas immediately adjacent to buildings, as they can heat up, reflect solar radiation inside, and also cause glare.
Use high albedo or reflective pavements to keep parking lots, pavements and inside roads cool because the increase in albedo decreases the pavement temperature approximately by 8°F for a change in albedo of 0.1.
Use light colored aggregates or ‘whitetop’ the pavements with 50 mm thick layer of cement concrete. Stabilize the pavements with porous or permeable materials such as sand, crushed

bricks, broken mosaic tiles or stones where the soil is stable or the traffic load is quite low. Recycled materials such as demolished concrete (rubble), broken china and mosaic tiles could also be used. Total paved area of site under parking, roads, paths or any other use should not exceed 25% of the site area. Imperviousness of the site should not exceed the imperviousness factor as prescribed by the National Building Code of India, Bureau of Indian Standards, 2005; Part 9 (Plumbing services) section 5.5.11.2.1.
Total surface parking should not exceed the area as permissible under the local bylaw Obtain minimum 50% of paved area on site to have pervious paving or shaded under vegetation or topped with finish having solar reflectance of 0.5 or higher.

Ministry of New and Renewable Energy- Government of India

Handbook on Energy Conscious Buildings

Chapter 2: Climate and Buildings

Table 2.2 Comfort requirements and physical manifestation

(Page No: 21)

Increase surface reflectivity: Pale color, glazed china mosaic tiles etc

2.2.1 Opportunities and Growth

India’s Construction Industry

As per a publication by IHS Global Insight on Indian Construction [14], construction is an important part of the industrial sector and one of the core sectors of India's economy. According to IHS Global Insight, US$175 billion was spent on construction in India in 2007 after growing 156% since 2005. Out of US$175 billion, US$140 billion was spent on non-residential, and the remaining US$35 billion was spent on residential construction. Construction spending is expected to increase to US$370 billion by the end of 2013, with residential totalling US$63 billion and non-residential registering US$307 billion. This represents a compound annual growth rate (CAGR) of 13.3%.

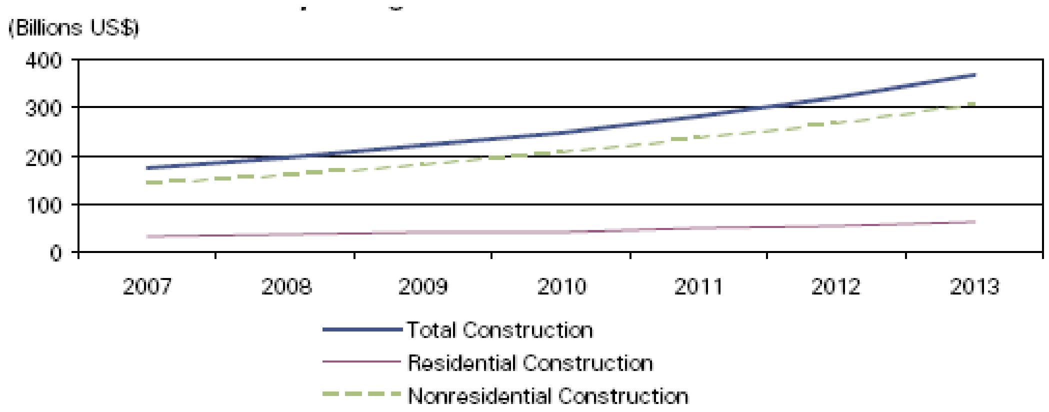


Figure 2.7: India's Construction Spending Outlook (Source: IHS Global Insight on Indian Construction)

IHS Global Insight's non-residential construction forecast for India, including major sub categories— transportation, public health, energy, office, commercial, institutional, and industrial— is expected to rise at a CAGR of 13.9% during 2007-13.

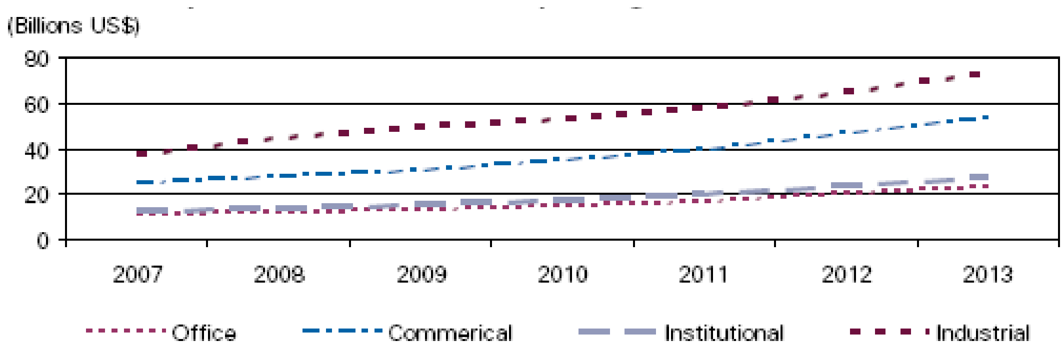


Figure 2.8: Sectoral Composition of Construction Spending (Source: IHS Global Insight on Indian Construction)

The construction sector is also the second largest employer in the country following agriculture, employing 18 million people directly and 14 million indirectly. Exports constitute about 5% of the size of domestic market and include construction materials, services, and cheap labour. The country's main international trading partners in this sector are the Middle East, Africa, and Malaysia. Indian companies have very limited exposure to large markets such as the United States, Japan, and West Europe.

The construction sector has increased its share of India's total employment from 2.8% in 1983 to 5.4% in 2003-04. The sector accounts for about 38% of gross investment and about 45% of India's total infrastructure costs.

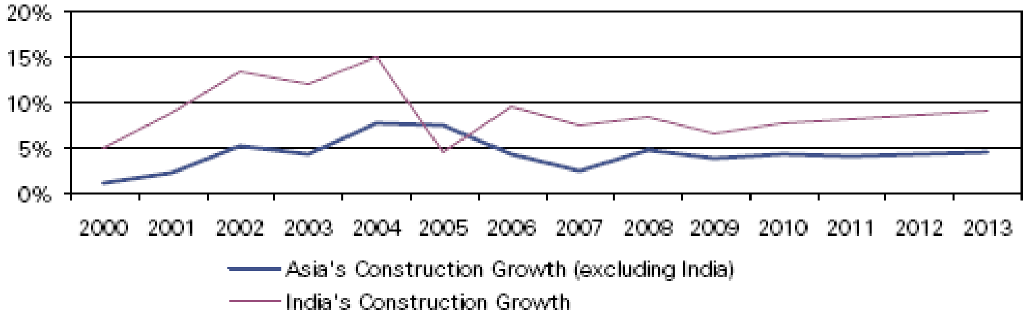


Figure 2.9: India's Construction Growth Relative to Asia (Source: IHS Global Insight on Indian Construction)

The most dynamic reforms taken up by the Government is initiation of Public Private Partnerships (PPP), which would add positive reinforcement and timely implementation of various plans.

Indian Real Estate Sector:

Real Estate is a €8 bn (by revenue) Industry in India. It is projected to grow to €34 bn by 2010. It has witnessed a revolution, driven by the booming economy, favourable demographics and liberalised foreign direct investment (FDI) regime. Growing at a scorching 30 per cent, it has emerged as one of the most appealing investment areas for domestic as well as foreign investors. The second largest employing sector in India (including construction and facilities management), real estate is linked to about 250 ancillary industries like cement, brick and steel through backward and forward linkages. Consequently, a unit increase in expenditure in this sector has a multiplier effect and the capacity to generate income as high as five times.

Market Potential

Commercial office real estate: Propelling growth [11]

The information technology/information technology enabled services (IT/ITES) industry continues to be one of the leading drivers of commercial office growth in India. IT exports, including hardware exports, registered a 32% growth in 2006-07 and 28% in 2007-08, translating into substantial demand for commercial office space. The contribution of IT/ITeS sector to the overall grade. A commercial office space is in the range of 75-80%. This momentum in growth rate is expected to continue for the next few years with the industry estimated to employ at least 3.75 million people by 2016. The entry and expansion of several banking and financial institutions as well as telecom and pharmaceutical companies also contributed to the demand for commercial office space in the last fiscal.

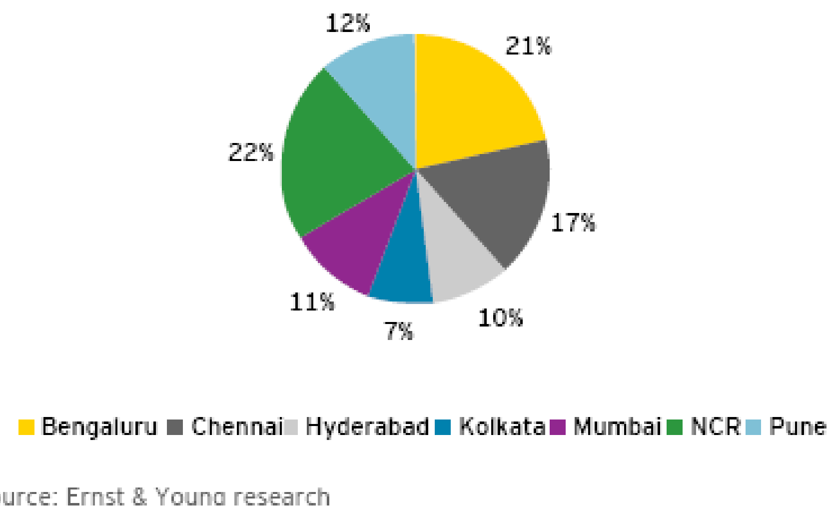


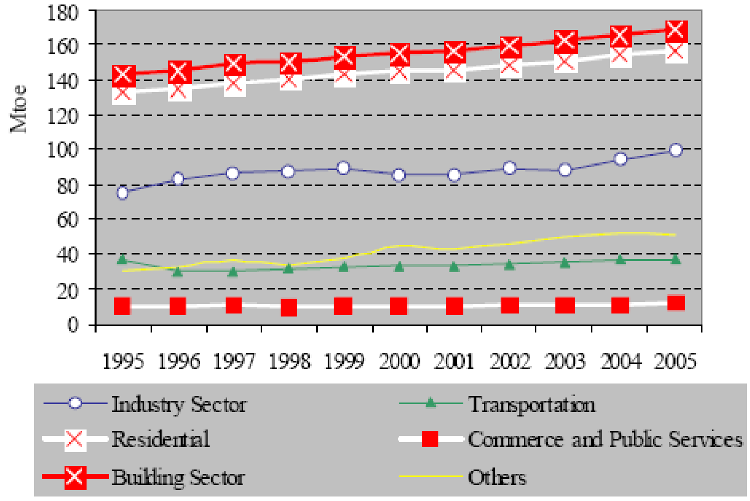
Figure 2.10: Absorption levels (approximately 47.5 million sq ft)

SEZs gaining ground:

The IT/ITes sector specific special economic zones (SEZs) became increasingly popular last year with the incentives they offered to both developers as well as the units. The total number of SEZs notified in 2007-08 stands at 129, out of which 55% are related to IT/ITeS. Leading developers such as DLF, K.Raheja and Unitech are developing SEZs in Hyderabad, Bengaluru, Delhi, Gurgaon, Noida and Chennai.

The ambiguity related to the extension of the sunset clause of the Software Technology Park of India (STPI) scheme till March 2010, which was previously deemed to be terminated in March 2009, has led most companies to defer their decisions on new space leasing.

Construction is a major economic driver in India[15]. Between 2004 and 2005, about 22 million square meters were added for commercial buildings, and 19 million square meters for residential buildings. Most new commercial buildings are equipped with air conditioning (Mathur, 2006). According to the International Energy Agency (IEA), the buildings sector accounted for the largest share of India's final energy use2 between 1995 and 2005



Notes: Energy consumption in this figure refers to final energy use, which includes consumption of renewable and waste energy; the sector "Others" includes agriculture, forestry, fishing, and non-specified and non-energy use.

Figure 2.11: Energy consumption by sector in India, 1995-2005 (Source: IEA, 2007)

Market Survey

AC consumption

Increasing number of AC consumers through the years:

Table 2.1: Ownership of household durables by type: 1990-2015

Per 100 households						
	1990	1995	2000	2005	2010	2015
Air conditioner	0.1	0.2	0.4	0.7	1.1	1.3

According to the FICCI [16] - "The Air-Conditioners Industry has reached at 1.2 million units during 2004-05 with a growth of 25 per cent from 9.8 lakh units in 2003-04.

Consumer Durables is one of the fastest growing industries in India

Table 2.2: Projected growth rates of consumer durable

Colour TVs	25-30%
Refrigerators	18-22%
Washing Machines	15-20%
Air Conditioners	**32-35%**
Others (including VCDs and DVDs)	35-40%

Split Air-conditioners

Split ACs have been growing at a much faster rate than window ACs - Growth of 97% in 2006-07 as compared to a 32% growth of window ACs as per study on consumer durables by India Brand Equity Foundation [17].

Roofing material in homes

As per 2001 Census [18], the roofing materials of the Indian homes are as in the following table:

Table 2.3: Proportion of homes by predominant material of roof: 2001

% of the population			
	Total	**Rural**	**Urban**
Tiles	30.30	35.40	17.60
Grass, thatch, mud, etc	21.40	27.50	6.40
Concrete	21.20	11.90	44.40
Metal, asbestos sheets	12.20	10.50	16.50
Plastic, polythene	0.50	0.40	0.70
Slate	1.10	1.30	0.60
Brick	5.70	5.60	5.80
Stone	6.90	6.70	7.30
Other material	0.70	0.70	0.60

Related Publications

1. User Guide to Energy Conservation Building Code. Published by: Bureau of Energy Efficiency, Ministry of Power, Government of India (development team member)
2. Cool Roofs for Cool Delhi: A Design Manual for Bureau of Energy Efficiency (BEE), Government of Power, India (review team member).

References

[1]. Annexure 3 – "Passive Architecture Design Systems". Eco-housing Assessment Criteria-Version-II. August 2009.

[2]. Paul Gut, Fislisbach, Dieter Ackerknecht, Zollikon. Climate Responsive Architecture – Appropriate Building Construction in Tropical and Subtropical Regions. Published by: SKAT, Swiss Centre for Development Cooperation in Technology and Management.

[3]. Energy Conservation Building Code. Published by: Bureau of Energy Efficiency, Ministry of Power, Government of India

[4]. National Building Code. Published by: Bureau of Indian Standards

[5]. User Guide to Energy Conservation Building Code. Published by: Bureau of Energy Efficiency, Ministry of Power, Government of India

[6]. IGBC Green Homes Reference Guide

[7]. IGBC Green Factory Reference Guide

[8]. LEED India Core and Shell

[9]. LEED India New Construction

[10]. GRIHA rating system

[11]. FICCI Indian real estate shifting gears. Published by: Ernst and Young

[12]. To save power, Delhi govt will paint roofs white .Updated on Wednesday, July 15, 2009, 18:51 IST. http://www.zeenews.com/news547300.html

[13]. Overview of Construction Industry in India, April 2008. Published by: Indo-Italian Chamber of Commerce and Industry Accessible at: http://www.centroesteroveneto.com/pdf/Osservatorio%20Mercati/India/Ricerche%20di%20Mercato/2009/Construction%20Sector.pdf

[14]. India Construction. March 2009. Accessible at: http://www.globalinsight.com/gcpath/India_Construction_1-7.pdf

[15]. http://www.energycodes.gov/implement/pdfs/CountryReport_India.pdf

[16]. FICCI Consumer Durable Goods, Survey-2005

[17]. Consumer Durables- October 2007. Published by: India Brand Equity Foundation

[18]. Census of India, 2001.

Chapter 3: Field Performance and Savings Potential of Cool Roofs in India

3.1: Introduction

In this chapter, the performance of various cool roof products that were installed on site (in IIIT Hyderabad) was observed. Further, a short analysis to show the savings potential of cool roof in various Indian climates has been performed through simulations.

A varied range of materials and technology are available these days for cool roofs. Use of china mosaic, white cement, lime and chalk, elastomeric coatings, and white ceramic tiles are some common practices. Development of cool colour coating is a very recent research going on in the field of cool roof materials. The study of aging of cool roof products is also important to understand the performance of various products over the life of the product and the savings that would be a result of that performance.

In a study performed by R.T.A. Prado et al [1], various roofs that are popularly seen in Brazil were evaluated. The materials considered for the performance evaluation were: red and white ceramics, fibrocement without asbestos, coated and uncoated aluminium, coated and uncoated stainless steel, aluminium and zinc coated metal, thermal-acoustic metal that can be aluminium, green, white and ceramics in colour, and coloured cement that can be light gray, dark gray, red and ochre in colour, with and without resin. The red and the white ceramics were the only materials among those that were measured that had reached surface temperatures lower than air temperatures, however, the metallic materials that had similar performances as the white and red ceramics, with value of albedo approximately equal to 0.55, showed much high surface temperatures. Therefore, the study terms emittance to be one important property of the product to be named as a "cool material".

R. Levinson et al [2] studies the effect of cooler tile –roofed buildings with near infrared reflective non-white coatings. In this work, the effect of increase albedo on these roofs was observed in three different cities of California. The results show that a savings of 5%, 6% and 1% are achieved in Fresno, San Bernardino and San Diego, respectively. These savings were half those previously reported for houses with non-tile roofs. Surface temperatures of all the cool tile coatings when compared to the standard colour coatings (black, blue, grey, terracotta, green, and chocolate), ranged between 2.3^{o}C – 14.4 ^{o}C, with the highest difference in black roof and lowest in grey roof.

R. Levinson et al [3] in one another paper documented the effects of soiling and cleaning on the reflectance and solar heat gain of a light-coloured roofing membrane. The study investigates the solar spectral reflectances and solar absorptances of 15 initially white or light grey polyvinyl chloride membrane samples taken from roofs across United States. The results show that at most soiled location on each membrane, the ratio of solar reflectance to unsoiled solar reflectance (a measure of cleanliness) ranged from 0.41 to 0.89 for the soiled samples, 0.53 to 0.95 for the wiped samples, 0.74 to 0.98 for the rinsed samples, 0.79 to 1.00 for the washed samples, and 0.94 to 1.02 for the bleached samples.

In a work by K. L. Uemoto et al [4], the thermal performance of cool coloured acrylic paints containing infrared reflective pigments where investigated in comparison to conventional coloured acrylic paints of similar colours (white, brown and yellow) applied on sheets of corrugated fiber cement roofing. Results demonstrated that the cool coloured pain formulations produced significantly higher near infra red reflectance, and the surface temperatures were 10^{o}C lower than those of conventional paints.

Therefore, the cool roof products, their maintenance, and life play a major role in the understanding the performance of a cool roof, and its effect on energy consumption of the building. In this work, a small scale field study, was performed at IIIT Hyderabad hostel roofs to observed the performance of various roof products those are available in the market. A detail of this study has been presented in this chapter.

Along with this, an introductory study on Indian climate and the effect of cool roof on cooling energy consumption of building in various Indian climates has been performed. From several studies [5][6][7][15][9][10][11] that documented the energy savings due to cool roof in cooling energy consumption, it can be observed that the savings vary widely, depending on the climate, roof type, roof solar reflectivity (SR) and type of building. . In a literature review by Jeff S. Haberl [15], study of 72 different research papers related to cool roof has been performed. This study states that the cooling energy savings can be averaged to about 20%, due to cool roofs. However, most of these studies are not for Indian cities. Hence, in this chapter simulations were performed to understand the possible savings in cooling energy consumption due to cool roof, for various climates of India.

3.2: Cool roof products: an insight into performance though a field installation

A field installation has been done to understand and observe the performance of 6 different cool roof products that are available in the market. The roof of the IIIT H hostel has been treated to observe the weathering and the surfaces temperatures of the roof. Six products that are widely available in the market were considered for installation. All the roof treatment was completed by the end of April 2010. Since then, till date the roof was exposed to various harsh weathers such as heavy rains and sun. The products that are installed on the terrace are:

- White Cement: Normal white cement which is generally available in any hardware shops and is in use by several common users. It has been observed that several products of this sort, which seem to have less life but are economical come into the market every summer.
- White ceramic tiles – matt finish: Ceramic tiles in white are installed over one roof. Though they seem to be less reflective when compared to the elastomeric reflective coatings, they tend to have better life.
- White ceramic tiles – gloss finish: The gloss finish tile was assumed to reflect more radiation. However, it is to be noted that it might cause a visual disturbance to the people using the terrace or the people in surrounding buildings
- Reinforced aluminium foil - with solar reflectance value around 0.8.
- Acrylic resin coating - A water-based pure acrylic resin coating, which is a combination of high Reflectance (82%) and high Emittance (94%).
- Modified acrylic water proofing coating - A waterproofing cum solar heat gain reduction coating, with SRI of 100 (solar reflectance of 0.79 and emissivity of 0.982)..

Pictures of the roofs after few months of their installation are as seen in Figure 3.1 - Figure 3.8.

Figure 3.1: Cool roof installed on site

Figure 3.2: Cool roof installed on site

Figure 3.3: Gloss tiles

Figure 3.4: Matt tiles

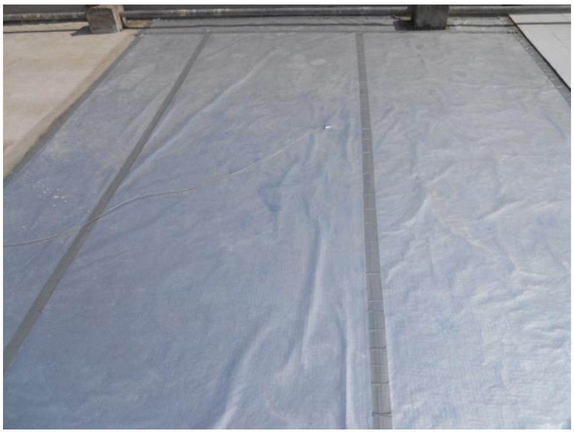


Figure 3.5: Reinforced aluminium foil

Figure 3.6: Modified acrylic coating

Figure 3.7: Acrylic resin coating

Figure 3.8: All products as installed on site

The performance of these products was initially (for a period of three months) monitored using temperature sensors and a data logging system. From those results, the outside surface temperature of the first installed three roofs (cool home, matt tiles and gloss tiles) for a day and half is as seen in Figure 3.9.

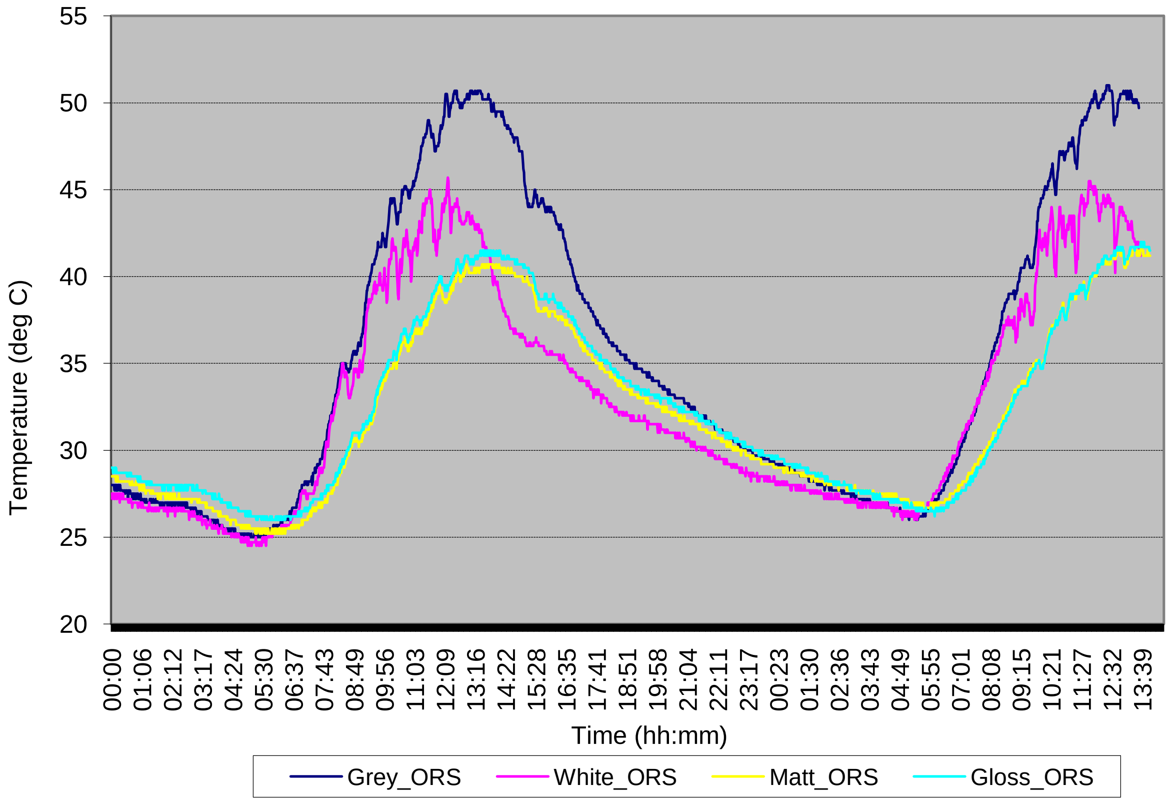


Figure 3.9: Roof outside surface temperatures (deg C) in month of April

From the graph, it is clear that the tiles performed better in comparison with the white coating. Further, a time lag can also be seen in case of the tiles.

Later during the month of July, all the roofing systems were monitored, and the outside surface temperatures are as in Figure 3.10. From this data it has been observed that the cool coating-2 performed the best and the tiles showed the least savings. This trend has been further observed over a period of time, and the observations show that the cool coating which have no thermal mass when compared to the tiles, have less surface temperature.

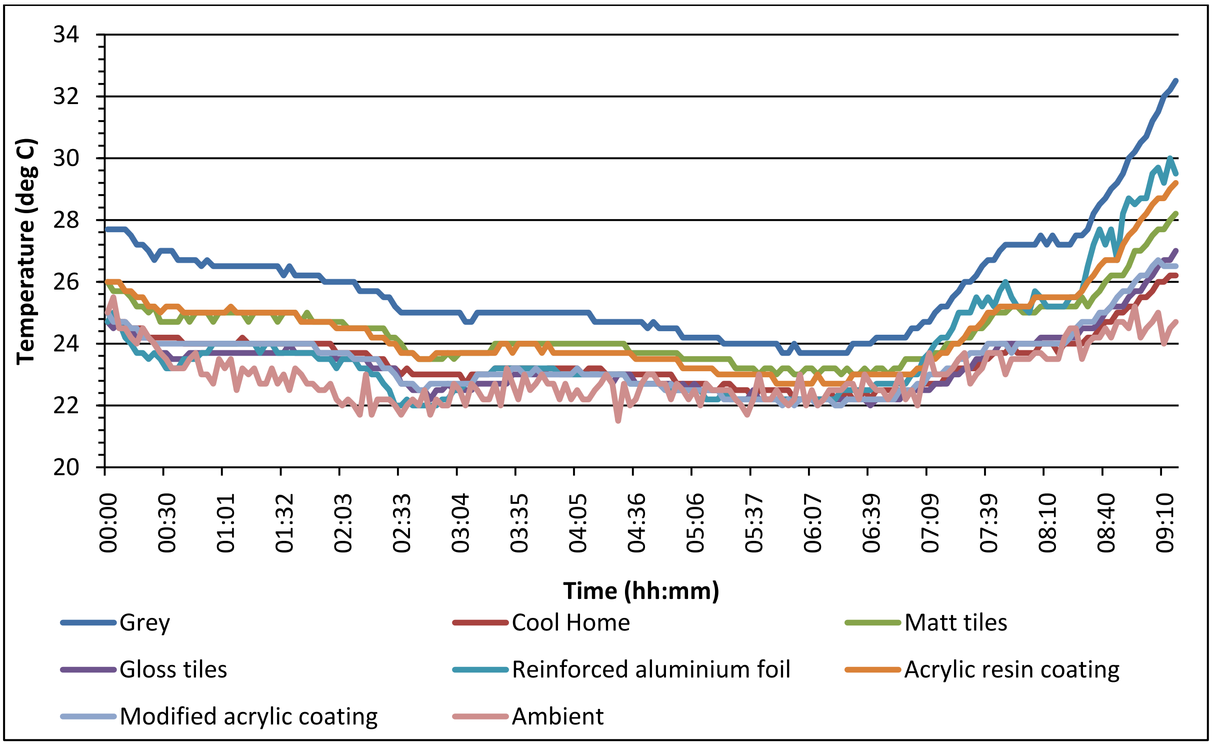


Figure 3.10: Roof outside surface temperatures (deg C) in month of July

However, over the span of one year it has been observed that due to weathering, the aluminium sheet got torn, the white coated roofs had dust, gravel and black carbon filled over, and also some of the paints got peeled off at places. Therefore, from the observations it can be concluded that, though the savings that can be achieved due to the floor tiles seem to be less, the life of these tiles is higher, due to which a good payback can be achieved over time.

3.3: Cool roof material

Some of the roofing materials and choices of cool roof can be as below:

Table 3.1: Common roofing material in India

Common roofing materials	**Cool Options**	**Pay back**
Cement roof	White cement	< 1 year
Tiles	White/light colour tiles	Negative to 1
Buildup roof	White/light colour coating	3-4 years
Metal roof	White paint/coating	< 1
Mud house	White wash roof	More comfort

333333333333Cool roofs can be selected from a wide variety of materials and colours, and can be advantageously applied to almost any building or roof type, and in most locations. Moreover, cool roofs are a viable option for both new and existing building applications. Some cool roof coatings and their properties are as listed in Table 3.2. A bigger list of material along with their respective manufactures is as listed in Appendix B: List of products, vendors and manufactures.

Table 3.2: Solar Reflectance Index (SRI) for typical roofing materials

Example SRI Values for Generic Roof Materials	*Solar Reflectance*	*Infrared Emittance*	*Temp Rise (C Deg)*	*SRI*
Gray EPDM	*0.23*	*0.87*	*38*	*21*
Gray Asphalt Shingle	*0.22*	*0.91*	*37*	*22*
Unpainted Cement Tile	*0.25*	*0.90*	*36*	*25*
White Granular Surface Bitumen	*0.26*	*0.92*	*35*	*28*
Red Clay Tile	*0.33*	*0.90*	*32*	*36*
Light Gravel on Built-up Roof	*0.34*	*0.90*	*32*	*37*
Aluminum	*0.61*	*0.25*	*27*	*56*
White Coated Gravel on Built-up Roofing	*0.65*	*0.90*	*16*	*79*
White Coating on Metal Roof	*0.67*	*0.85*	*16*	*82*
White EPDM	*0.69*	*0.87*	*14*	*84*
White Cement Tile	*0.73*	*0.90*	*12*	*90*
White Coating – 1 coat-8 mils	*0.80*	*0.91*	*8*	*100*
PVC White	*0.83*	*0.92*	*6*	*104**
White Coating – 1 coat-20 mils	*0.85*	*0.91*	*5*	*107**

*Materials that have reflectance and emittance values greater than those of Standard White, will have a SRI value greater than 100.

(Source: Cool Roofs for Cooler Delhi: Design Manual)

3.4: Climate Analysis

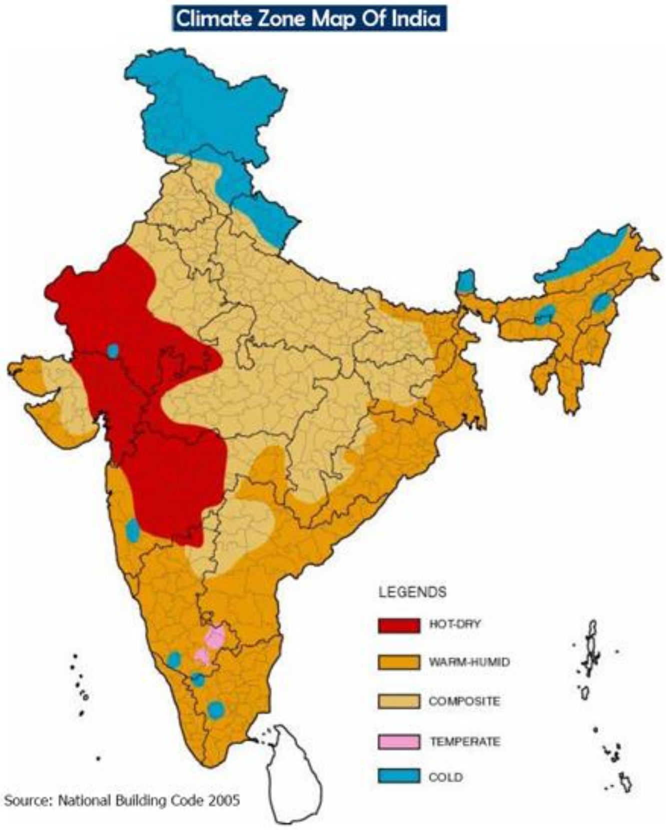


Figure 3.11: India climate zone classification as specified in ECBC

India is a land of different climatic conditions varying from very hot and dry to cold and humid. The characteristics of each climate differ and accordingly the comfort requirements vary from one climatic zone to another. Based on the intended use, comfort requirements and design type, the energy requirement of buildings change. There are five climatic zones based on the hourly temperature, various climatic parameters and solar radiation:

- Composite
- Hot-dry
- Moderate
- Warm-humid
- Cold

The climatic conditions of the important cities in each of the above climatic zones are detailed in the following pages.

Ahmedabad

Longitude:	E 72° 37'
Latitude:	N 23° 4'
Elevation:	55m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	44.2°C
Minimum Dry Bulb temperature:	8.9°C
Maximum Dew Point temperature:	28.6°C
Minimum Dew Point temperature:	0.5°C
Annual cooling degree-days (18°C baseline):	3517 days
Annual heating degree-days (18°C baseline):	0 days

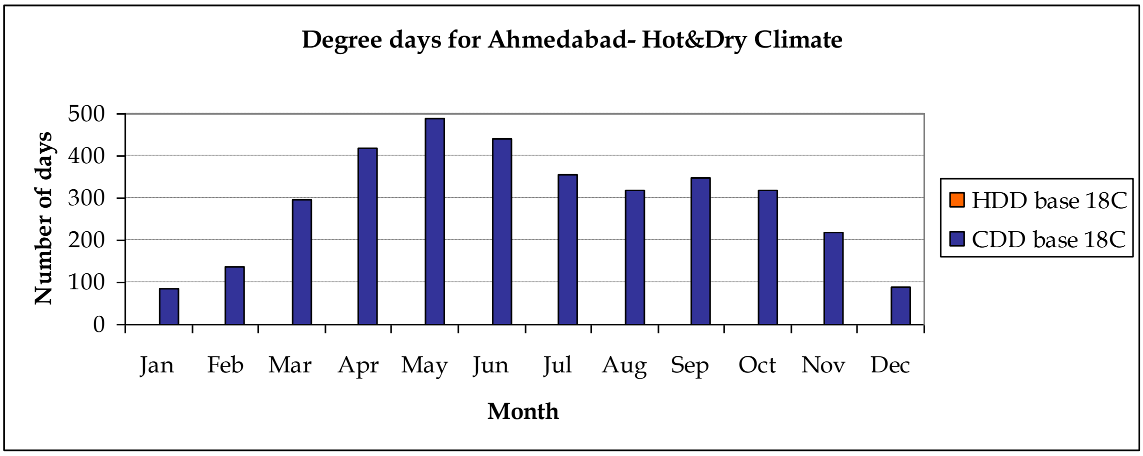


Figure 3.12: Degree days for Ahmedabad. The hot and dry climate of Ahmedabad doesn't show any heating degree days at 18^{o}C temperatures.

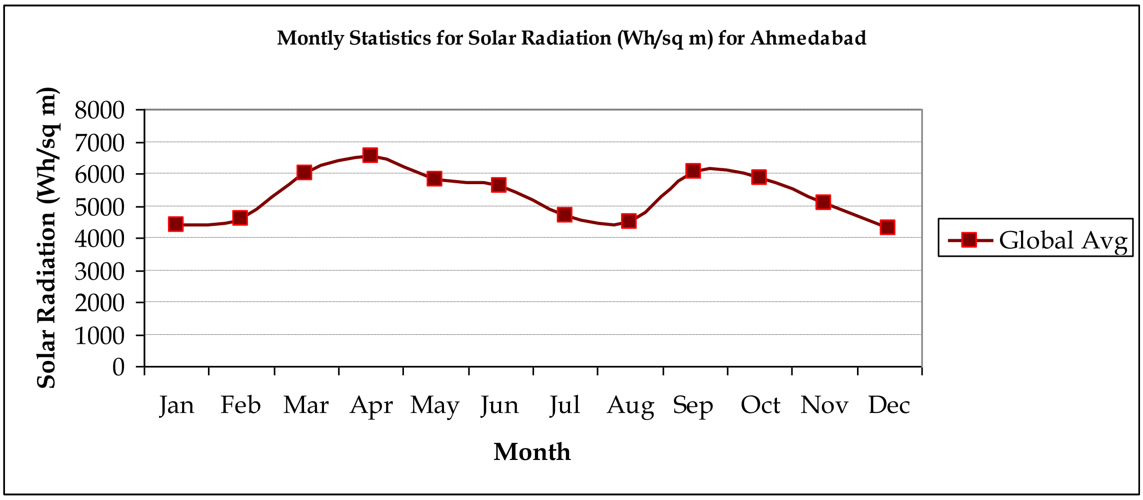


Figure 3.13: Monthly solar radiation in Ahmedabad. The average global horizontal solar radiation ranged between 4000- 7000 (Wh/m^{2})

Chennai

Longitude:	E 80° 10'
Latitude:	N 13° 0’
Elevation:	16m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	39.5°C
Minimum Dry Bulb temperature:	14.5°C
Maximum Dew Point temperature:	28.5°C
Minimum Dew Point temperature:	10.6°C
Annual cooling degree-days (18°C baseline):	3718 days
Annual heating degree-days (18°C baseline):	0 days

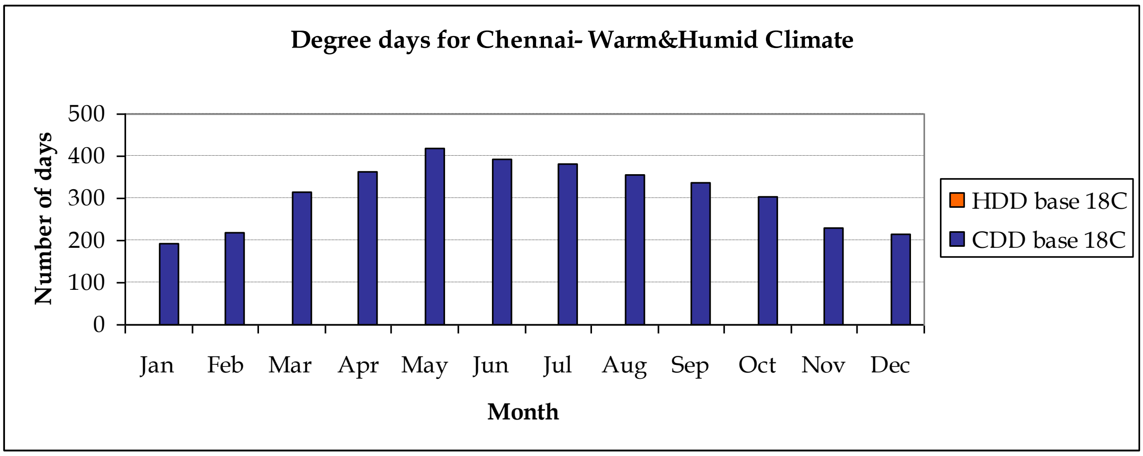


Figure 3.14: Degree days for Chennai. The warm and humid climate of Chennai doesn’t show any heating degree days at 18^{o}C temperatures.

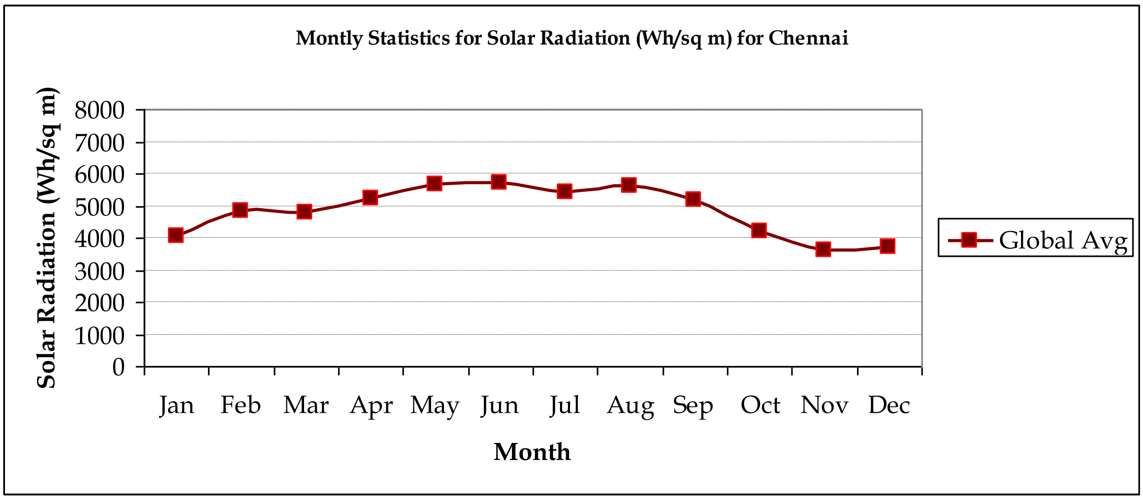


Figure 3.15: Monthly solar radiation in Mumbai. The average global horizontal solar radiation ranged between 4000- 6000 (Wh/m^{2})

New Delhi

Longitude:	E 77° 11'
Latitude:	N 28° 34'
Elevation:	216m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	44.3°C
Minimum Dry Bulb temperature:	5.2°C
Maximum Dew Point temperature:	28.9°C
Minimum Dew Point temperature:	0.2°C
Annual cooling degree-days (18°C baseline):	2721 days
Annual heating degree-days (18°C baseline):	278 days

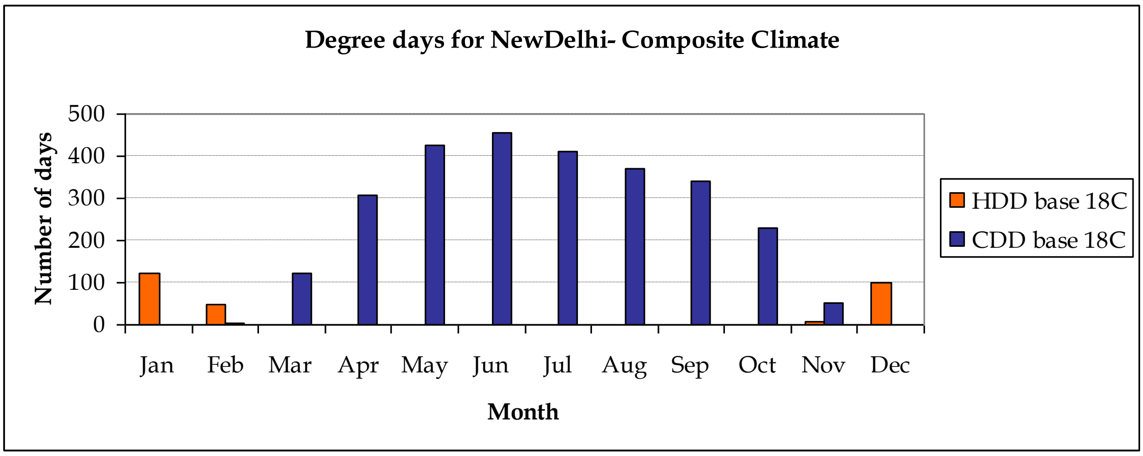


Figure 3.16: Degree days for NewDelhi. Heating degree days at temperature of 18°C can be observed for four winter months

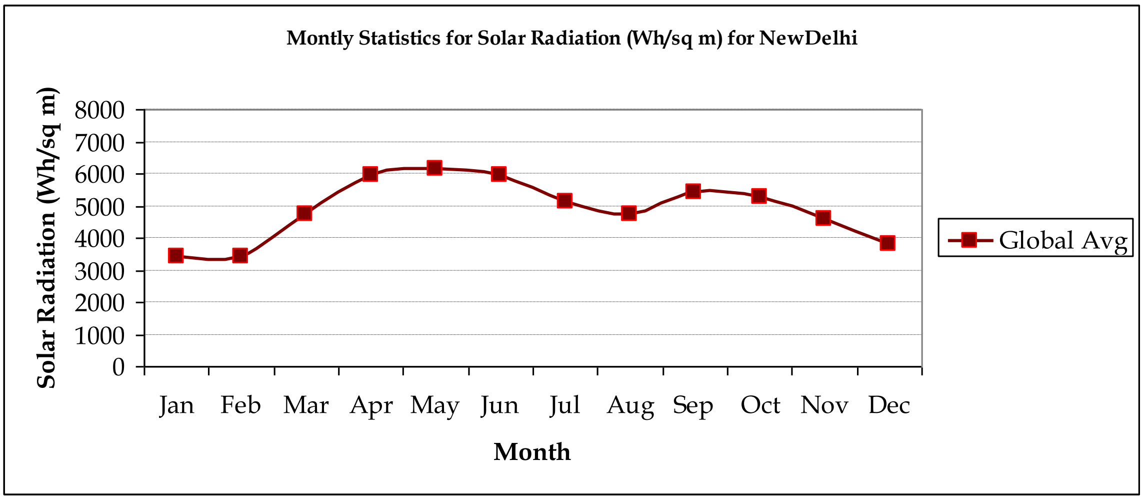


Figure 3.17: Monthly solar radiation in NewDelhi. The average global horizontal solar radiation ranged between 3000- 6000 (Wh/m^2)

Bengaluru

Longitude:	E 77° 34'
Latitude:	N 12° 58'
Elevation:	921m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	36.6°C
Minimum Dry Bulb temperature:	13.0°C
Maximum Dew Point temperature:	24.4°C
Minimum Dew Point temperature:	0.0°C
Annual cooling degree-days (18°C baseline):	2036 days
Annual heating degree-days (18°C baseline):	0 days

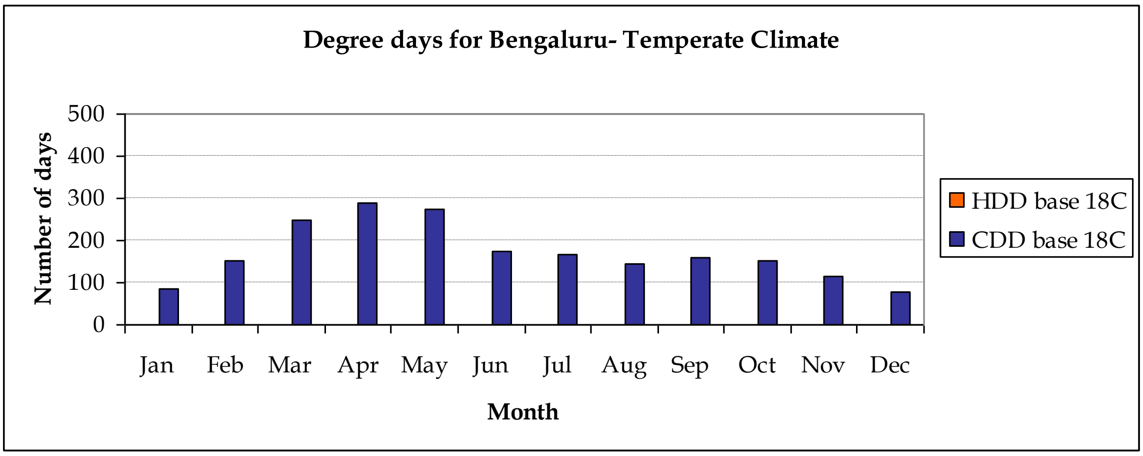


Figure 3.18: Degree days for Bengaluru. The temparate climate of Bengaluru doesn't show any heating degree days at 18^{o}C temperatures.

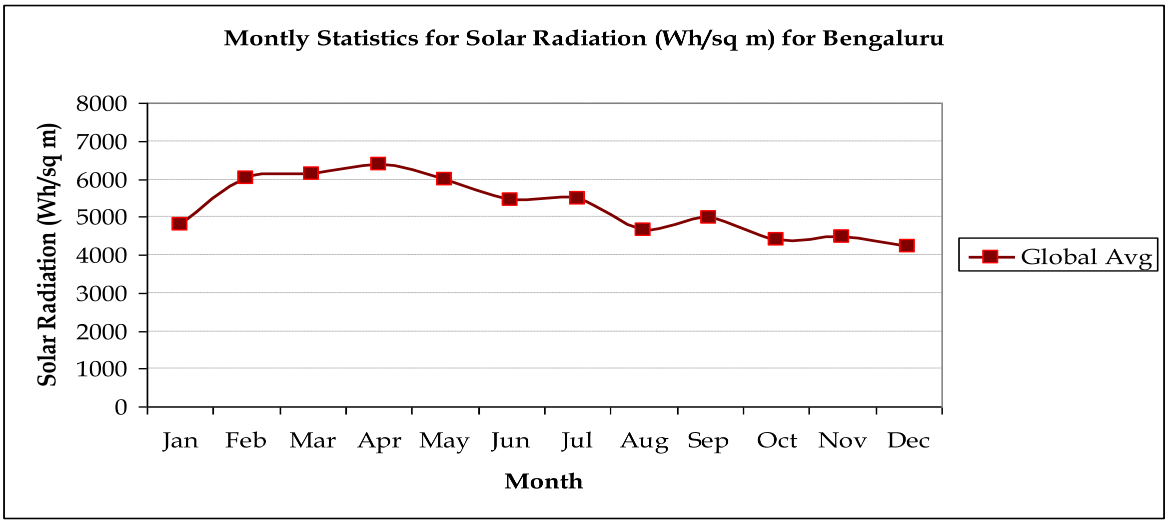


Figure 3.19: Monthly solar radiation in Bengaluru. The average global horizontal solar radiation ranged between 5000- 6500 (Wh/m^2)

Hyderabad

Longitude:	E 78° 28'
Latitude:	N 17° 27'
Elevation:	545m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	41.2°C
Minimum Dry Bulb temperature:	11.7°C
Maximum Dew Point temperature:	24.6°C
Minimum Dew Point temperature:	0.0°C
Annual cooling degree-days (18°C baseline):	3183 days
Annual heating degree-days (18°C baseline):	0 days

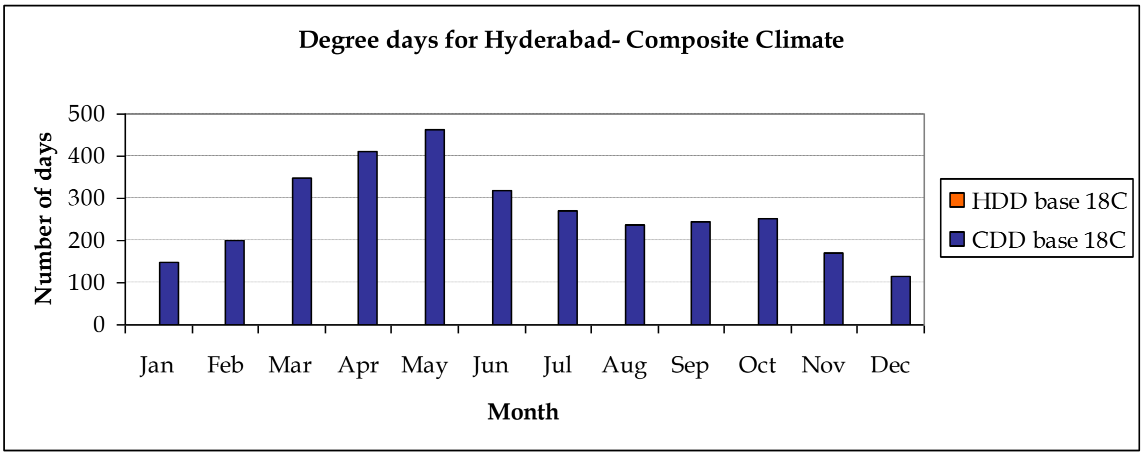


Figure 3.20: Degree days for Hyderabad. The composite climate of Hyderabad doesn't show any heating degree days at 18°C temperatures.

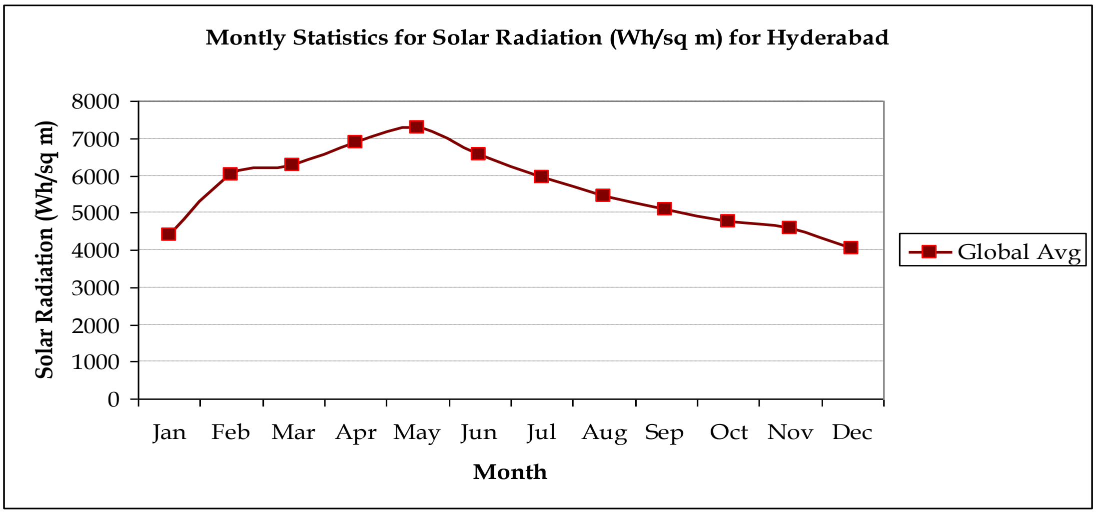


Figure 3.21: Monthly solar radiation in Hyderabad. The average global horizontal solar radiation ranged between 4000- 7500 (Wh/m^2)

Mumbai

Longitude:	E 72° 50'
Latitude:	N 19° 7’
Elevation:	14m above sea level
Data Source:	ISHRAE Data
Maximum Dry Bulb temperature:	38.5°C
Minimum Dry Bulb temperature:	14.2°C
Maximum Dew Point temperature:	28.0°C
Minimum Dew Point temperature:	2.9°C
Annual cooling degree-days (18°C baseline):	3349 days
Annual heating degree-days (18°C baseline):	0 days

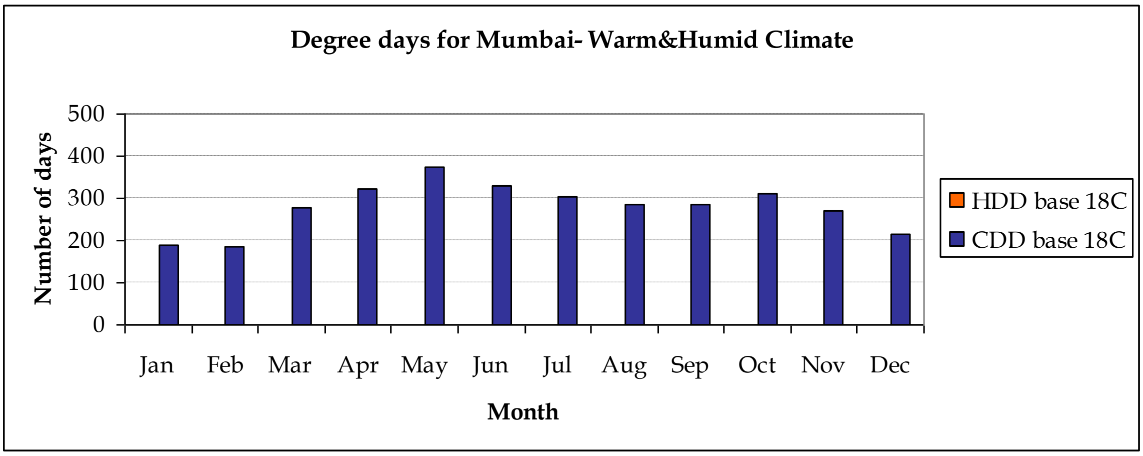


Figure 3.22: Degree days for Mumbai. The warm and humid climate of Mumbai doesn’t show any heating degree days at 18°C temperatures.

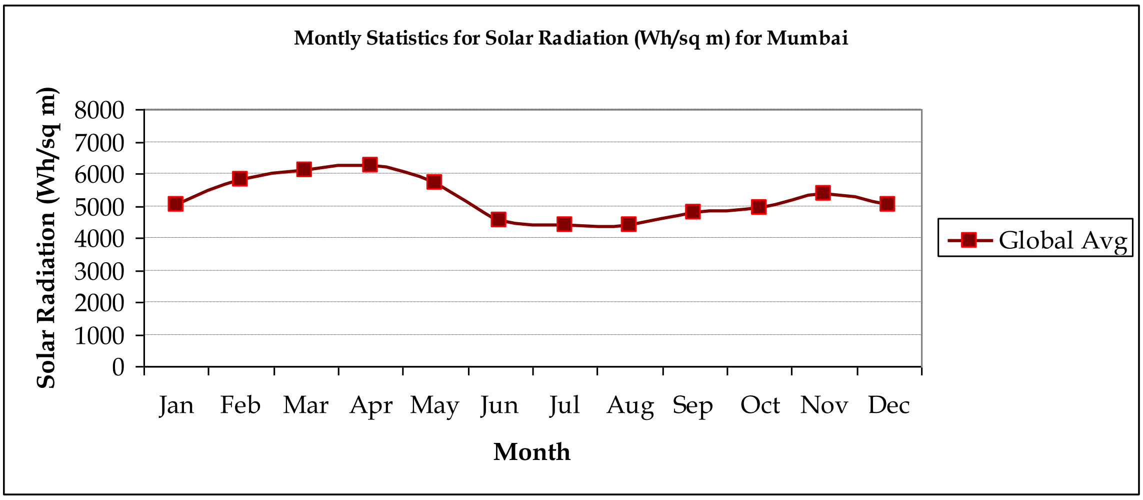


Figure 3.23: Monthly solar radiation in Mumbai. The average global horizontal solar radiation ranged between 5000- 6000 (Wh/m^2)

Kolkata

Longitude:	E 88° 26'
Latitude:	N 22° 38'
Elevation:	6m above sea level
Data Source:	IWEC Data
Maximum Dry Bulb temperature:	41.2°C
Minimum Dry Bulb temperature:	10.9°C
Maximum Dew Point temperature:	30.4°C
Minimum Dew Point temperature:	6.4°C
Annual cooling degree-days (18°C baseline):	3021 days
Annual heating degree-days (18°C baseline):	11 days

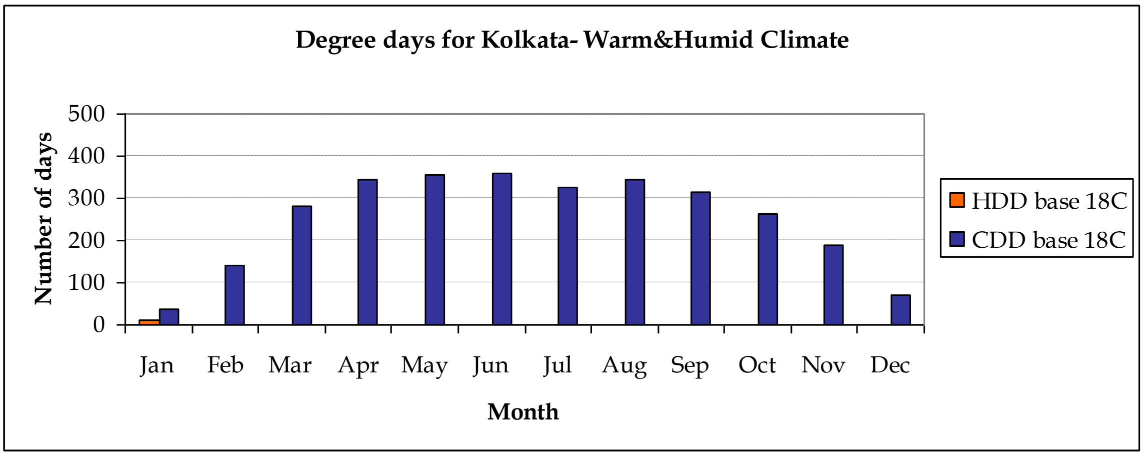


Figure 3.24: Degree days for Kolkata. The warm and humid climate of Kolkata doesn't show any heating degree days at 18°C temperatures.

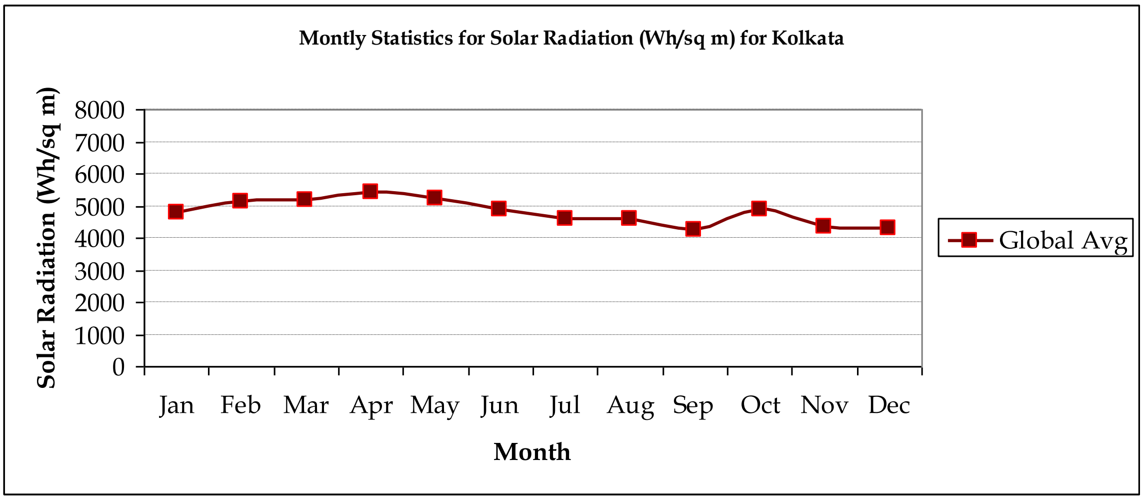


Figure 3.25: Monthly solar radiation in Kolkata. The average global horizontal solar radiation ranged between 4000- 5000 (Wh/m^2)

3.5: Simulation for cool roof

A simulation model has been developed to observe the HVAC energy savings resulted due to cool roof, for a building in various climatic zones of India. The characteristics of the simulation model are:

- 900 m^2 conditioned floor area
- A square shaped building
- Single storey
- Perimeter and core zoning
- Office schedules and activities
- Equipment power density:15 W/ m^2
- Lighting power density: 10.8 W/ m^2
- Occupancy density: 0.11 person/m^2
- Window to wall ratio: 30%
- Single Glaze 6mm glass with SHGC of 0.25
- RCC framed structure with brick wall
- Air Cool chiller with COP of 3

The simulations were performed for two cases, based on the roof type: 1. Roof with insulation, and 2. Roof without insulation. The savings in HVAC consumption for different roof types in different cities by use of cool roof as compared to normal grey roof, in percentage is as shown in Table 3.4 and Table 3.4

Table 3.3: Savings in HVAC energy consumption due to cool roof, for different climates

	Roof without Insulation (kWh/sq m)	**Roof with Insulation (kWh/sq m)**
Hyderabad	15.69	2.86
New Delhi	16.28	3.01
Mumbai	16.79	3.13
Bengaluru	16.48	3.07
Chennai	18.48	3.32

Table 3.4: Percentage savings in HVAC energy consumption due to cool roof, for different climates

	% savings Roof without Insulation	**% savings Roof with Insulation**
Hyderabad	20.40%	4.35%
New Delhi	21.88%	4.90%
Mumbai	22.15%	4.89%
Bengaluru	28.02%	6.28%
Chennai	20.78%	4.51%

Related Publications

1. Cool Roofs for Cool Delhi: A Design Manual for Bureau of Energy Efficiency (BEE), Government of Power, India (review team member).

References

[1]. Racine Tadeu Araújo Prado, Fabiana Lourenço Ferreira. “Measurement of albedo and analysis of its influence the surface temperature of building roof materials”. Energy and Buildings 37 (2005) 295–300.

[2]. Ronnen Levinsona, Hashem Akbaria, Joseph C. Reilly. “Cooler tile-roofed buildings with near-infrared-reflective non-white coatings”. Building and Environment 42 (2007) 2591–2605.

[3]. Ronnen Levinsona, Paul Berdahl, Asmeret Asefaw Berhe, Hashem Akbari. “Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane”. Atmospheric Environment 39 (2005) 7807–7824.

[4]. Kai L. Uemoto, Neide M.N. Sato,Vanderley M. John. “Estimating thermal performance of cool colored paints”. Energy and Buildings 42 (2010) 17–22.

[5]. Hashem Akbari , Ronnen Levinson , Leo Rainer. Monitoring the energy-use effects of cool roofs of California commercial buildings. Energy and Buildings 37 (2005) 1007–1016.

[6]. Craig Wray, Hashem Akbari. “The effects of roof reflectance on air temperatures surrounding a rooftop condensing unit”. Energy and Buildings 40 (2008) 11–28

[7]. Berdahl, P. and S. Bretz. 1997. "Preliminary Survey of the Solar Reflectance of Cool Roofing Materials," Energy and Buildings - Special Issue on Urban Heat Islands and Cool Communities, 25(2):149-158.

[8]. Konopacki, S., L. Gartland, H. Akbari, and L. Rainer. 1998. “Demonstration of Energy Savings of Cool Roofs,” Lawrence Berkeley National Laboratory Report No. LBNL-40673, Berkeley, CA.

[9]. Hildebrandt, E., W. Bos, and R. Moore. 1998. “Assessing the Impacts of White Roofs on Building Energy Loads.” ASHRAE Technical Data Bulletin 14(2).

[10]. Konopacki, S. and H. Akbari. 2001. “Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin.” Lawrence Berkeley National Laboratory Report LBNL-47149. Berkeley, CA

[11]. Parker, D., J. Sherwin, and J. Sonne. 1998b. “Measured Performance of a Reflective Roofing System in a Florida Commercial Building.” ASHRAE Technical Data Bulletin 14(2).

[12]. Haberl, J. S.; Cho, S. “Literature Review of Uncertainty of Analysis Methods (Cool Roofs)”. October 2004. Published by: Energy Systems Laboratory (http://esl.tamu.edu), Texax A & M University. Accessible at: http://hdl.handle.net/1969.1/2071

Chapter 4: Analysis of raw data of a cool roof demonstration project

4.1: Introduction

This chapter comprises of the analysis of raw data that has been collected in a yearlong experimental monitoring project that has been conducted by IIIT Hyderabad in collaboration with Lawrence Berkley National Laboratory, US. The analysis aims in understanding the effect on cool roof on cooling energy consumption through a field experiment. Some part of this study has been earlier reported in M.S. by research thesis [1] of Murari HariBabu of Centre for IT in Building Science. Further analysis has been performed over the data taking a different approach. The preliminary results reported earlier and the analysis data was revisited, and a new set of data has been developed through which the final results were derived. Since, the experimental study was done in collaboration with the Lawrence Berkley National Laboratory; USA, the report is now being finalized with the revised results, and is under publication at LBNL. Details of the experiment, preliminary analysis and the revised final analysis have been discussed in this chapter. The major contribution of this work includes the analysis of the hourly, daily and annual data, to derive the savings due to a cool roof.

Various prior studies of cool roof show different percentage savings in cooling and HVAC energy consumption, which are generally dependent on several other variables. Experiments- both laboratory and field installations, simulations, and mathematical modelling, were various modes used in researching the advantages of cool roof on buildings and global level. J.R. Simpson and E.G. McPherson [2] in their project, monitored the electrical use of wall-mounted air conditioners, roof temperatures, and related environmental factors, for a ¼ scale building models situated in Tucson, Arizona. In this experiment they found that the hourly peak electrical use for AC is approximately reduced by 5% in case of a ceiling insulated roof, when painted white (SR 0.75), when compared to grey (SR 0.3) or silver (SR 0.49) colour roofs. These savings were more in case of an un-insulated roof. In another study by S.K. Meyn and T. R. Oke [3], six different roof assemblies in Vancouver, Canada, and observed them across a range of wind and moisture conditions. One important conclusion from this study was that there are significant differences in the heat conduction characteristics of different industrial/commercial and residential roof assembly types. H.Akbari et al [4] monitored the effect of cool roofs on energy use and environmental parameter in six California buildings at three different sites. Results showed that installing a cool roof reduced the daily peak roof surface temperature of each building by 33-42 K. Further, depending on the monitoring period, climate and type of building, the average air conditioning energy savings varied between 3%-52%, with the highest in the retail store in Sacrameto, and the lowest in a cold storage facility in Reedley. J. H. Jo et al [5] documented the energy saving and surface temperature reduction achieved by replacing the existing commercial building's flat roof with a more reflective cool roof surface material. The results revealed that reduction of 1.3 – 1.9% and 2.6 – 3.8% of the total monthly electricity consumption can be achieved from the 50% cool roof replacement already implemented and a future 100% roof replacement respectively. However, all these works were in climates other than India. Hence, for this study, before deciding with the experiment site, the team from LBNL in consultation with USAID's Global Climate Change team studied three countries – Brazil, India and Mexico. The study was mainly to analyze parameters such as: (1) local climate, (2) potentials for electricity and Green House Gases (GHG) savings, (3) available data and resource capacity for climate simulations and local air pollution modeling, (4) manufacturers as potential collaborators, and (5) government agencies and other institution as partners. Based on all this analysis, Hyderabad was selected for the field experiment.

4.2: About the experiment

On a macro level, the major goal of this complete project was to understand the benefits from extensive application of cool roofs, through a micro level field experiment. This was achieved through field evaluations, model simulations, and knowledge transfer. LBNL earlier has a monitored the impact of reflective roofs on energy use of commercial and residential building in the United States. In this experiment a field study has been performed to monitor and demonstrate the effect of cool roofs in two buildings in Satyam Learning Centre, Hyderabad, India. Hyderabad being a composite climate with hot summers has a large potential for cool roofs. The experiment has been conducted in three phases in the top floor of two typical building of the project site. Yearlong monitoring has been done to measure the heat flux through roof, surface temperatures, indoor air temperatures and temperatures within the plenum. Along with these, a weather station has been set up to monitor the local weather conditions such as: outdoor dry bulb temperature, humidity, and solar radiation. Reduction in heat flux, power demand and AC energy consumption are the major observations of the experiment.

4.3: Experimental Setup

The complete experimental setup can mainly be explained under three main categories such as: the building description, monitoring equipment, and the schedule of the experiment. This would provide an overview of the complete setup and further explain various phases of the experiment in which the properties of the roof material are varied to observe the necessary output parameters.

4.3.1 Building description

Two identical buildings within a same campus of an IT learning centre were selected for the experiment. The Satyam Learning Centre, Hyderabad has two buildings: the East wing and the West wing, of the training centre. Both the buildings are nearly identical, have same atmospheric conditions, design and almost same kind of usage pattern. Both buildings (i.e., East building, West building) are G+1 structure. They are made from concrete and bricks and the structure is a typical beam and column construction. It has a conventional concrete slab with gypsum board false ceiling. Both the East and the West wings face each other and are oriented on the East-West axis. The floor height is 12' with a clear space of 8'3", 3' for the air conditioning ducts and false ceiling. The thickness of the slab is 6" and it has 3" thick flooring.

SLC is a learning center with labs, cabins, cubicles, discussion rooms, library, toilets, pantry, electrical rooms, UPS rooms etc. with a high usage level of air conditioning. The first floor of both the blocks is occupied by labs which are primarily used for training and lie in the central core with other areas arranged around it. The East wing has 4 labs, each of 22'3"x34'10" for 30 people, 120 computers for all the four labs whereas the West wing has 2 computer labs of about 44'x34'housing 60 computers each. The labs are well insulated from three sides by corridors thus there is less ingress of external heat load to the main air conditioned space. Roof area of each of the building is 700 m^2. Figure shows

The air conditioning is done through ductile split units of different capacities with AHU's on both the floors to facilitate the distribution of conditioned air to all the required spaces. Each wing has two air handling units consisting of about 27TR capacity in each. Unlike the corridors of the East wing, the corridors of the West wing were air-conditioned initially but the diffusers were closed later (before the start of the experiment). However, it was observed that there was some leakage in these diffusers, which might be the reason for slightly more AC consumption in the West wing.

The East and the West wings have separate AHU's. There are two AHU's on the first floor of each building. The study required monitoring of top floor (1st floor) air-conditioning load, which was possible due to availability of separate systems on the top floor of each building.

The building has single glazed sealed windows on the periphery. The panel rooms are located on the same floor, where the Data Logger was installed.

4.3.2 Monitoring equipment

Various research-grade sensors were used to measure indoor and outdoor air temperatures, outdoor air relative humidity, roof surface temperatures, roof heat fluxes, solar radiation, and electric power consumed by the HVAC, UPS, and lighting systems serving the test spaces.

Table 4.1: Measurement point summary

Measurement Points	***Sensor Type***	***Locations***
8 indoor air temperatures	Campbell Scientific 108-L temperature probe	1 in each of 4 ceiling return plenums and 4 conditioned spaces (West building Labs 1 and 2; East building Labs 1 and 3)
1 outdoor air temperature	Campbell Scientific 108-L temperature probe inside fan-aspirated radiation shield	1 on weather tower near center south side of West building roof
1 outdoor air relative humidity	Vaisala HMP45C-L relative humidity and air temperature probe inside naturally-aspirated radiation shield	1 on weather tower near center south side of West building roof
8 roof surface temperatures	Minco S667 surface temperature sensor with Minco TT246 temperature transmitter	1 on top surface of roof and 1 between bottom surface of roof and insulation above each of 4 ceiling plenums (West building Labs 1 and 2; East building Labs 1 and 3)

4 heat fluxes	Campbell Scientific HFT3 heat flux sensor	1 between bottom surface of roof and insulation above each of 4 ceiling plenums (West building Labs 1 and 2; East building Labs 1 and 3)
1 total horizontal solar radiation	Kipp and Zonen CM3 pyranometer	1 on weather tower near center south side of West building roof
14 HVAC, UPS, and lighting electric power consumptions	Continental Control Systems Wattnode WNA-3Y-400P pulse output watt-hour transducer with split-core current transformers	1 for each of 8 HVAC systems, 1 for each of 4 UPS systems, and 1 for each of 2 lighting systems serving conditioned spaces (West building Labs 1 and 2; East building Labs 1 through 4)

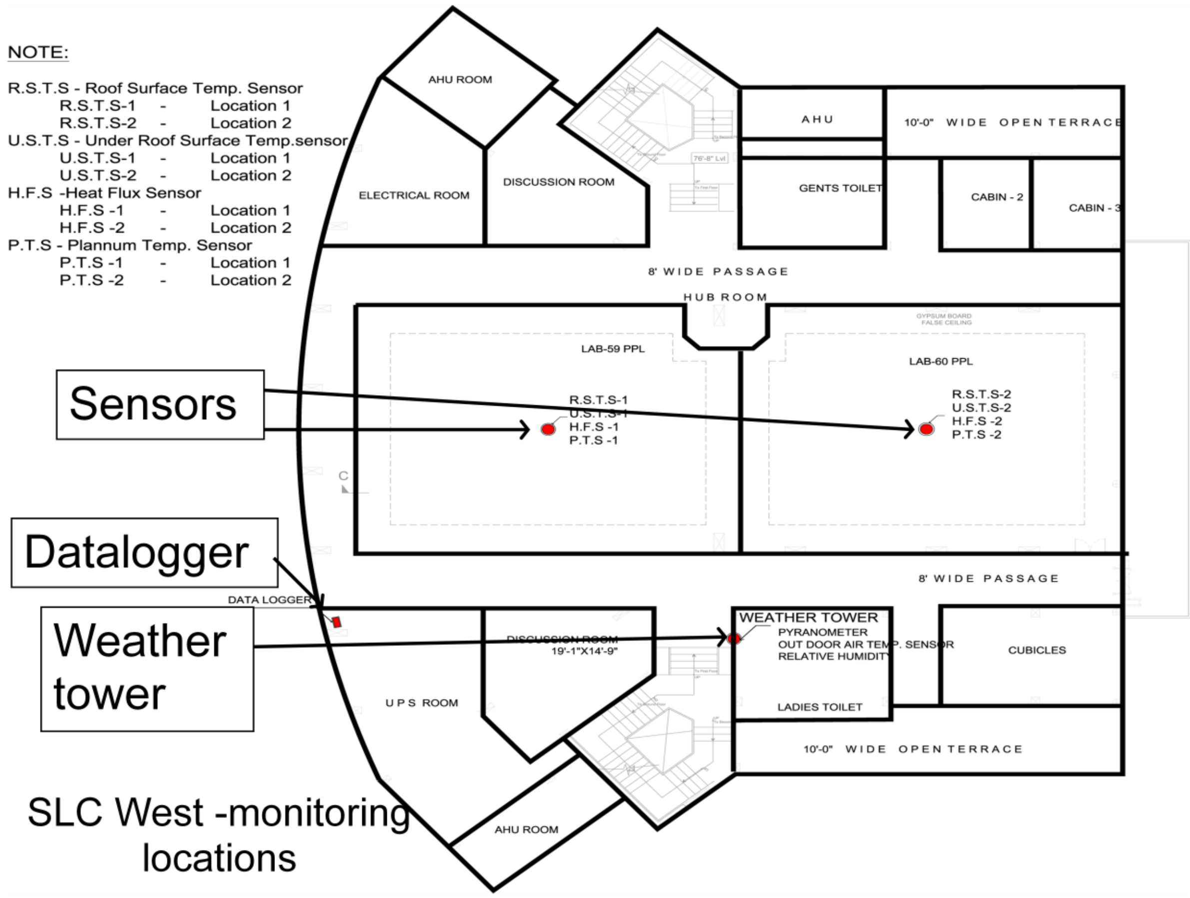
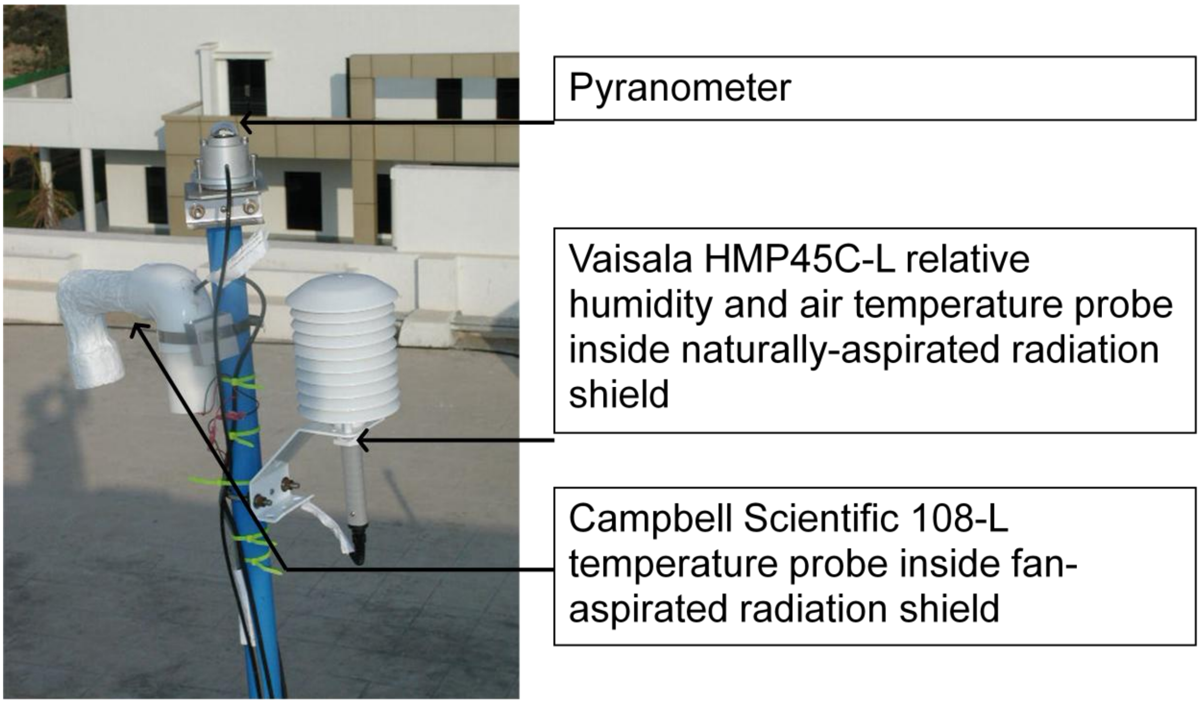


Figure 4.1: Location of sensors and monitoring points

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

The main monitoring points were:

- Air Temperature
    - Outdoor temperatures
    - Indoor temperatures
- Surface Temperature
- Outdoor Air Relative Humidity
- Horizontal Isolation
- Roof Heat Fluxes
- Electric Power Consumption



19

Figure 4.2: Weather tower installated onsite

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

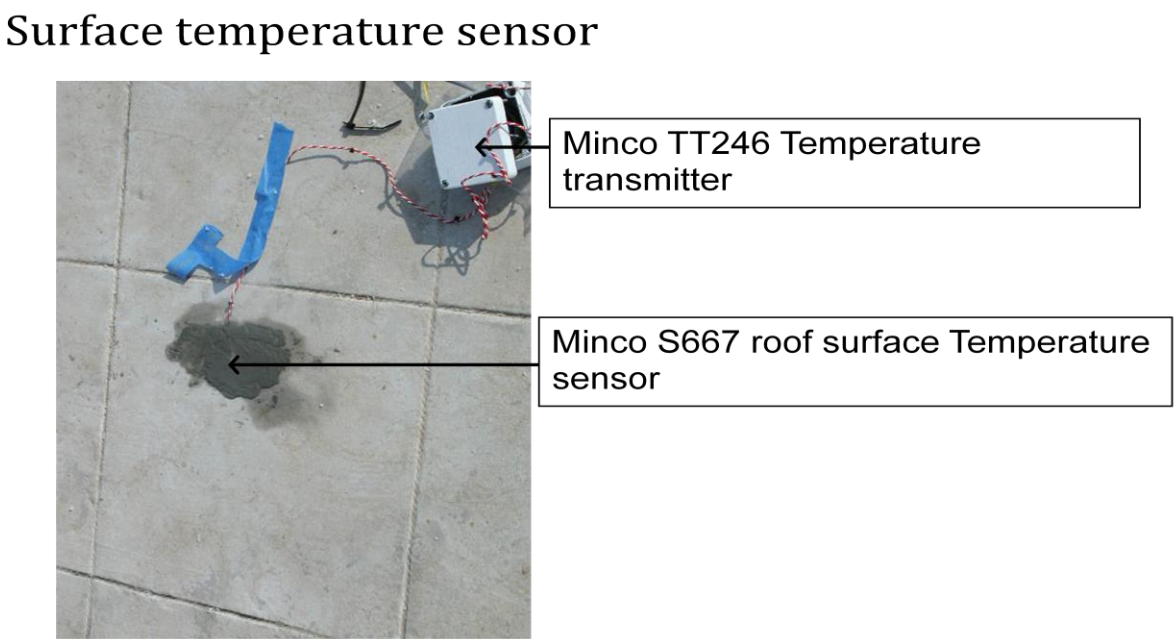


Figure 4.3: Surface temperature sensor seen installed on a grey roof

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

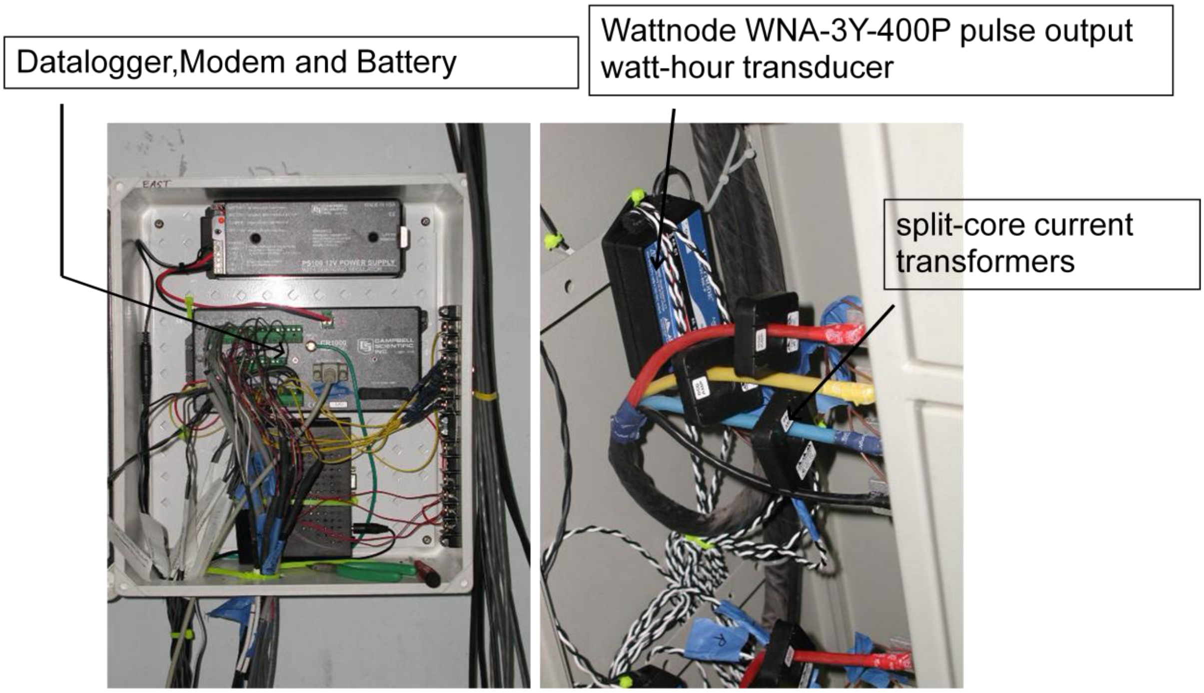


Figure 4.4: Dataloggers and wattnodes used for monitoring data onsite

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

4.3.3 Schedule of the experiment

All sensors were continuously scanned and averaged values were recorded every 30 seconds. Data were downloaded remotely via a modem about once a day. Out-of-range data were investigated to determine whether a sensor or monitoring error existed.

From January 15, 2006 to March 22, 2006, monitoring was done on the buildings with the roof exteriors as found (bare concrete with no coatings). During the period of March 23 to 26, 2006, a cool roof (initial reflectivity of 0.80 and aged reflectivity of about 0.7) on the West building and a hot roof (initial and aged reflectivity of 0.12) on the East building was installed. Monitoring continued with this cool versus hot configuration to July 23, 2006. By August 3, 2006, installation of a cool roof on the East building was completed and monitoring was continued until mid November mid-November 2006.

Table 4.2: Monitoring periods and roof conditions of the West and East buildings through the phases of the experiment

Period	Dates	West Building Roof	East Building Roof
	13-15 January 2006	Monitoring equipment installed	Monitoring equipment installed
Phase I	16 January 16 to 22 March, 2006	Concrete roof	Concrete Roof
	23-26 March 2006	White coating of roof	Black coating of roof
Phase II	27 March to 22 July 2006	Cool roof	Hot roof
	23 July to 3 August 2006		White coating of roof
Phase III	4 August to 16 December 2006	Cool roof	Cool roof

Figure 4.5: Coating work under process at the field experiment site

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

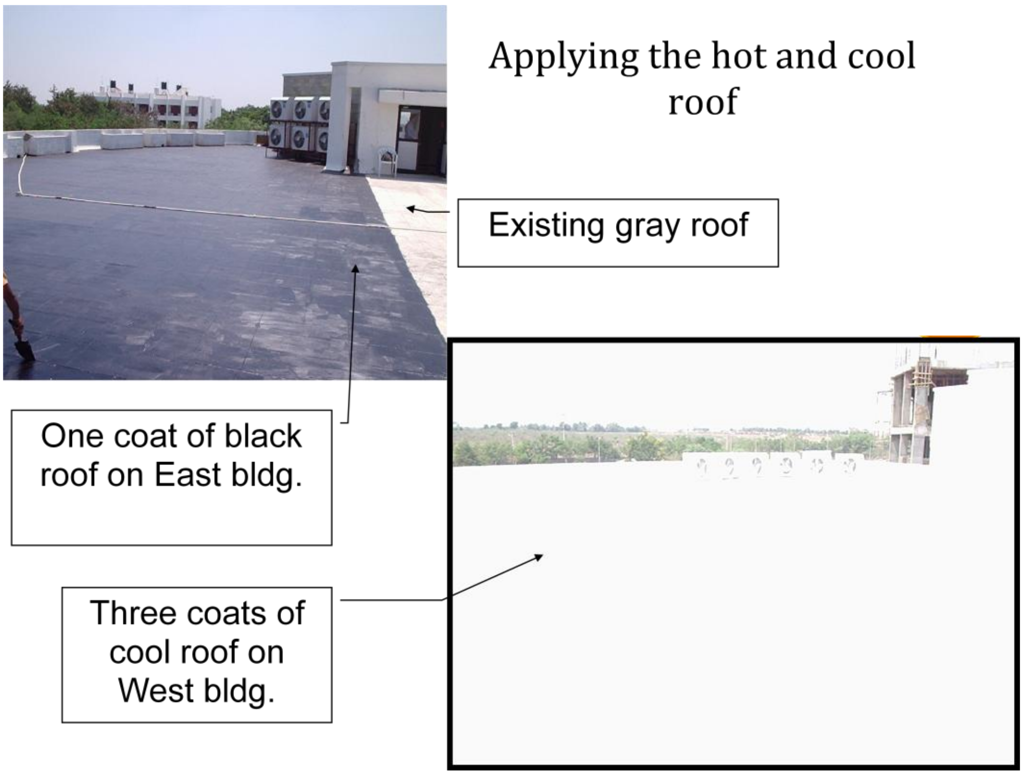


Figure 4.6: East building roof coated in black and the west building roof coating in white during the experiement

(Image Source: Presentation by Prof. Vishal Garg on Energy Savings by Cool Roof A case study of two buildings in Hyderabad)

4.4: Data Analysis

4.4.1 Analysis methodology

The results were mainly presented as energy savings and a comparison of pre- and post-coating heat fluxes, and temperatures. Through the experiment, while the coating tasks were carried out in sequence with concurrent monitoring in both buildings, it was assumed that each building maintained its own normal occupancies and operation. From the monitored data it has been observed that there exist difference in the consumption patterns and loads of both the buildings. Therefore, the impact analysis was performed by quantifying the correlations of the energy metrics between the two buildings grouped by three phases of the study- Phase I (both the buildings with un-coated grey roofs), Phase II (white roof on the West building and black roof on the East building), and Phase III (both the building with white coated roofs). A parallel experiment is hence analyzed in series to calculate the savings due to white roof when compared to the black roof.

Through a correlation graph, in order to assess the difference in air conditioning energy use with black and white roof of the East building, the difference between Phase II and Phase III as it corresponds to the same energy use in the reference case as would be seen in the West building has been calculated. From this, the daily air-conditioning energy reduction due to the impact of changing a black roof to a white roof for the East building has been calculated. Based on the correlation analysis, the concurrent cooling energy use in the East building and the energy savings in East building due to the roof whitening compared to the black roof has been calculated. Using this analysis process, the data has been filtered several times using various filtering options to achieve the most appropriate case which would allow the representation of the West building in terms of the East building.

4.4.2 Previous Analysis

Initially the analysis of this data has been done by Murari [1] in his Master's Thesis. Data monitored throughout the year has been analyzed to observe the reduction in heat flux, and AC electricity consumption.

This analysis was mainly based on the number of operating hours of each building. One predicted cause of the difference in energy consumptions between the West and East buildings of SLC is the difference in their number of operating hours. Hence, the daily data has been filtered based on the difference in the operating hours. From the 339 days on which the data was monitored, data was available for 271 days. Rest, 68 days were when there were issues with the sensors or the data loggers, and hence the data hasn't been logged correctly. . Out of these 271 days, 123 days were filtered on which the difference in number of operating hours between the West and East building is less than one hour were analyzed. For these 123 days, the West building AC consumption has been normalized based on number of operating hours difference between the East and West. Further, the AC consumption of the West building is normalized based on internal loads. Figure 4.7 shows the comparison of air conditioning energy use for West and East buildings.

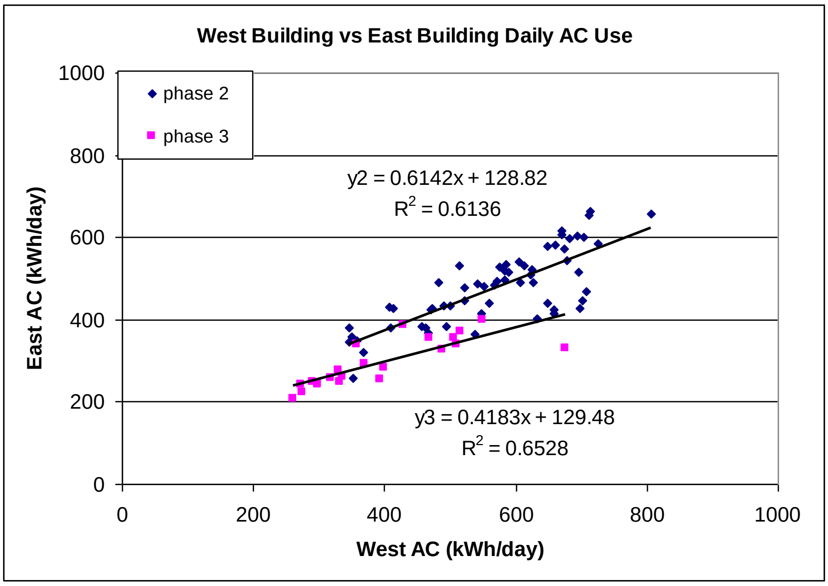


Figure 4.7: Pre- and post-coating comparison of air-conditioning energy usage for both buildings (two phases) considering 123 days of data

For calculating the energy consumption:

Phase II: E1 = 0.6142Ww + 128.82 (eq.1)

Phase III: E2 = 0.4183 Ww + 129.48 (eq.2)

To calculate the energy savings:

ΔE = E1-E2 = 0.1959Ww -0.166, in kWh/day (eq.3)

With the percentage of daily air-conditioning energy reduction being

ΔE/E2 = (0.1959Ww -0.166)/ (0.4183 Ww + 129.48) (eq.4)

Using the concurrent data of West and East buildings for equations 3 and 4, the calculated energy savings due to roof-whitening (compared to black roof) ranged from approximately 58 to 116kWh/day per 700 m^2 roof area (i.e., 0.08-0.165 kWh/mr2/day), representing a range of energy savings attributed to cooler roofs, with surface reflectance changed from 0.10 (black roof) to 0.70 (white roof).

4.4.3 Final Analysis

Observing differences in energy consumption between both the buildings, it's understood that difference in the number of operating hours could be one reason that is the cause for this difference. Though, the experiment was performed in parallel, the data is being analyzed as a series (energy consumption of the East building with the black roof is compared to the energy consumption of the East building with white roof), and the consumption of the East building is being calculated in terms of the West building. Hence, it is necessary that these two building should closely perform in terms of energy consumption. Therefore, in the analysis done by Murari, the hourly data has been filtered based on the difference in number of operating hours. Based on that previous analysis, the saving resulted were 58 -116 kWh/day. However, in this analysis, out of the 271 days with data, only 123 days were utilized for calculating the energy savings. As an attempt to increase the use of more number of days on which the data has been collected, for this analysis, the raw data was once again revisited.

Table 4.3: Summary of number of days used in the proposed analysis

Criteria	Number of Days
Total number of days of the experiment	339
Days on which all the data was available for both the buildings	271
Day on which 9am-5pm data is available in both the buildings	270
Days after filtering weekends in the available 270 days	198
Days after filtering only those weekends with discrepancies in data (consumption < 50 kWh)	267

Since, it has been clearly understood that the differences in energy consumption between both the buildings can be due the difference in number of operating hours, in this analysis, instead of the difference in number of operating hours, the daily consumption, heat flux, and temperatures were considered for 8 hours (9 am – 5pm) of operation during the day. Hourly data of both the buildings has been used to calculate the energy consumption, average temperatures, average heat flux and average solar radiation, during the day, between 9 am to

5 pm, for 8 hours, for all the 271 days. From the 271 data available days, one day has been deleted on which there is no energy consumption between 9am-5pm in the East building. A summary of number of days available and the analysis that has been performed is as mentioned in Table 4.3.

Hence, the analysis of these 270 days was performed in three steps:

- Case 1: Complete 270 days were analysed
- Case 2: Only the weekdays (198 days) of the 270 days were analysed
- Case 3: All the days except three days on which the energy consumption in either of the buildings is less than 50 kWh.

Therefore, in Case 1, the set of 270 days has been plotted to check the relation between the Phase II and Phase III energy consumption of both the buildings. Figure 4.8 shows the correlation between the East and West building for these 270 days, in Phase II and Phase III of the analysis.

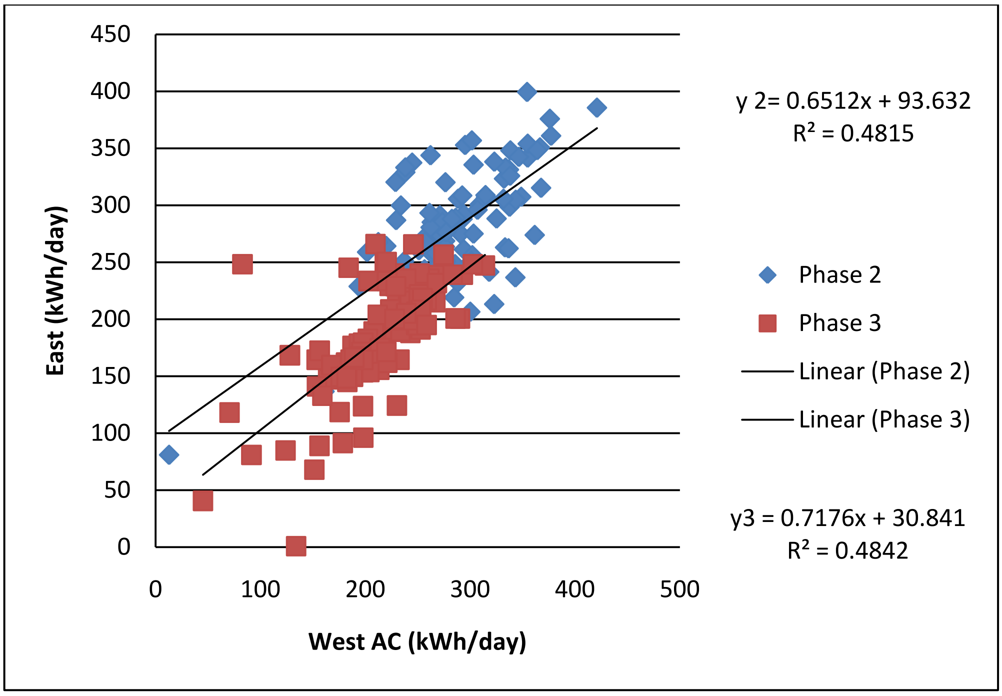


Figure 4.8: Pre- and post-coating comparison of air-conditioning energy usage for both buildings (two phases), considering9am- 5pm data for all 270 days.

From this analysis, it can be observed that though the slopes of the trend line of the Phase II data is close to that of Phase III data, when compared to the previous analysis, there is still a certain difference, which might be due the points with some discrepancy in data. To further decrease this discrepancy, assuming that the weekend ends are the cause for this behavior of the data, only the weekdays were filtered for the analysis. Out of 270 available days 198 days could be analyzed based on this filter.. Figure 4.9 show this correlation plot of the 9am-5pm daily weekday data for these198 days.

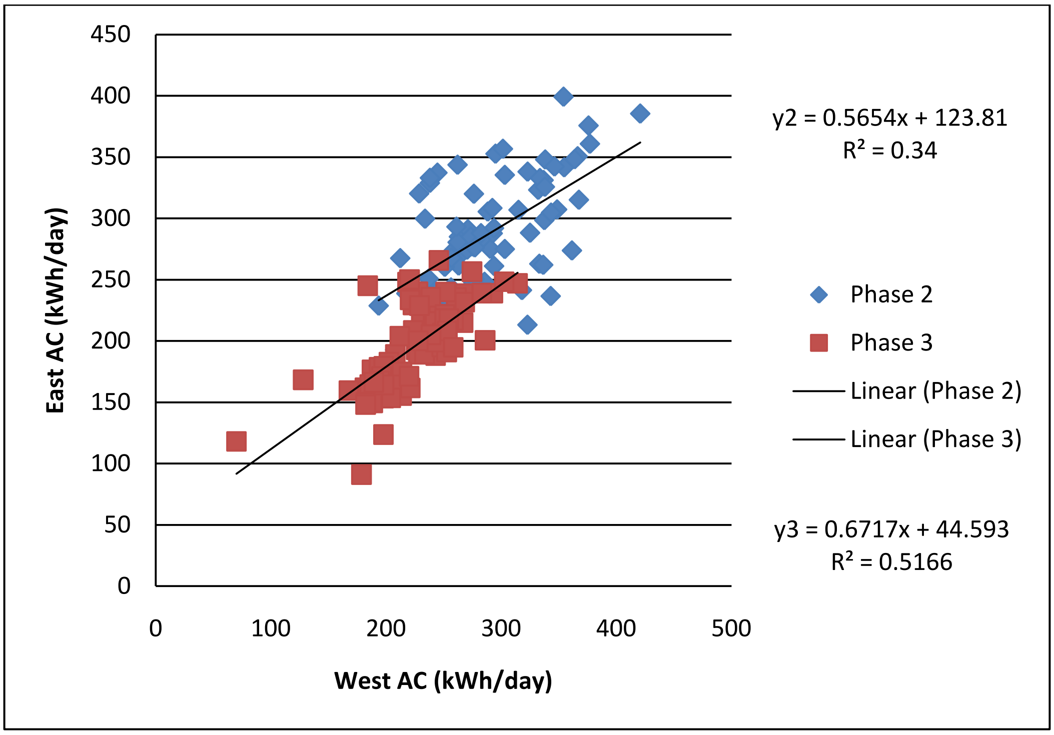


Figure 4.9: Pre- and post-coating comparison of air-conditioning energy usage for both buildings (two phases) considering 9am -5pm data, for 198 weekdays

This analysis too, still tended to have difference in slopes of both the Phase II and Phase III trend lines. Hence, all the 270 days, 9am -5pm data has been once again analyzed. In this case, the energy consumption of both the buildings has been closed observed and the days on which there is a major difference in the energy consumption values when compared to the other days, were deleted.For all the three phases, there are three days when the energy consumption of the either of the building's is less than 50 kWh. Hence, these three days are further filtered from the data of 270 days, resulted in 267 days for the analysis. Table 4.4 shows the three days that are filtered and the energy consumption on each of these days.

Table 4.4: Three days with energy consumption less than 50 kWh in either of the buildings and are deleted from the analysis dataset

Filtered three days			
Sunday	9-Jul-06	13	81
Sunday	3-Sep-06	134	1
Sunday	8-Oct-06	45	41

From this it can be observed that these three days are Sundays, when the energy consumption in either the East building or the West building is very low (< 50 kWh). Hence these days were deleted and the rest 267 days were considered for the final analysis. Figure 1.1 shows the correlation plot for these 267 days.

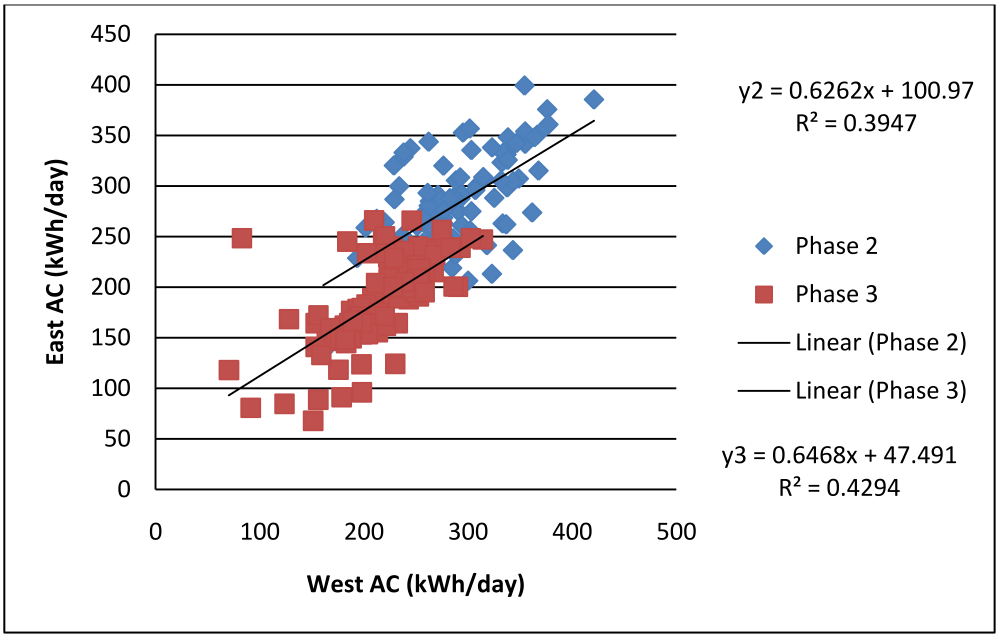


Figure 4.10: Pre- and post-coating comparison of air-conditioning energy usage for both buildings (two phases) considering 9am-5pm data for 267 days

Almost equal slopes and a good quantity of data considered for the analysis has been taken as selection criteria, and hence this case was decided to be the final analysis using with the energy consumption of the East building shall be calculated in terms of the West building. Also, the temperatures and heat flux values were calculated for 8 hours (9 am – 5pm) during the day and were compared pre- and post coating of the roofs in all the three phases.

Table 2.3 shows the comparisons of performance metrics, including roof surface temperatures, heat flux through ceiling, air conditioning energy use, between the West and the East buildings before and after the white roof coating and black roof coating was applied to the West building and the East building, respectively. For the West building, the maximum roof surface temperatures decreased from 54.7^{o}C in Phase I to 41.2^{o}C (a reduction of 13.5^{o}C) in Phase II, after white coating was applied to the original concrete roof, and further decreased to 38.3^{o}C in Phase III. For the East building, the maximum roof surface temperatures increased from 54.7^{o}C in Phase I to 71.3^{o}C in Phase II (an increase of 18.2^{o}C), after the black coating was applied to the original concrete roof), and decreased to 39.6^{o}C in Phase III after white coating was applied. In Phase III after both roofs were painted white, the maximum roof temperatures of both roofs were close to each other.

For the West building, the peak heat flux through ceiling decreased slightly from 12.8 W/m^2 in Phase I to 12.6 W/m^2 in Phase II after white coating was applied to the original concrete roof, and further decreased to 7.6 W/ m^2 in in Phase III. For the East building, the peak heat flux increased from 11.0 W/ m^{2}in Phase I to 21.9 W/ m^2 in Phase II after the black coating was applied to the original concrete roof, and decreased to 8.6 W/ m^2 in in Phase III after white coating was applied. In Phase III after both roofs were painted white, the peak heat flux of both roofs was close to each other.

Table 4.5: Monitoring results for the West and East buildings in the Satyam Learning Center

	West Building	**East Building**
Roof Area (m^2)	700	700
Phase I - Initial roof reflectance	Concrete 0.30,	Concrete 0.30
Phase II - Modified roof reflectance	White 0.80 (fresh coating) 0.70 (aged coating)	Black 0.10
Phase III - Final roof reflectance	White 0.70	White 0.70
Phase I - Maximum roof surface temperature (°C)	54.7	54.7
Phase II - Maximum roof surface temperature (°C)	41.2	71.3
Phase III - Maximum roof surface temperature (°C)	38.3	39.6
Phase I - Maximum roof heat flux (W/m^2)	12.8	11.0
Phase II - Maximum roof heat flux (W/m^2)	12.6	21.9
Phase III - Maximum roof heat flux (W/m^2)	7.6	8.6
Phase I – Average roof heat flux (W/m^2), 9AM to 5 PM	2.2	2.8
Phase II – Average roof heat flux (W/m^2), 9AM to 5 PM	3.6	9.7
Phase III – Average roof heat flux (W/m^2), 9AM to 5 PM	0.1	0.8
Phase I - Average daily AC use, (kWh/day), 9AM to 5 PM	219	200
Phase II - Average daily AC use (kWh/day), 9AM to 5 PM	285	280
Phase III – Average daily AC use (kWh/day), 9AM to 5 PM	215	187
Phase I – Average outdoor air temperature (°C) and solar radiation (W/m^2), 9AM to 5 PM	29.1°C, 653 W/m^2	
Phase II - Average outdoor air temperature (°C) and solar radiation (W/m^2), 9AM to 5 PM	32.4°C, 643 W/m^2	
Phase III - Average outdoor air temperature (°C) and solar radiation (W/m^2), 9AM to 5 PM	27.2°C, 529 W/m^2	

For the average heat flux between 9 AM and 5 PM in Phases I and III, both buildings exhibited similar magnitudes with lower values happening in Phase III which was slightly cooler. In Phase II, West building with white roof exhibited higher average heat flux during daytime than that of Phase I or Phase III, because of higher outdoor air temperatures than in Phase I or Phase III. This implies that the impact of the higher outdoor temperatures on average heat flux is more evident than that of white roof (compared to concrete roof). By contrast, in Phase II, East building with black roof exhibited much higher average heat flux during daytime than that of Phase I or Phase III. This indicates that collective impacts of higher outdoor air temperatures and darker roof on average heat flux though roofs were significant.

The table also shows average daily air-conditioning electricity use in each building with various roof coatings applied sequentially during the course of this study. The daily cooling energy use has been analyzed for each building from 9 AM to 5 PM. One would expect that the average daily air conditioning energy use in the buildings tended to increase with the increase in outdoor temperatures and a decrease in roof surface reflectance. For the West building, from Phase I to Phase II even though the average outdoor temperatures exhibited an increase from 29.1^{o}C to 32.4^{o}C because of the seasonal change, it was observed that there was an reduction in the maximum roof surface temperature (by 12.5^{o}C) due to white roof, and a reduction in the maximum roof heat flux (by 0.2 W/ m^{2}), while there was an increase of average energy use from 219 to 285 kWh/day with an increase of average heat flux from 2.2 to 3.6 W/ m^{2}.

While it is clear that cooler roof (e.g., with white coating) has contributing to lowering the roof surface temperatures and moderating the heat flux through roof into the buildings, as exhibited in the measurements were performed (e.g., Phase I and Phase II), the cooling energy savings attributed solely to reflectance changes was not apparent by the direct measurements because the actual cooling energy is affected by other concurrent factors, such as outdoor air temperatures, occupancies, and operation. The quantification of the reduction in cooling energy use attributable to roof reflectance changes remains a challenging task. The following section describes the analytical approach that has developed for estimating the effects of cool roofs on cooling energy use based upon concurrently measured data from this field study in India.

Figure 4.11 shows the correlation of air-conditioning energy use between the two buildings grouped on the bases of pre- and post-coating monitoring, i.e., Phases I through III. The quantification of the correlations between the two buildings using the West one as a reference case can then be used to predict the energy savings potentials attributed to roof reflectance changes. The following describes the calculation method and analysis.

The correlations between cooling energy data from the two buildings and their statistical significance were then examined. Specifically, the following regression equations of air-conditioning energy use of the East building as it related to the air-conditioning energy use in the West building, with all p-values far lower than 10^{-3} indicating statistical significance, were established.

Phase I: $E1 = 0.7102Wc + 44.722$ (eq. 1)

Phase II: $E2 = 0.6262Ww + 100.97$ (eq. 2)

Phase III: $E3 = 0.6468Ww + 47.491$ (eq. 3)

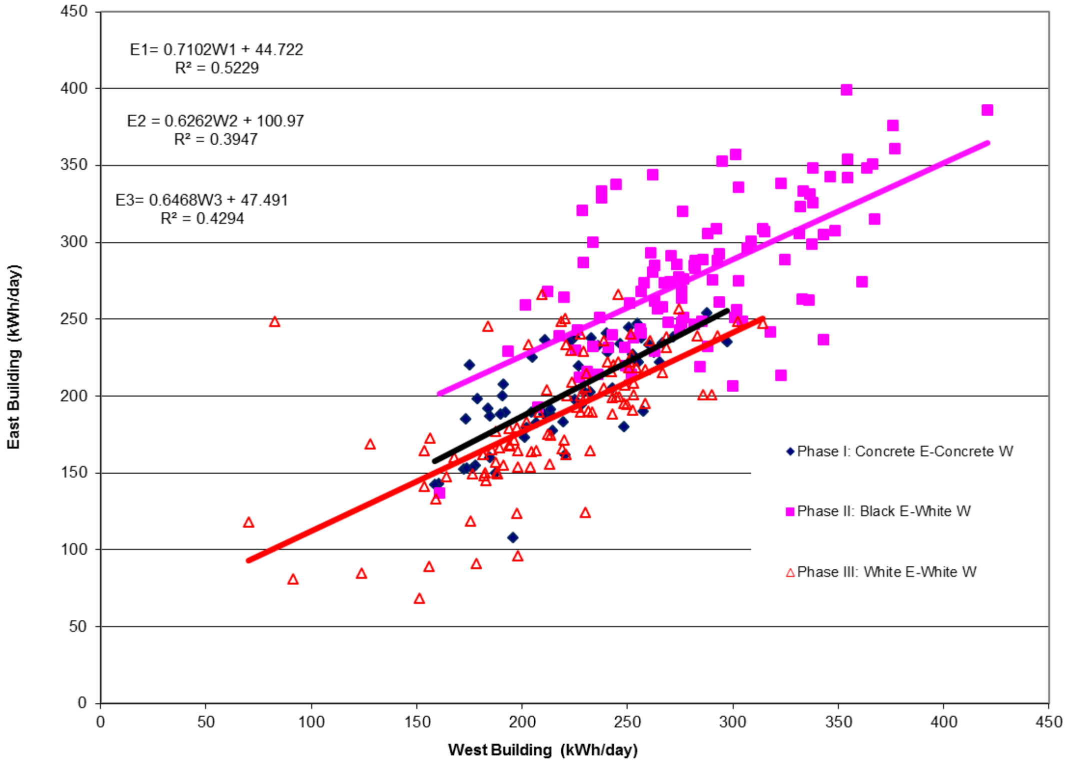


Figure 4.11: Pre- and post-coating comparison of air-conditioning energy usage for both buildings (three phases) considering 9am-5pm data for 267 days

Where

E1, E2 and E3 denote the daily cooling energy use in the East building in each of the three phases (concrete roof in Phase I, and black roof in Phase II, and white roof in Phase III), respectively

Wc and Ww denote the daily cooling energy use in the West building with concrete roof in Phase I, and white roofs in Phases II and III, respectively;

Third, in order to assess the difference in air-conditioning energy use with black and white roofs of the East building, then the difference between was calculated for phase II and phase III as it corresponds to the same energy use in the reference case as would be seen in the West building. Therefore, the daily air-conditioning energy reduction due to the impact of changing a black roof to a white roof for the East building was:

$\Delta E = E2 - E3 = -0.0206Ww + 53.479$, in kWh/day (eq.4)

With the percentage of daily air-conditioning energy reduction being

$\Delta E/E2 = (-0.0206Ww + 53.479)/ (0.6262Ww + 100.97)$ (eq.5)

As the next step to quantify energy savings, based upon the field observations that typical air-conditioning energy use of the West building ranged between 150 kWh/day and 350 kWh/day during the monitoring periods. Based upon the equations, the concurrent cooling energy use in the East building, and the energy savings potential in the East building due to roof-whitening, were calculated.

Using the concurrent data of West and East buildings for equations 4 and 5, the calculated energy savings due to roof-whitening (compared to black roof) ranged from approximately 46 to 50kWh/day for 700 m^2 roof area (i.e., 0.066-0.072 kWh/m^2/day), representing a range of approximately 14% to 26% of cooling energy savings attributed to cooler roofs, with surface reflectance changed from 0.10 (black roof) to 0.70 (white roof). The normalized energy savings per unit of reflectance reduction would be 77-84 kWh/day or approximately 0.11-0.12 kWh/ m^2/day.

Furthermore, given that the Satyam Learning Center operated 25 days a month throughout the year (300 days of operation per year), it was found that annual energy savings potential from roof-whitening (from black roofs) ranged from 20-22 kWh/ m2 roof area, corresponding to air-conditioning energy use reduction of 14%-26% , in commercial buildings. The monitoring results also indicated that a warmer day, while associated with actual cooling energy savings similar to that of a cooler day, would correspond to slightly lower percentage in energy savings due to cooler roof. Overall, the actual field measurement results indicated that cool roof can significantly reduce the energy use by air conditioning systems in commercial building, with the warmer season corresponding to the lowered savings percentage (albeit with similar reduction in actual cooling energy use for the building).

4.5: Conclusion

In the field study, field evaluations and measurements were performed to understand the effectiveness of applying cool coating on roofs and to quantify its impacts on energy savings in two commercial buildings in India. The field results quantified direct energy effects of cool roofs on individual commercial buildings. Using the comparative methods presented in this paper, the energy savings potential has been quantified from roof-whitening (from black roofs) to be ranging from approximately 14%-26% air conditioning energy savings in commercial buildings. With surface reflectance changed from 0.10 (black roof) to 0.70 (white roof), the normalized energy savings per unit of reflectance reduction would be 77-84 kWh/day or 0.11-0.12 kWh/m^2/day.

Overall, this study has demonstrated the effectiveness of cool roof technology in India. The outcomes can be used for support and recommendations for developing cool roof building standards in India.

Related Publications

1. Hashem Akbari, Tengfang Xu, Haider Taha, Craig Wray, and Jayant Sathaye. Vishal Garg, Surekha Tetali, M. Hari Babu and K. Niranjan. "Using Cool Roofs to Reduce Energy Use, Greenhouse Gas Emissions, and Urban Heat-island Effects: Findings from an India Experiment". LBNL Report (To be published).
2. Cool Roofs for Cool Delhi: A Design Manual for Bureau of Energy Efficiency (BEE), Government of Power, India.

References

[1]. Murari Hari Babu (2010). "Cool Roofs Impacts on energy usage, Two High-tech Educational Buildings in Hyderabad, India" (Thesis). MS by Research, IIIT Hyderabad.

[2]. J.R. Simpson and E.G. McPherson. "The effects of roof albedo modification on cooling loads of scale model residence in Tuscon, Arizona." Energy and Buildings 25 (1997) 127-137.

[3]. Stephanie K. Meyn, T.R. Oke. "Heat fluxes through roofs and their relevance to estimates of urban heat storage". Energy and Buildings 41 (2009) 745–752.

[4]. Hashem Akbari, Ronnen Levinson, Leo Rainer. "Monitoring the energy-use effects of cool roofs on California commercial buildings". Energy and Buildings 37 (2005) 1007–1016

[5]. J.H. Jo, J.D. Carlson, J.S. Golden, H. Bryan. "An integrated empirical and modeling methodology for analyzing solar reflective roof technologies on commercial buildings". Building and Environment 45 (2010) 453–460.

Chapter 5: Development of an Online Cool Roof Calculator

5.1: Introduction

Increasing need for cooling the buildings and cities is increasing the awareness of easy and affordable energy conservation measures such as cool roofs. However, there is still certain confusion among its users, due to the availability of a varied of range of material these days in the market, and the awareness levels of cool roof technology, its benefits and savings.
Therefore, one of the major challenges that a common man face in applying cool roof for his building is the selection of the most appropriate technology/material for their building location and roof type. There are wide variety of cool roof materials with differences in their emissivity, reflectivity, life and initial cost. Performance of each of the materials varies over a wide range with change in climatic conditions, roof type, Heating Ventilation and Air-Conditioning (HVAC) system type, etc. Availability of a wide range of varieties and their varying performance with various prevailing conditions, are the two major reasons because of which estimation of energy savings from cool roof is difficult. Correct choice of the cool roof material should therefore be made by considering various building features, keeping into consideration the payback and Life Cycle Cost (LCC).

Researches in field of cool roofs include various studies related to the effect of cool roof on buildings and the urban climate. These studies are mostly either experimental demonstration or theoretical evaluation through simulations and models. Considering the advantage, and flexibility in evaluating the effect of cool roof through simulations and models, research exists in development of various simulation models and tools calculating the effect of cool roof. With rapid computerization taken place in the last decade, the scope of availability of a personal computer and internet to common man has greatly increased. Hence, several internet based tools, both commercial and academic in nature, are being developed. Some of such tools are: DOE Cool Roof Calculator Roof Savings Calculator (RSC) (http://www.roofcalc.com/), and Roofing Calculator .org (http://www.roofingcalculator.org/)

The DOE Cool Roof Calculator [1] calculates the annual energy savings in cooling and heating for a given roof solar reflectivity (SR) in comparison with a black roof, for low slope roofs. Alternatively, the tool also calculates the necessary roof insulation R-value to achieve the same savings as achieved by the given solar reflectivity. This tool has mainly been developed for the US weather data. There are 243 different locations that are available in the pull-down list of the calculator, with 235 of them belonging to US, Pacific territories and Puerto Rico, and the rest 8 to Canada. The inputs those are to be provided by the user in this calculator are: R value, solar reflectivity, infrared emissivity (IE), electricity costs and HVAC equipment efficiency. The output include: cooling and heating energy savings and the required R value of the roof to achieve a same savings that has been achieved by the given solar reflectivity value. Further, this calculator [2] also estimates the energy and peak demand savings for a given solar reflectivity in comparison with a black roof. The input fields are the same; however, the outputs include the heat load reduction values during the cooling season. Also, the DOE steep slope calculator [3] estimates cooling and heating savings for residential roof with non black surfaces, for steep roofs.

The Roof Savings Calculator [4] developed by ORNL and LBNL together, has been very recently updated, and is now running in its beta release. Earlier the calculator use to simulate a typical kind of building without any mention of the building type. Now, there exist two categories: Residential and Commercial, and two modes: simple and advanced. The calculator performs whole building energy simulations are performed using DOE 3.1e engine for fast energy simulation and integrates AtticSim for advanced modelling of modern attic and cool roofing technologies. The calculator runs an hourly simulation for the provided building properties such as: conditioned floor area, number of floors, window details, HVAC details, and the existing and proposed roof details, for the selected location. Annual energy savings reported are based upon heating and cooling loads and thus this calculator is only relevant to building with a heating and/or cooling unit.

All the above discussed tools are especially design for US weather files and work on DOE 2.1 engine for simulations. However, the tool that has been developed as a part of this thesis works on EnergyPlus and does online simulations for all Indian cities. Compared to the other tools, the Cool Roof Calculator provides more input details about the building and also a different set of results. One other major difference between the Cool Roof Calculator and the other two is that, the former has a capability of simulating an un-conditioned building, for which the comfort achieved through the use of cool roof will be reported. Therefore, from many others, some of the major differences of the Cool Roof Calculator compared to other calculators can be the features as listed below:

- performs online simulation
- works on EnergyPlus engine
- capable of modelling an un-conditioned space
- generates thermal comfort results
- does payback analysis
- works for all major Indian cities

Hence, the cool roof calculator has been designed to suit the Indian context. The developmental details of the tool, along with an explanation of the front end and the simulation templates considered, are as discussed further in this chapter.

Further, there exists a site with the nameRoofingCalculator.org [5] which has several online roof calculators that estimate various properties of roof such as: pitch of the roof, roofing prices, metal roofing calculator, roofing materials, and metal roofing panels. However, any of these does not directly deal with energy savings or cool roof. Development of this kind of tools and websites show the importance of building components such as roofs and the awareness levels that are being increased among all the stakeholders. Cool Roof Calculator, thus, is an attempt to increase the awareness among Indian users in terms of the savings, payback and comfort that would be a result of cool coating over the roof. This indirectly helps in increasing the use of cool roof, which has several advantages both at micro and macro level.

The Cool Roof Calculator development project was a 6 months project that has been funded by The ClimateWorks Foundation in USA. This Cool Roof Calculator helps in comparing two identical building models that differ by the roof external finish. The users can input the parameters of the building either in the simple calculator or the detail calculator, based on which the energy savings and payback, or the comfort shall be calculated. Simulations for this tool are carried on the EnergyPlus v6 simulation software.

5.2: About the tool

5.2.1 Backend

The tool is developed on Apache/2.2.6 (UNIX). Web pages are developed in PHP and use Ajax Technologies. At the back end, socket programming has been implemented, the code for which is written in C. The inputs submitted from the UI are posted to a PHP script for simple or detailed case which generates the corresponding IDFs (base and proposed for normal and cool roof) for EnergyPlus simulations. The IDF name and the weather file name are then sent to an executable waiting for a socket connection (to open). The executable then calls a shell file which performs the simulations while the front end shows the simulation progress. Once the simulations are done, the UI is redirected to the results page which shows the results as well as gives options for downloading the simulation result files. Details of the working are mentioned ahead.

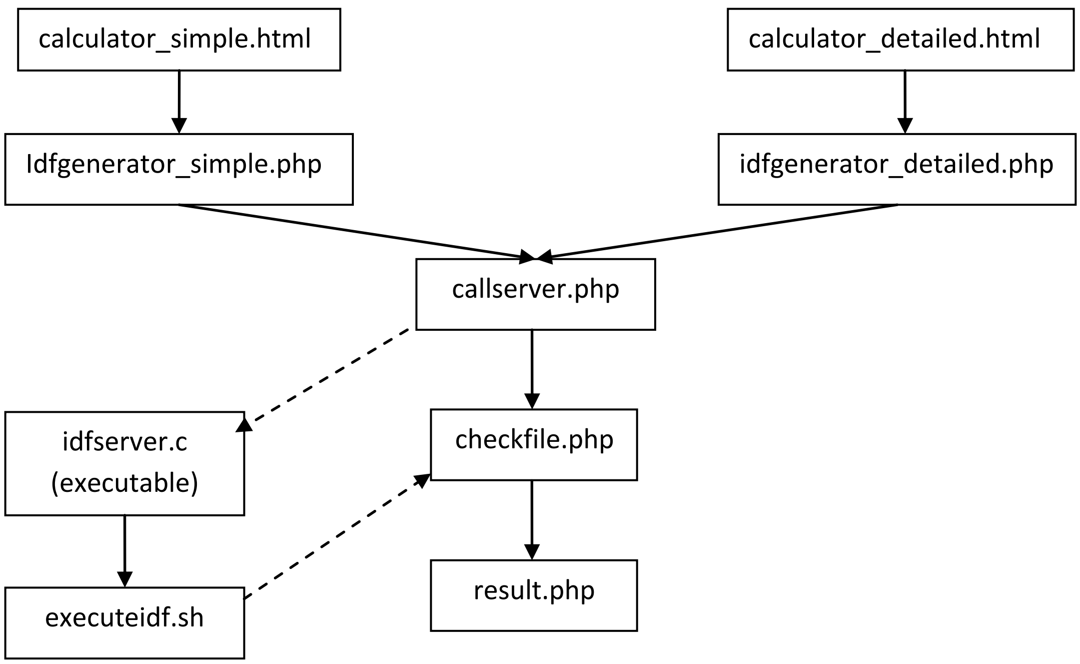


Figure 5.1: Tool Architecture

The calculator_simple.html and calculator_detailed.html pages consist of a form that the user has to fill in order to submit the parameters for simulation. It consists of various fields such as floor area, window percentage, window, roof, wall, floor types etc. On submission of the form, either of idfgenerator_simple.php or idfgenerator_detailed.php is called depending on which form is submitted- simple or detailed. These PHP scripts create two IDFs (for normal and cool roof base and proposed) based on the parameters received and then calls the page callserver.php using "http-equiv" attribute of the <meta> tag and also passes the count value (IDF no) in the URL as given below. The count value is used to identify the IDF uniquely.

As PHP runs under Apache server, it is not able to run system commands from the PHP page. Another alternative would be to use a C program that makes the system call and call the C program from the PHP page. Thus, the callserver.php page opens a socket connection with idfserver.c and passes the weather file and the count value (IDF no). Once the socket connection is established, callserver.php redirects itself to checkfile.php. The job of this file is to check if the simulation is completed. The file refreshes every 5 seconds to check if the simulation has finished. It also makes the environment more interactive, for it can cancel a running simulation, while it is being simulated. It also shows a progress bar and the system time in order to ensure that the simulation is going on. On the backend, idfserver.c (the object file of it) passes the count value (IDF no) and the weather file name to executeidf.sh. This script file makes the system calls to perform EnergyPlus simulations. Once the simulations are done, it signals checkfile.php to redirect itself to the results page i.e. results.php. The file results.php is called with the count value (IDF no), so it knows which results are to be parsed. It parses the results file to get the energy savings for the model simulated.

5.2.2 Interface

When compared to the existing cool roof calculators, the calculator developed in this project is more detailed in terms of the inputs that are to be provided by the user. Broadly the inputs can be put under the headings of building envelope, internal loads, HVAC, building geometry, and the location.

The main navigation bar of the calculator has links to the other pages of the site. All the major pages of the site are as listed below:

- Home: provides introduction to the cool roof technology and the need for the calculator
- Calculator: this leads to the main calculator page which is created in two modes, simple and detailed.

- Glossary: this provides information on the inputs that are to be provided in both the detailed and simple modes
- Documentation: provides an introduction on the cool roof technology and describes the tool – cool roof calculator. A link to the description of the model can also be found on this page.
- Contact Us: list the development team and their contact details

The header of the page and the main navigation bar is as shown in Figure 2.1.

Figure 5.2: Cool Roof Calculator showing the main navigation bar

The home page provides an introduction about the cool roof technology. Along with this, the cool roof calculator directly provides links to related external sites such as:

- DOE Cool Roof Calculator (http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm)
- Roof Savings Calculator (http://www.roofcalc.com/)
- Heat Island Group (http://heatisland.lbl.gov/)
- Cool Colours Project (http://coolcolors.lbl.gov/)
- Cool Roof Rating Council (http://www.coolroofs.org/)

On the calculator page is the main input data forms and the simulation option. The main calculator has been developed in two different modes- based on the detail of the inputs that the user specifies. They are:

- Simple
- Detailed

In the simple form, details such as roof type, roof finish, roof area and HVAC system type are the inputs. In the detail form, the building envelope data includes details such as: the window to wall ratio on each of the four major orientations of the exterior walls, roof insulation detail, the normal roof solar reflectivity and the cool roof solar reflectivity. Internal loads such as the equipment and the lighting density are also the inputs which the user needs to provide. In HVAC, system type and COP is the data which the user needs to input. By default a square block with perimeter and core zoning is considered for the simulation. Location of the building is another major input which is to be selected by the user. The city in which the building is located can be selected from the list.

The results generated for the models simulated in simple mode show the percentage savings in end use energy consumption and the electricity savings in rupees. Along with these results, the payback due to the cool roof is included as a result generated after simulating the building using detailed mode.

Simple calculator

In the simple mode the user need to specify some very basic information about the designed building over which they wish to apply a cool roof coating.

The simple form of the tool is as shown in Figure 5.3.

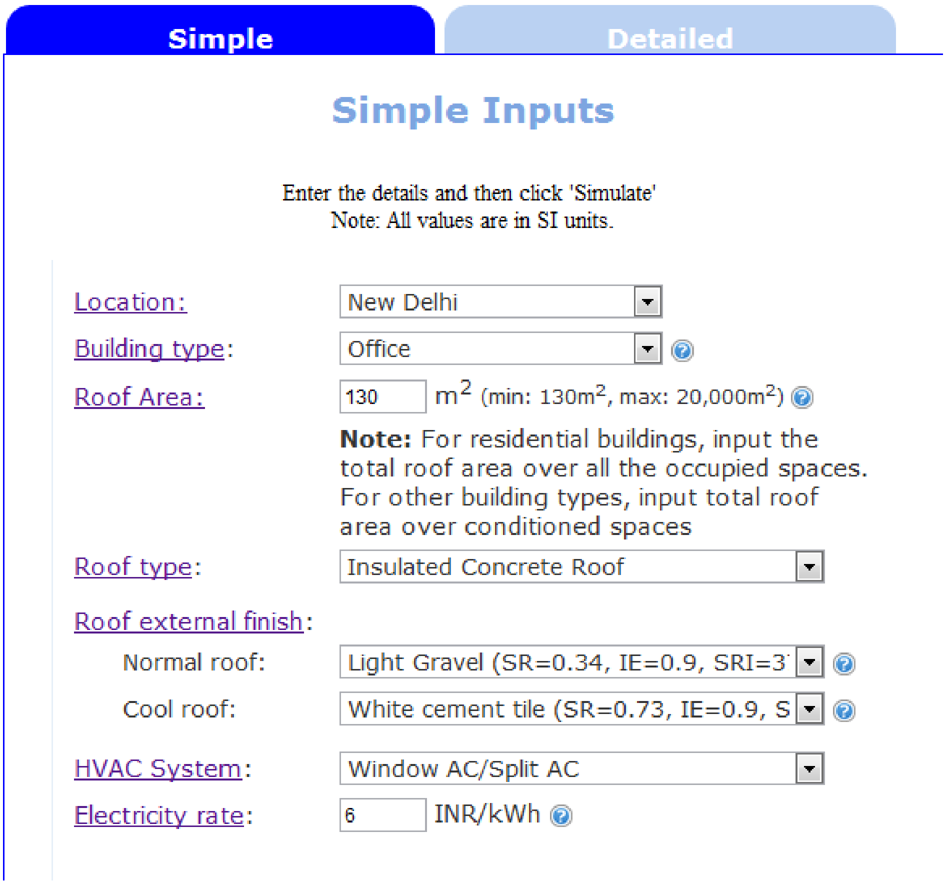


Figure 5.3: Simple mode of Cool Roof Calculator

The inputs in this simple form are:

- Location
- Building type
- Roof Area
- Roof type
- Roof external finish
- HVAC system
- Electricity rate

Detailed Calculator

In the detailed mode the user need to specify some additional details about the designed building over which they wish to apply a cool roof coating. Compared to the simple mode, the detailed mode has more number of inputs that are to be provided by the user. Also, for some the inputs, such as the roof construction type, the user will have to input the layers of construction in detail. The inputs in this detailed mode are:

- Location
- Building type
- Roof area
- Roof type
- Roof external finish
- HVAC details
- Internal loads
- Window area
- Electricity rate

The detailed mode of the tool is as shown in Figure 5.4.

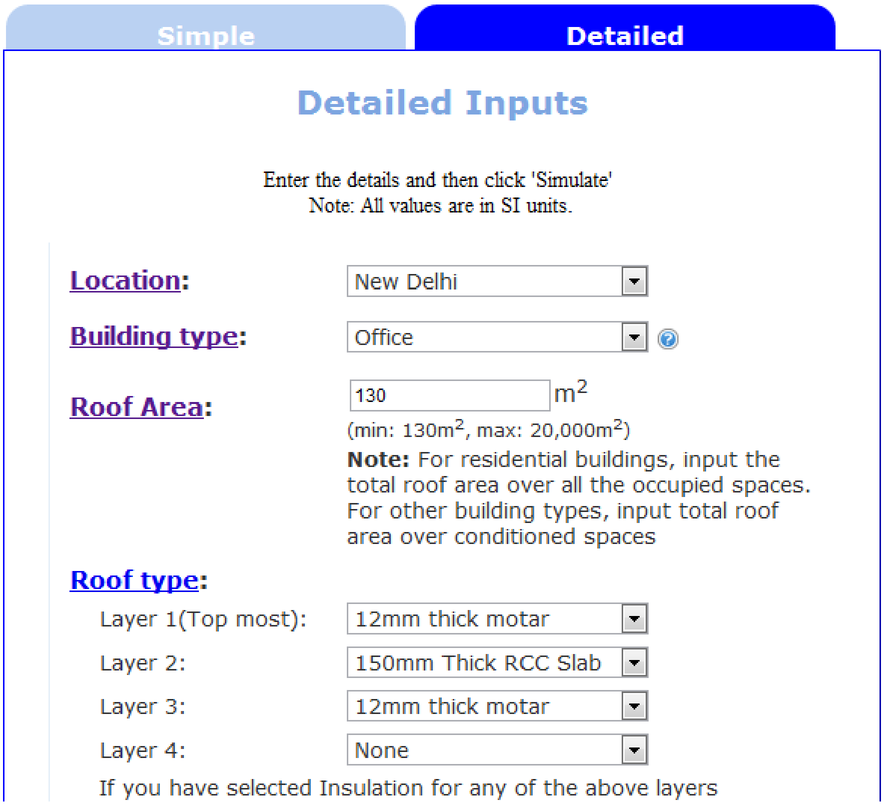


Figure 5.4: Detailed mode of Cool Roof Calculator

All the fields in the detailed form are shown in Table 5.1.

Table 5.1: Input detail in the detailed form

➢ **Location**	*Select from dropdown*
➢ **Activity**	• Residential (all day) • Residential (only night) • Retail • Office • Institutional
➢ **Roof Area**	________________ (m^2)
➢ **Roof Type**	
○ Layer 1 (Top most):	*Select from dropdown*
○ Layer 2 :	*Select from dropdown*
○ Layer 3 :	*Select from dropdown*
○ Layer 4:	*Select from dropdown*
If you have selected Insulation for any of the above layers	
R value of Insulation	________________ (m^2 K/W)
➢ **Roof External Surface Finish**	________________
○ Normal roof reflectivity	________________
○ Normal roof emissivity	________________
○ Normal roof cost per m^2	________________
○ Cool roof reflectivity	________________
○ Cool roof emissivity	________________

○ Cool roof cost per m^2	___________________
○ Cool roof life in years	___________________
➢ **HVAC Details**	
○ HVAC System Type	• Window AC/Split AC/VRV • Air cooled chilled water system • Water cooled chilled water system
○ System COP	___________________ (W/W)
➢ **Internal Loads**	
○ Lighting power density	___________________ (W/m^2)
○ Equipment power density	___________________ (W/m^2)
➢ **Window Area**	
○ North	___________________ (%/m^2)
○ South	___________________ (%/m^2)
○ East	___________________ (%/m^2)
○ West	___________________ (%/m^2)
➢ **Electricity Rate**	___________________ (INR/kWh)

More information on these terms is as provided in Appendix C: Description of input variables of Cool Roof Calculator.

5.2.3 Output

After providing these inputs, the user can simulate the normal roof model and the cool roof model to generate the results. The results that are displayed are:

- Expected energy savings in each energy use category
- Energy cost savings
- Graph showing a comparison of monthly cool and heating consumption of the normal roof model and the cool roof model
- End use energy consumption category wise breakup
- Thermal comfort analysis – if the building is unconditioned
- Payback analysis

However, the thermal comfort results are shown only in case of un-conditioned spaces which exist only in the detailed form. An example of the output graphs generated after simulation, and the payback calculation is as shown in Figure 5.5.

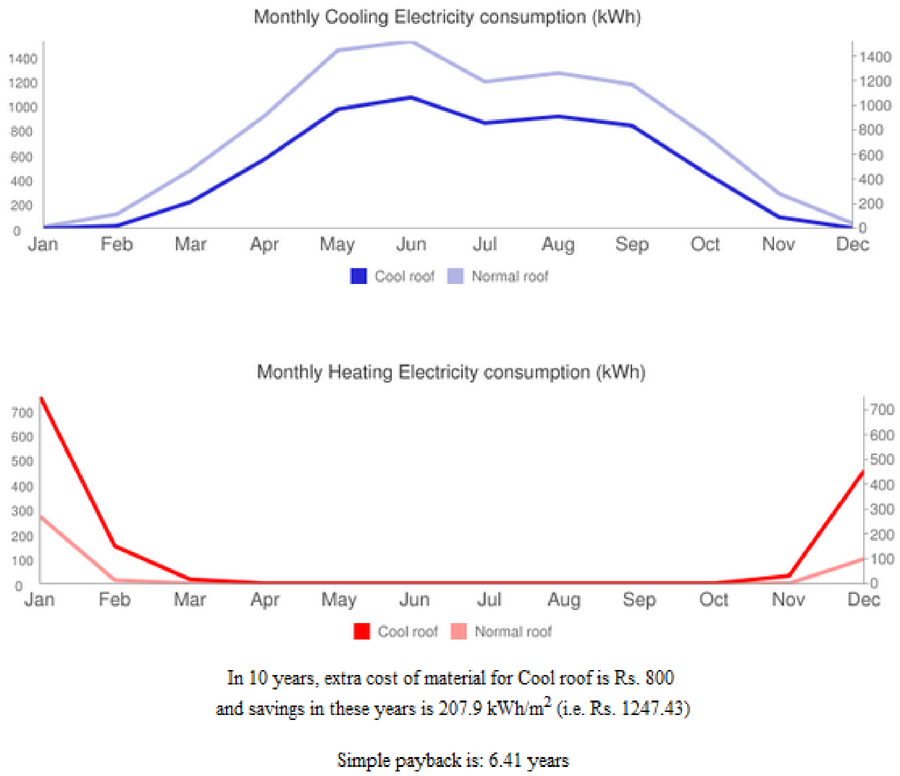


Figure 5.5: Example graph comparing of heating and cooling electricity consumption

The annual energy consumption comparison of the normal roof and the proposed roof will also be reported in the output, in a tabular format. Along with these values, the savings achieved in cooling, heating and overall HVAC is also provided. A screenshot a sample table as displayed on the output page is shown in Figure 5.6.

The annual savings achieved due to cool roof specified by you as compared to normal roof, specified by you is **2,703 kWh**, which results in an annual savings of ₹ **16,217**

	Total savings (kWh/year)	Savings per unit area (kWh/m^2 per annum)	Saving in cost (INR/year)
Savings in cooling	3,214.00	24.72	₹ 19,284.00
Savings in heating	-1,023.78	-7.88	₹ -6,142.68
Overall savings	2,702.76	20.79	₹ 16,216.56
Note: Negative value means loss			

EndUseCategory	Electricity [kWh]		% Saving
	Normal roof	Cool roof	
Heating	383.33	1407.11	-267.08
Cooling	9176.60	5962.60	35.02
Interior Lighting	2920.34	2920.34	0.00
Interior Equipment	4367.00	4367.00	0.00
Fans	1576.82	1064.28	32.50
Pumps	0.00	0.00	0
Heat Rejection	0.00	0.00	0
Total	18424.09	15721.33	14.67

Figure 5.6: Example of the output table

5.3: Simulation input and database

Based on the functionality of the calculator several EnergyPlus input data files have been created as the base template files. Both the simple and detailed form of the calculator takes input of various building types such as: Office, Institutional, Retail, Residential (All Day) and Residential (Only Night). For each of these building types, a separate template has been created which was then used as the based file over which the other values are input. Some default input values considered for the model are as specified in Table 5.2.

Table 5.2: Default inputs considered for the simulation model

Variable	Units	Input
Location		5 different climates (as per ECBC climatic zone classification) (details as shown in Table 4)
Geometry	Meters	Square (14.4 x 14.14)
Floor area	Square meters	200
Activity & Internal Loads		
Usage		Office
Occupancy schedule		Day time use building (Schedules as shown in Table 2)
Working days per week		5
Occupancy load	m^2 /person	14
Equipment power density	W/ m^2	16.15
Lighting power density	W/ m^2	10.8
Infiltration	ACH	Perimeter zones: 0.2 Core Zones: 0.1
Construction		
External wall U value	W/ m^2K	0.44 (Mass wall: Insulated brick wall)
Roof U value	W/ m^2K	Varies with insulation (Mass roof: RCC roof with varying insulation thickness, insulation above deck)
Openings		
Glazing type		Single glazing
U value of fenestration	W/ m^2K	3.3
SHGC		0.25
Light transmission		0.2
HVAC		
Type		PTAC (Packaged terminal air conditioner)
Heating COP	W/W	1.0 (Electrical)
Cooling COP	W/W	3.0
Heating set point temperature	^oC	20
Cooling set point temperature	^oC	25

A data base of various other inputs related to the simulation model are created and accordingly added to the base template that can be selected through the building type. A detail of all the variables and the inputs considered in various cases has been further specified in this chapter.

The five main schedules based on which the templates have been created are specified in table

Table 5.3: Schedules for Office

Lighting, Occupancy, Equipment, Fans	**Activity**
Schedule:Compact, BLDG_LEOF, Fraction, Through: 12/31, For: Weekdays SummerDesignDay, Until: 09:00, 0, Until: 17:00, 1, Until: 24:00, 0, For: Weekends WinterDesignDay AllOtherDays, Until: 24:00, 0;	Schedule:Compact, ACTIVITY_SCH, Any Number, Through: 12/31, For: AllDays, Until: 24:00, 120.;
Infiltration	**Cooling Setpoint**
Schedule:Compact, INFIL_SCH, Fraction, Through: 12/31, For: Weekdays SummerDesignDay, Until: 09:00, 1, Until: 17:00, 0, Until: 24:00, 1, For: Weekends WinterDesignDay AllOtherDays, Until: 24:00, 0 1; 1	Schedule:Compact, CLGSETP_SCH, Temperature, Through: 12/31, For: Weekdays SummerDesignDay, Until: 09:00, 40, Until: 17:00, 24, Until: 24:00, 40, For: Weekends WinterDesignDay AllOtherDays, Until: 24:00, 0 40; 1
Heating Set point	
Schedule:Compact, HTGSETP_SCH, Temperature, Through: 12/31, For: Weekdays SummerDesignDay, Until: 09:00, 10, Until: 17:00, 22, Until: 24:00, 10, For: Weekends WinterDesignDay AllOtherDays, Until: 24:00, 0 10; 1	

Table 5.4: Schedules for Retail

Lighting, Occupancy, Equipment, Fans	**Activity**
Schedule:Compact, BLDG_LEOF, Fraction, Through: 12/31, For: WinterDesignDays, Until: 24:00, 0, For: SummerDesignDays AllOtherDays, Until: 10:00, 0, Until: 22:00, 1, Until: 24:00, 0 0; 1	Schedule:Compact, ACTIVITY_SCH, Any Number, Through: 12/31, For: AllDays, Until: 24:00, 200;
Infiltration	**Cooling Setpoint**
Schedule:Compact, INFIL_SCH, Fraction, Through: 12/31, For: WinterDesignDay, Until: 24:00, 1, For: SummerDesignDay AllOtherDays, Until: 10:00, 1, Until: 22:00, 0, Until: 24:00, 0 1; 1	Schedule:Compact, CLGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 40, For: SummerDesignDay AllOtherDays, Until: 10:00, 40, Until: 22:00, 24, Until: 24:00, 0 40; 1
Heating Set point	
Schedule:Compact, HTGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 10, For: SummerDesignDay AllOtherDays, Until: 10:00, 10, Until: 22:00, 22, Until: 24:00, 0 10; 1	

Table 5.5: Schedules for Institutional

Lighting, Occupancy, Equipment, Fans	Activity
Schedule:Compact, BLDG_LEOF, Fraction, Through: 12/31, For: Weekdays SummerDesignDay, Until: 8:00, 0, Until: 24:00, 1, For: WinterDesignDay AllOtherDays, Until: 24:00, 0;	Schedule:Compact, ACTIVITY_SCH, Any Number, Through: 12/31, For: AllDays, Until: 24:00, 120;
Infiltration	**Cooling Setpoint**
Schedule:Compact, INFIL_SCH, Fraction, Through: 12/31, For: Weekdays SummerDesignDay, Until: 08:00, 1, Until: 24:00, 0, For: WinterDesignDay AllOtherDays, Until: 24:00, 1;	Schedule:Compact, CLGSETP_SCH, Temperature, Through: 12/31, For: Weekdays SummerDesignDay, Until: 08:00, 40, Until: 24:00, 24, For: WinterDesignDay AllOtherDays, Until: 24:00, 40;
Heating Set point	
Schedule:Compact, HTGSETP_SCH, Temperature, Through: 12/31, For: Weekdays SummerDesignDay, Until: 08:00, 10, Until: 24:00, 22, For: WinterDesignDay AllOtherDays, Until: 24:00, 10;	

Table 5.6: Schedules for Residential (AC all day)

Lighting, Occupancy, Equipment, Fans	**Activity**
Schedule:Compact, BLDG_LEOF, Fraction, Through: 12/31, For: WinterDesignDay, Until: 24:00, 0, For: SummerDesignDay AllOtherDays, Until: 24:00, 1;	Schedule:Compact, ACTIVITY_SCH, Any Number, Through: 12/31, For: AllDays, Until: 24:00, 200;
Infiltration	**Cooling Setpoint**
Schedule:Compact, INFIL_SCH, Fraction, Through: 12/31, For: WinterDesignDay, Until: 24:00, 1, For: SummerDesignDay AllOtherDays, Until: 24:00, 0;	Schedule:Compact, CLGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 40, For: SummerDesignDay AllOtherDays, Until: 24:00, 24;
Heating Set point	
Schedule:Compact, HTGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 10, For: SummerDesignDay AllOtherDays, Until: 24:00, 22;	

Table 5.7: Schedules for Residential (AC only night)

Lighting, Occupancy, Equipment, Fans	Activity
Schedule:Compact, BLDG_LEOF, Fraction, Through: 12/31, For: WinterDesignDay, Until: 24:00, 0, For: SummerDesignDay AllOtherDays, Until: 24:00, 1;	Schedule:Compact, ACTIVITY_SCH, Any Number, Through: 12/31, For: AllDays, Until: 24:00, 200;
Infiltration	**Cooling Setpoint**
Schedule:Compact, INFIL_SCH, Fraction, Through: 12/31, For: WinterDesignDay, Until: 24:00, 1, For: SummerDesignDay AllOtherDays, Until: 05:00, 0, Until: 21:00, 1, Until: 24:00, 0 0; 1	Schedule:Compact, CLGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 40, For: SummerDesignDay AllOtherDays, Until: 05:00, 24, Until: 21:00, 40, Until: 24:00, 0 24; 1
Heating Set point	
Schedule:Compact, HTGSETP_SCH, Temperature, Through: 12/31, For: WinterDesignDay, Until: 24:00, 10, For: SummerDesignDay AllOtherDays, Until: 05:00, 22, Until: 21:00, 10, Until: 24:00, 0 22; 1	

Using these schedules five different .idf files was created which call for the other inputs from the database as per the selected input by the user.

5.4: Testing of the tool

Initially the tool was run on trial and has been tested only in terms of the inputs and the outputs provided. It was very simple with less number of details. A screen shot of the tool is as shown in Figure 5.7. Based on the feedback received from several subjects who took part in the testing of the tool, the website has been further developed. In the latest version, a simple and detail form both exists targeting a wide user group. The input details requested from the user also varied from the old to the new.

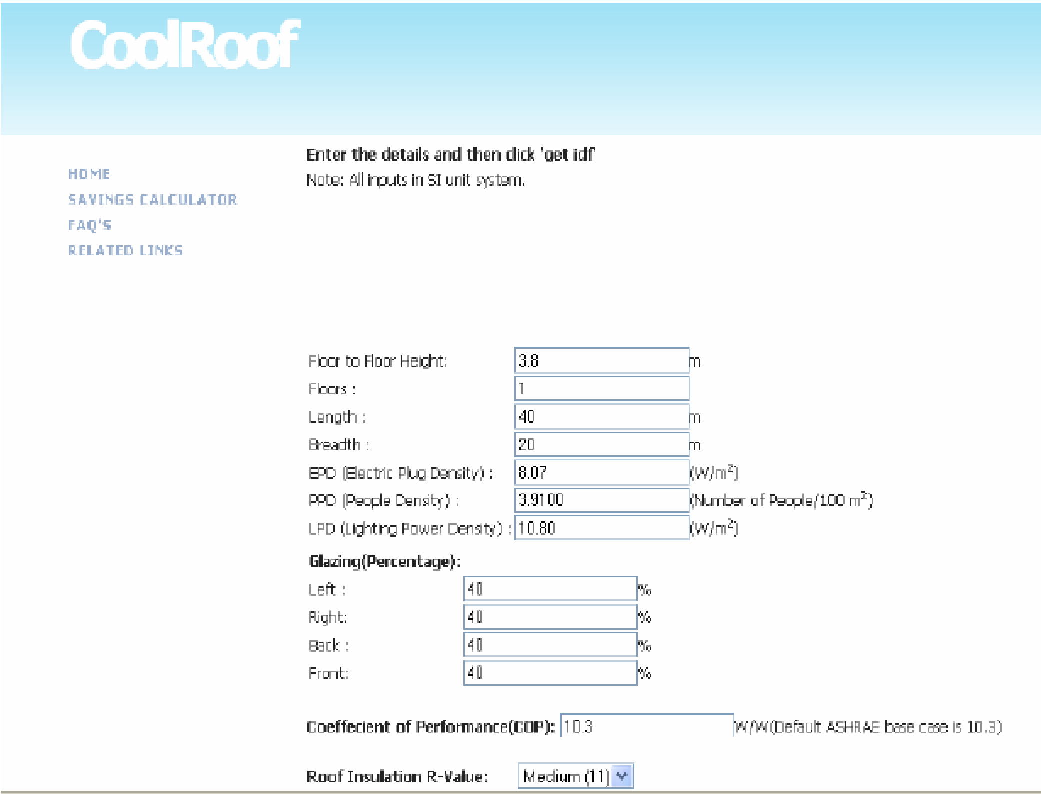


Figure 5.7: Screenshot of the tool developed in initial stages

Further, the updated site has been tested to understand the usability of the tool, amongst various user groups. Several users from different backgrounds were selected for the usability testing. A questionnaire has been prepared as shown in Appendix D: Feedback form on Cool Roof Calculator and was provided to the users for feedback. Along with this feedback, the website has been reviewed by several national and internationally reputed experts. The group of experts include but are not limited to: Dr. Akbari (University of Concordia), Mr. Ronnen Levinson (LBNL), Mr. Nick (NREL), Dr. Bhandari (NFRC), Ms. Surabi Menon (LBNL), Dr. Satish Kumar (IRG), Prof. Rajan Rawal (CEPT), etc. Feedback from these experts included comments on the user interface as well as the simulation models. Based on the feedback provided by these experts, modifications were done in the tool. Removing of inputs such as number of floors, conditioned and unconditioned area, adding a separate button for "Calculate your savings", revision in some default inputs of the simulation models, were some modifications that are done to the tool.

The testing of the tool includes users from diverse fields, and especially students and professionals between 23-29 years. However, there are comments which are related to novice, layman, and builders. These promise to be of great help in further enhancing the site. From the testing, results and the comments received for some of the major questions are as documented from Figure 5.8 - Figure 5.12.

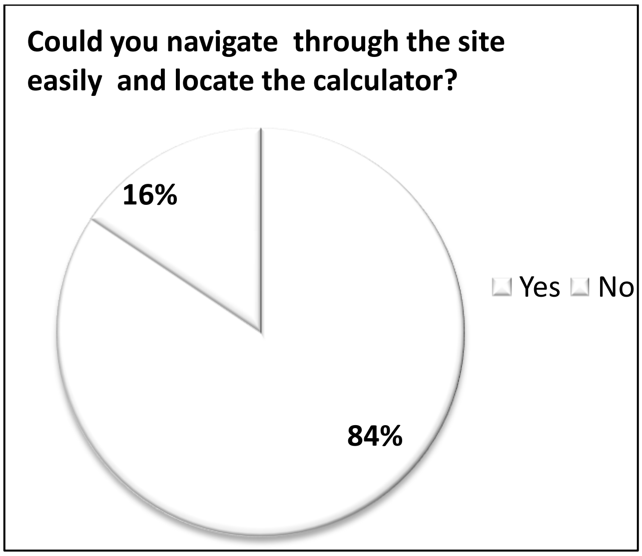


Figure 5.8: 84% of the users could locate the calculator easily, however they still suggest for a better button that is more obviously seen

When asked if the tool is complete interface of the site is usable or not, all the users said, yes, it was usable. But, some critical comments received were:

- "A bigger and more obviously seen button for "calculate your savings" and more easily observable way to divide into the sections - "simple" and "detailed" – would have been more helpful."
- "In (simple) roof type drop down menu, units are not given for thickness, however, it is mentioned at the top that it is SI. But I didn't see it in the starting. May be its not bold enough."

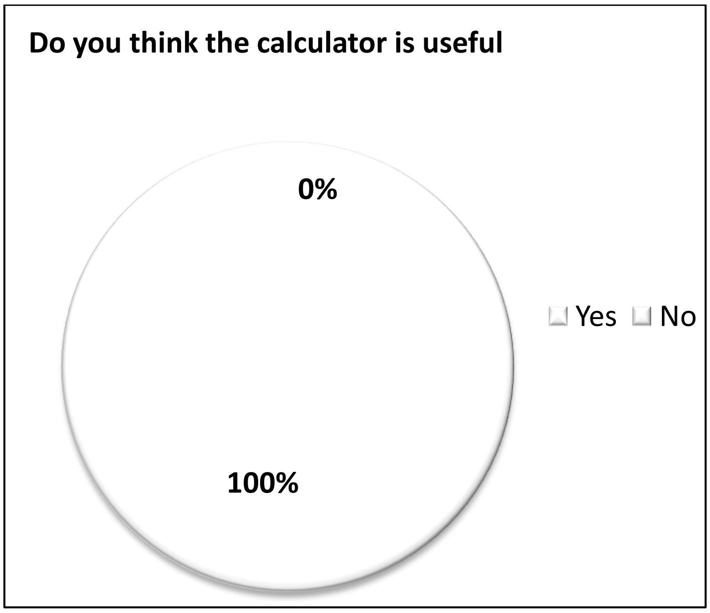


Figure 5.9: All the users say that the calculator is a useful tool

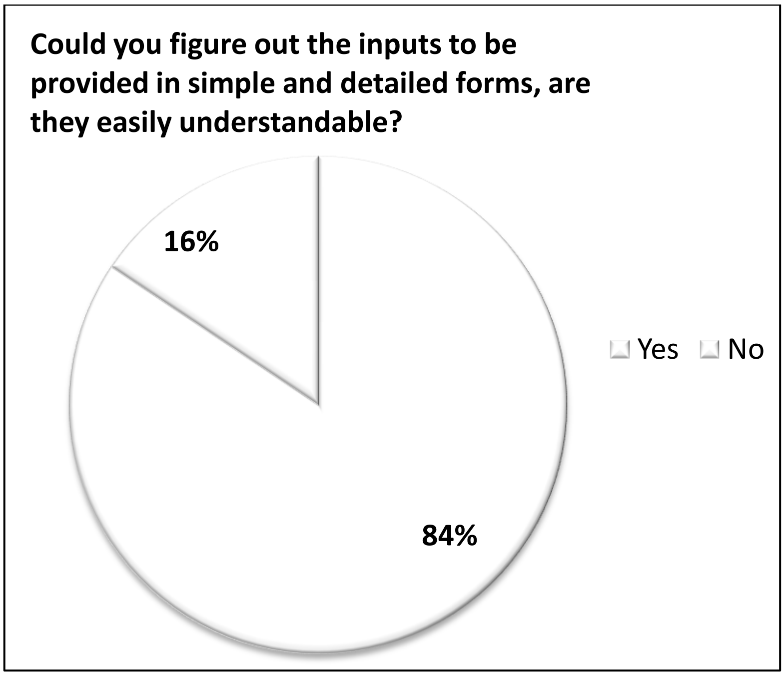


Figure 5.10: 16% users were found difficulty with the input details requested, especially when it comes to detailed form.

Some comments received for the same are:

- "Yes. Except SR, IE, etc. If a normal house owner has a way to know those details, fine."

- "If it is for lay man it is bit difficult. Inputs can be in general language."
- For roof external finish – The normal and cool roofs have the same options which I don't understand
- "At least I am more used to using surface area in sq. feet rather than sq. meters for buildings. The calculator seems to require input area only in sq. meters."

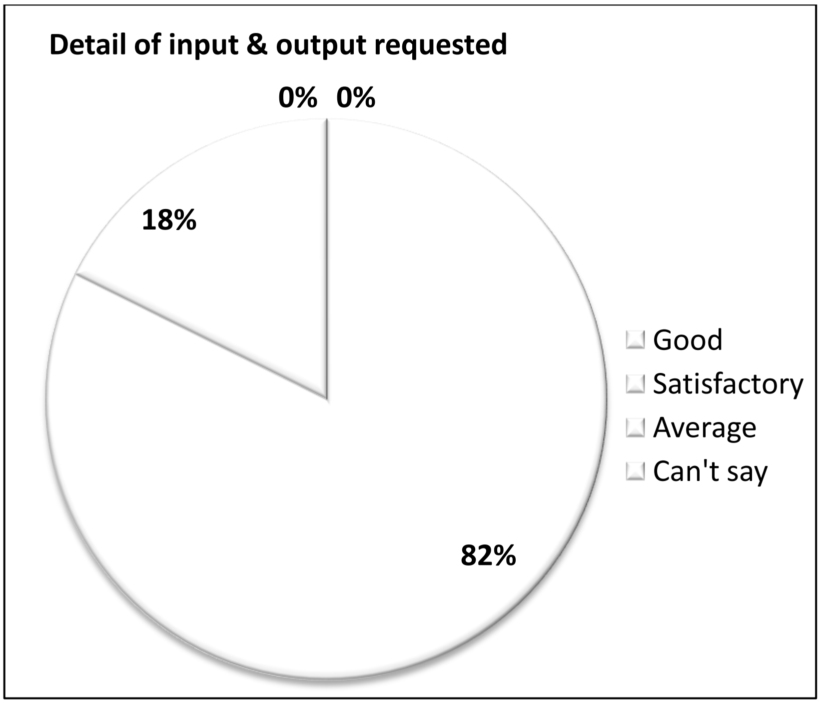


Figure 5.11: User at least with little technical knowledge about buildings could comment on the detail of input requested. 75% of the users were very satisfied with the input requested.

Comments received on the detail of output:

- "Useful. Just the cooling and heating savings might mislead a naïve user who might think they should some up to the total savings."
- "I think one more output window should open separately so that user can see results and inputs back and forth."

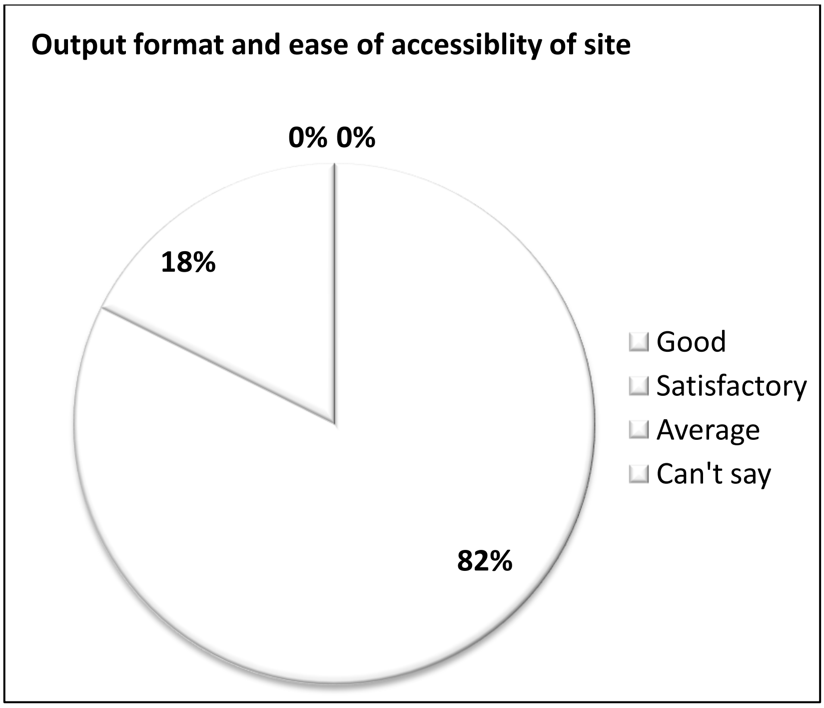


Figure 5.12: The ease of accessibility of the overall site and the output format generated receive the kind of feedback. 18% were felt satisfactory with these, and 82% say that they are good.

Other than these, the all the users could run a simulation (simple form) and check the savings achieved due to proposed roof. Around 80% of user could also run simulation using the detailed form.

90% user specified that the tool is good, and 10% specified it to be satisfactory. On a whole, some of the most important suggestions received on the overall site are:

- It is a simple and straight forward tool. I found it very useful. A supporting spread sheet with different roof finishing products available in market and their respective properties would have been handy.
- It seems to be a very very simple quick tool. The detailed version seems to be a little better with proper demarcation of details. I would like to see drop down menus with 4 products of cool roof products (paints) because when you try to enter its specifications it gets difficult finding the accurate numbers for a layman
- It’s very simple to understand and immediately knowing probable saving by cool roof. Can you mention some special type of white paints or brand companies which have very good quality of reflective paint.

- I would suggest you to mention the maximum temperature difference between normal roof and reflective roof, if possible to you. Its gives good feeling.
- This only deals with reduction in cost by reducing temperature conditioner usage. The cool roof could be a means for obtaining more comfortable environment in a regular household without AC. I do not know if this could be used as a motive for people to go for cool roof.
- And the documentation is quite helpful. Would be better if the options are elaborated a little more in detail for a layman to be using the calculator (explaining the various options the form provides). Assuming they are also a part of your target audience.

During the survey, each user, on an average spent 16.86 mins on the website. The average time spent for filling the simple and detailed forms are 4.12 mins and 3.67 mins, respectively. From this testing, it has been observed that users, who do not have domain related knowledge, couldn't use the detailed form. However, users who belong to the field could use the detailed from almost as quickly as the simple form. From this study, some important suggestions that would be helpful in the future development of the tool are:

- Inclusion of the list of vendors/manufactures of the cool roof products
- More explanation on the input related to detailed form
- Graphical representation of the properties/input of the building, wherever relevant.

Most of the technical comments received which are within the scope of the project, have been incorporated.

5.5: Conclusion

In a scenario where standardization of models is becoming very important to decide with any energy conservation measure and understand its effect on the energy consumption, this calculator would help in providing a standard model for calculating the savings due to a cool roof. This online tool would be very useful to understand the potential savings for a cool roof strategy in a proposed building. Through this tool, simulations tend to become easier and doable by any common man, thereby encourage the use of simulations before decided with any proposed energy conservation measure. The ease to use a simulations process to understand an energy conservation strategy is much increased due to a more user friendly and simple interface. User with least or no simulation knowledge can even use this tool to estimate the energy saving resulted by cool roof application. Hence, this tool would be of importance in deciding with cool roof as an energy conservation measure for a proposed building.

Related Publications

1. Vishal Garg, Surekha Tetali, Kshitij Chandrasen, Jyotirmay Mathur. “Online Energy Savings Calculator for Cool Roof”. Clima 2010 - REHVA World Congress, Antalya, Turkey, 2010.

References

[1]. DOE Cool Roof Calculator- Estimates Cooling and Heating Savings for Flat Roofs with Non-Black Surfaces. Accessible at: (http://www.ornl.gov/sci/roofs%2Bwalls/facts/CoolCalcEnergy.htm)

[2]. DOE Cool Roof Calculator – Estimates Energy and Peak Demand Savings for Flat Roofs with Non-Black Surfaces. Accessible at: http://www.ornl.gov/sci/roofs%2Bwalls/facts/CoolCalcPeak.htm

[3]. DOE Steep Slope Calculator. Accessible at: http://www.ornl.gov/sci/roofs+walls/SteepSlopeCalc/index.htm

[4]. Roof Savings Calculator. Accessible at: http://www.roofcalc.com/

[5]. Roofing Calculator. org. Accessible at: http://www.roofingcalculator.org/

Chapter 6: Effect of Cool Roof on Requirement of Roof Insulation Thickness in Office Buildings in India

6.1: Introduction

In this chapter, an analysis has been performed to understand the relevance and effect of roof insulation on HVAC energy consumption in top floors of buildings with varying roof surface reflectivity. Simulations were performed for varying roof insulation thickness, and roof Solar Reflectivity (SR), over a simple perimeter and core block, with a typical day time office schedule, for various climates in India, using EnergyPlus. From the simulation results it was observed that the savings achieved by adding insulation had diminishing returns, and the insulation has negligible effect on cooling energy consumption in case of high SR roofs. In some cases, when the roofs are highly reflective (SR of 0.7 and 0.8), adding insulation led to increase in cooling energy consumption. Further, based on these results, this work also suggested that the Energy Conservation Building Code recommendations for the prescriptive method are to be revisited.

Most of the locations in India receive a very high solar radiation, with the average global horizontal radiation ranging around 5000 Wh/m^2/day [1]. Due to this radiation and high temperatures, in most of the places cooling in buildings is a major requirement. Out of various components of the building envelope such as: roof, walls, and glazing, roof is major component which receives maximum amount of direct radiation over the day. It is a well known fact that, increase in the thermal resistance of the roof (R value) decreases the cooling energy consumption of buildings in hot climates; however, insulation can also adversely affect the performance of a building.

Halwatura and Jayasinghe [2], through an experiment, studied the effect of roof insulation thickness on heat flow and on air conditioning load in a building with RCC slab and 40mm thick reinforced concrete screed finish. The experimental results showed that there is a significant decrease in slab soffit temperature and heat flow, for a roof with 25mm and 50 mm insulation, in comparison to an un-insulated roof. The cooling loads analysed for various insulation thicknesses show that a larger insulation thickness can have a reasonable effect on the sensible component of the total air conditioning. This analysis is specific to a flat grey roof building in tropical climates.

D'Orazio et al [3] compared the thermal behaviour of different high insulated roofs, through a series of tests on full scale experimental building with different roof systems, in the Mediterranean climate of Italy. The authors mentioned the overuse of insulation in the buildings in hot Mediterranean climate due to which the effectiveness of traditional passive strategies employed to reduce solar heat gain in summer, are reduced. Further, the study specifies that this "over insulation" can have adverse effects on the internal comfort if it is not combined with suitable systems to check and manage free gains and to prevent the "box effect" (heat sources inside the building, solar irradiation through transparent surfaces, etc).

Masoso and Grobler [4] performed simulations to study the effect of wall insulation on the energy consumption of a building located in Botswana. The authors concluded that wall insulation cannot always do good in terms of cooling energy consumption. They specified that, there is a point, which they named as "point of thermal inflexion" at which, for a specific combination of the cooling set point temperature and internal gains, the building switches from "the lower the u-value the better" to "the higher the u-value the better". For the building that is simulated in this study, this point of inflexion occurred at 25.72 ^{o}C for 80 mm thick XPS. Below this temperature, the insulation brought positive savings and after this temperature it shows negative savings.

Lollini et al's [5] study aimed in defining the best insulation level for the envelope of the new residential buildings of Italy, considering the economic, energy and environmental issues. The study shows that better insulated building can reduce the heating energy demand. The identification of the best insulation level showed that, in Italy, it is not necessary to have too many centimetres of insulation materials and that all extra material has a short financial and economic payback time. The study specifies that use of insulation can provide consistent savings throughout the lifecycle of the building.

Thus, various prior studies show that, use of insulation in buildings decrease the heat ingress but there might be instances where the insulation might act adverse by increasing the energy consumption in the building. One other well known energy saving measure in hot climates is a cool roof. Cool roof is being widely promoted these days in countries like India, which mainly have cooling requirement throughout the year.

Ronnen Levinson and Hashem Akabari [6] studied the potential benefits of cool roofs on commercial buildings. The annual heating and cooling energy uses of four commercial building prototypes—new office (1980+), old office (pre-1980), new retail (1980+), and old retail (pre-1980)—were simulated in 236 US cities. The simulations showed that substituting a weathered cool white roof (solar reflectance 0.55) for a weathered conventional gray roof (solar reflectance 0.20) yielded annually a cooling energy saving per unit conditioned roof area of 5.02 kWh/m^2 nationwide, and a heating energy penalty of 0.065 $therm/m^2$ nationwide.

Harry Suehrcke et al [7] studied the effect of roof solar reflectance on the building heat gain in hot climate. This study aims in understanding the decrease in heat gain through roof due to the use of high reflective roofs. Calculations were performed for north Australia and it has been observed that a light-coloured roof has about 30% lower total heat gain than a dark coloured roof. Further, the paper also discusses the effect of thermal mass on the downward roof heat transfer. It specifies that in hot climates insulation may hinder the desired night time cooling and a light roof colouring in combination with only a reflective roof air space may be preferable for non-air-conditioned buildings.

A. Synnefa et al [8] had estimated the effect of cool coatings on energy loads and thermal comfort in residential building in various climatic conditions. Simulations where performed for a residential building for 27 cities around the world. The results show that increasing the solar reflectance of the roof reduces the cooling loads by 18-93%, which is around 9-48 kWh/m^2/year.

Similarly in several other studies [9][10][11][12][13] ,the advantages of a highly reflective roof were demonstrated. Studies show that there can be a difference of 10 degree in the outer surface temperature of a dark roof and a cool roof, and the there can be a annual savings of ranging between 60kWh/1000ft^2 - 600 kWh/1000 ft^2, in cooling energy consumption due to cool roof.

Hence, there exist several studies that prove the advantages of a cool roof, both through experimental and theoretical evaluation. However, relatively less work has been done on analysing the combined effect of a cool roof and roof insulation in combination, on HVAC energy consumption. As per various building energy codes and rating systems, such as Energy Conservation Building Code in India, a cool roof and roof insulation are both suggested as separate requirements for energy efficiency in buildings. The work presented through this paper presents the combined impacts of a cool roof and roof insulation together on the HVAC energy consumption of office buildings in climates in India. The study aims to understand the impacts due to the use of these two (cool roof and roof insulation) energy saving measures together in different combinations. The same has been studied also in accordance with the Energy Conservation Building Code of India.

6.2: Methodology

6.2.1 Input for the simulation model

To estimate the possible energy savings through use of roof insulation on a building with cool roof, a model has been developed and simulated for various weather files using EnergyPlus V 6. A single storey office block of 200 m^2 roof area has been considered for the simulation. Building materials like wall and glass, and the lighting power density are modelled as per the requirements specified by Energy Conservation Building Code of India. Commercial sector in India is experiencing a huge growth, and several offices such as private, public, governmental, etc, occupy a substantial share. Hence, in this paper, a typical day time office use building has been assumed for the simulations. Table 6.1: Details of the simulation modelTable 6.1 lists the input details of the building which are used in the simulation. Table 6.2 shows the schedule considered for the simulations.

Table 6.1: Details of the simulation model

Variable	Units	Input
Location		5 different climates (as per ECBC climatic zone classification) (details as shown in Table 4)
Geometry	Meters	Square (14.4 x 14.14)
Floor area	Square meters	200
Activity & Internal Loads		
Usage		Office
Occupancy schedule		Day time use building (Schedules as shown in Table 2)
Working days per week		5
Occupancy load	m^2 /person	14
Equipment power density	W/ m^2	16.15
Lighting power density	W/ m^2	10.8
Infiltration	ACH	Perimeter zones: 0.2 Core Zones: 0.1

Construction		
External wall U value	W/ m²K	0.44 (Mass wall: Insulated brick wall)
Roof U value	W/ m²K	Varies with insulation (Mass roof: RCC roof with varying insulation thickness, insulation above deck)
Openings		
Glazing type		Single glazing
U value of fenestration	W/ m²K	3.3
SHGC		0.25
Light transmission		0.2
HVAC		
Type		PTAC (Packaged terminal air conditioner)
Heating COP	W/W	1.0 (Electrical)
Cooling COP	W/W	3.0
Heating set point temperature	°C	20
Cooling set point temperature	°C	25

Table 6.2: Hourly schedules used in the simulation model

			00:00 - 09:00	**09:00 - 17:00**	**17:00 - 24:00**
Schedule Name	**Schedule Type**	**Day Type**			
Occupancy	Fraction of design value	Weekdays	0	1	0
		Weekends	0	0	0
Lighting	Fraction of design value (10.8 W/m²)	Weekdays	0.05	1	0.05
		Weekends	0.05	0.05	0.05
Equipment	Fraction of design value (16.15 W/m²)	Weekdays	0.05	1	0.05
		Weekends	0.05	0.05	0.05
Cooling Setpoint	Temperature (Set point temperature)	Weekdays	40	25	40
		Weekends	40	40	40
Heating Setpoint	Temperature (Set point temperature)	Weekdays	10	20	10
		Weekends	10	10	10
HVAC Fan	On/Off	Weekdays	0	1	0
		Weekends	0	0	0
Infiltration	On/Off	Weekdays	1	0	1
		Weekends	1	1	1

6.2.2 Roof Insulation details

An over deck roof insulation that is practically available in the market has be considered for the analysis. Styrofoam from Dow Chemical which is popularly used insulation in most parts of the world has been selected. The material properties of the insulation, available thicknesses and the cost are as specified in Table 6.3.

Table 6.3: Properties of the roof insulation

Variable	Value
Thermal Conductivity	0.028 W/m K
Density	32 kg/m^3
Specific Heat	1400 J/kg K
Available thickness	25mm, 30 mm, 40 mm, 50 mm and 75 mm
Cost	INR* 8000 / m^3

1 USD approximately equal to 45 INR

6.2.3 Climatic Data:

As specified in the Energy Conservation Building Code of India [14] the country has five major climatic zones. Table 6.4 list the characteristic features of a selected city from each climate zone, for which the simulations are performed.

Table 6.4: Climatic zone in India and their salient features

ECBC climatic zone classification	City selected for simulation	Latitude	Longitude	Degree Days		Maximum Daily Direct Normal Solar (Wh/m^2)	Maximum Daily Global horizontal (Wh/m^2)	EPW Weather file used
				Cooling 18°C	Heating 18°C			
Hot and Dry	Ahmedabad	N 23° 4'	E 72° 37'	13	3381	7429	5548	IND_Ahmedabad.426470_IWEC
Warm and Humid	Mumbai	N 19° 7'	E 72° 50'	0	3300	7062	5017	IND_Mumbai.430030_IWEC
Composite	New Delhi	N 28° 34'	E 77° 11'	321	2680	7196	5366	IND_New.Delhi.421820_IWEC
Temperate	Bengaluru	N 12° 58'	E 77° 34'	0	2036	8450	5244	IND_Bangalore.432950_ISHRAE
Cold	Shillong	N 25° 24'	E 91° 52'	1454	121	7967	3836	IND_Shillong.425160_ISHRAE

6.2.4 Variations Analysed

To observe the energy consumption for several combinations of roof insulation and roof reflectivity values, simulations were performed by varying roof insulation thickness and roof solar reflectivity values. Table 6.5 shows the roof insulation thickness and their respective R values considered for the simulations, and Table 6.6 presents the SR values of the roof considered for analysis. Along with a varying roof insulation thickness between 0 mm – 100 mm, a specific case – ECBC case, in which the R value and solar reflectivity (SR) of the roof is as per the code, has also been considered for the simulations. Out of all these solar reflectivity values, it is to be noted that, a SR of 0.3 represent general grey roof, SR 0.45 is the aged reflectivity of the roof as defined by building codes and SR 0.6 is the aged reflectivity of the roof that can be considered for a well maintained white roof. In case of roof insulation, the practically available thicknesses are 25 mm, 30mm, 40mm, 50mm and 75 mm. Hence, for the ease of representation of results, for these particular SR and R values, the text in the rows and columns is shown in **bold.**

Table 6.5: Roof insulation thickness and relevant R value of the roof assembly

Insulation thickness (mm)	R value (m^2 K/W)
00	0.309
05	0.487
10	0.666
15	0.845
20	1.022
25	**1.202**
30	**1.380**
35	1.557
40	**1.736**
45	1.916
50	**2.096**
55	2.273
60	2.450
65	2.631
70	2.810
75	**2.985**
80	3.165
85	3.344
90	3.521
95	3.704
100	3.876
ECBC roof	2.445

Table 6.6: Roof solar reflectivity values

	SR0.2	**SR0.3**	SR0.4	**SR0.45 (ECBC case)**	SR0.5	**SR0.6**	SR0.7	SR0.8
Reflectivity	0.2	**0.3**	0.4	**0.45**	0.5	**0.6**	0.7	0.8
Emissivity	0.9							

6.3: Results

Simulations were performed for various combinations of roof insulation thickness and roof SR values, for typical cities in all five major climatic zones of India. The output variables that are analysed to understand the performance of the building are: the cooling energy consumption, heating energy consumption, and the overall HVAC energy consumption (which includes fan energy consumption along with heating and cooling).

6.3.1 Cooling Energy Consumption

In all the climates of India except cold, space cooling plays a major role in buildings. Space cooling occupies a substantial share in the HVAC energy consumption, as well as the overall energy consumption, especially in office buildings. Figure 6.1 - Figure 6.5 shows how the cooling energy consumption per unit area varies with increase in roof insulation thickness for roof with different solar reflectivity values, in different climates.

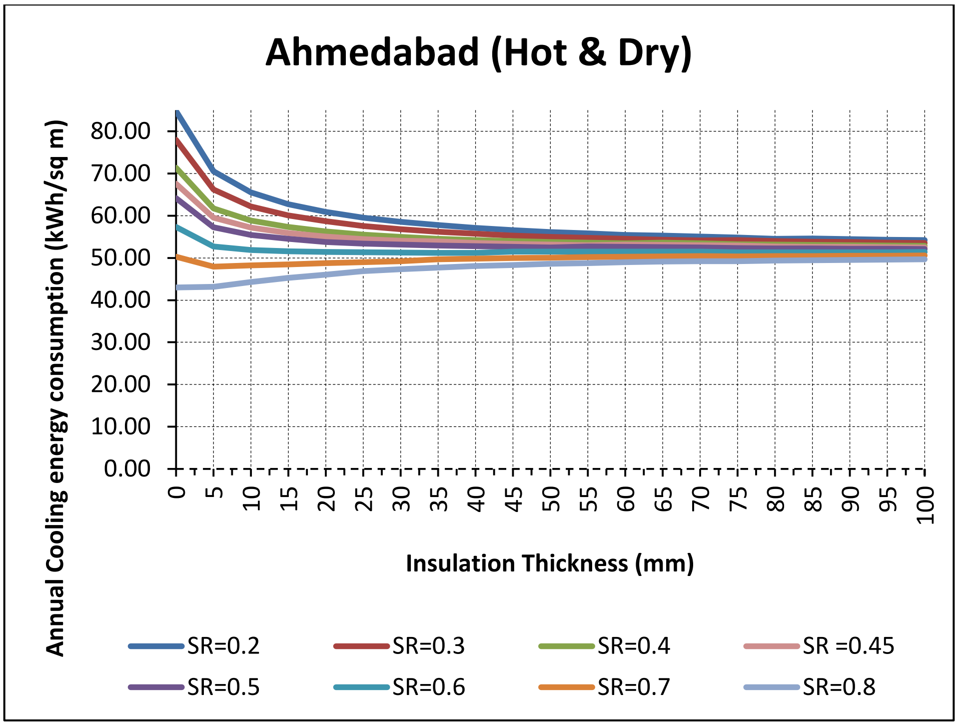


Figure 6.1: Cooling energy consumption varying with roof insulation thickness for different roof SR values, in Hot and Dry climate (Ahmedabad), show the decrease in incremental savings after 30 mm of insulation for roofs with SR value up to 0.5

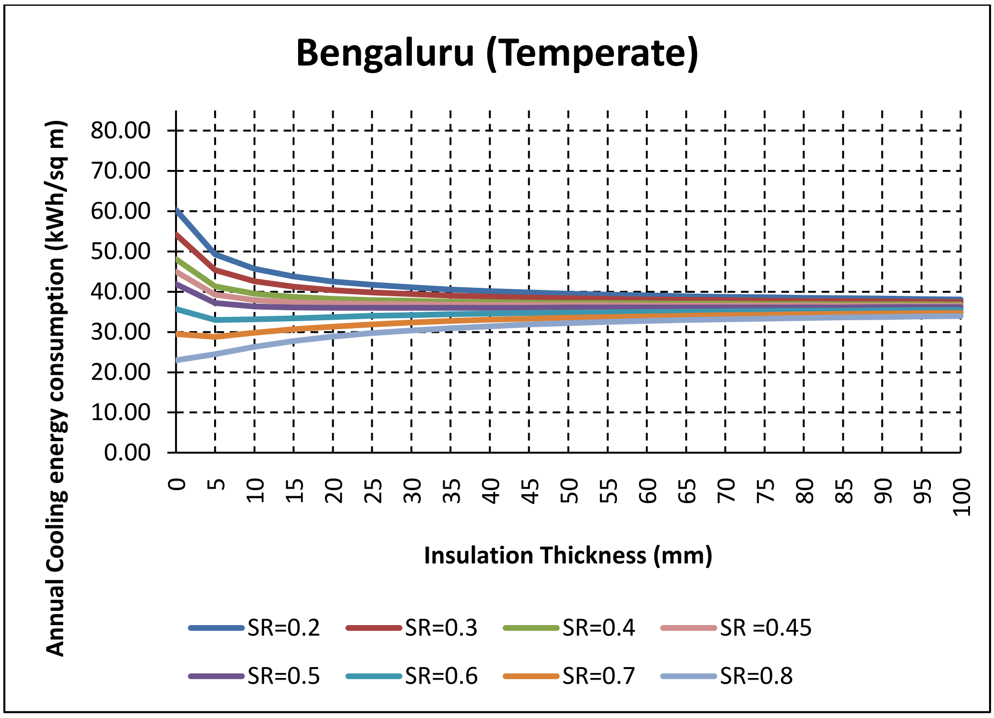


Figure 6.2: Cooling energy consumption varying with roof insulation thickness for different roof SR values, in Temperate climate (Bangalore), show the decrease in incremental savings after 10 mm of insulation for roofs with SR value up to 0.3

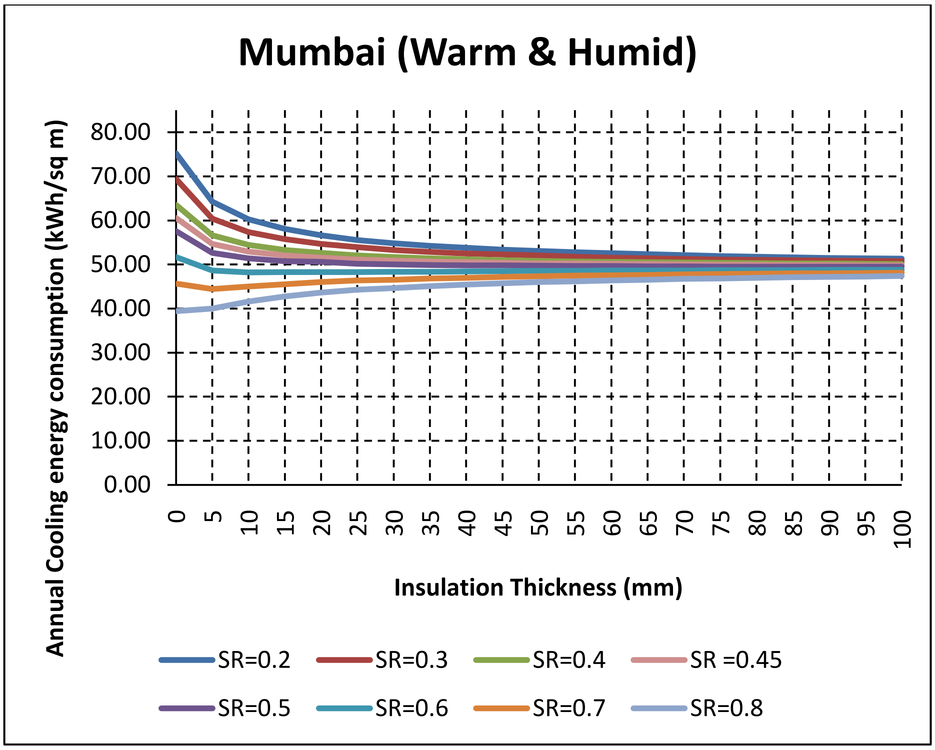


Figure 6.3: Cooling energy consumption varying with roof insulation thickness for different roof SR values, in Warm and Humid climate (Mumbai), show the decrease in incremental savings after 15 mm of insulation for roofs with SR value up to 0.45

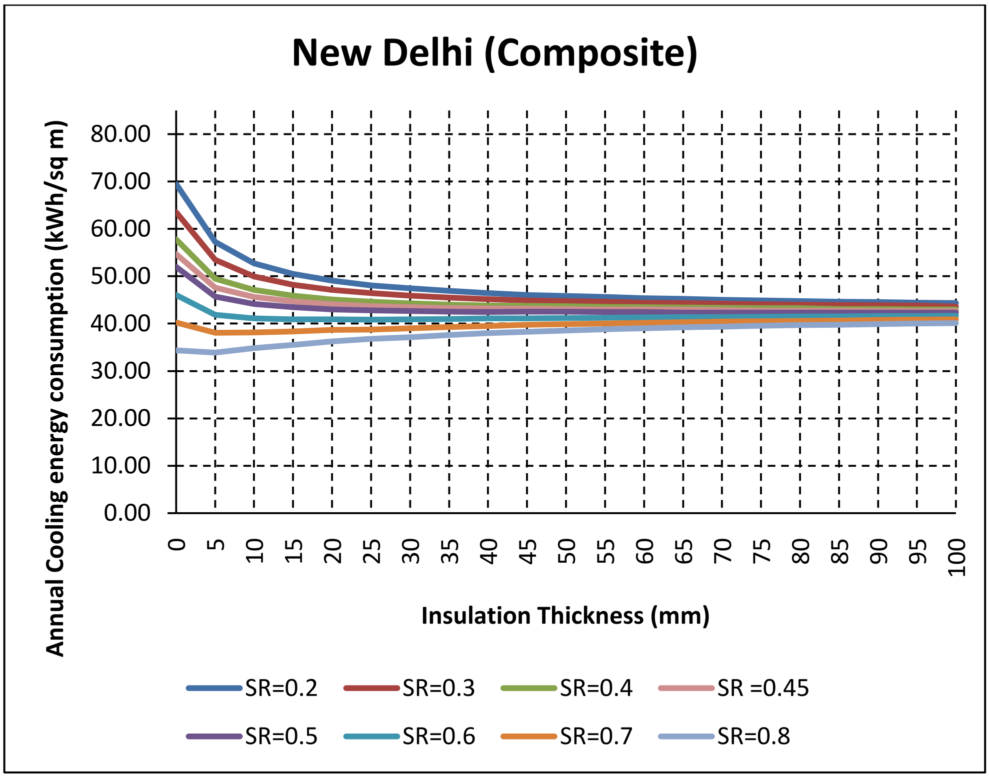


Figure 6.4: Cooling energy consumption varying with roof insulation thickness for different roof SR values, in Composite climate (NewDelhi), show the decrease in incremental savings after 30 mm of insulation for roofs with SR value up to 0.5

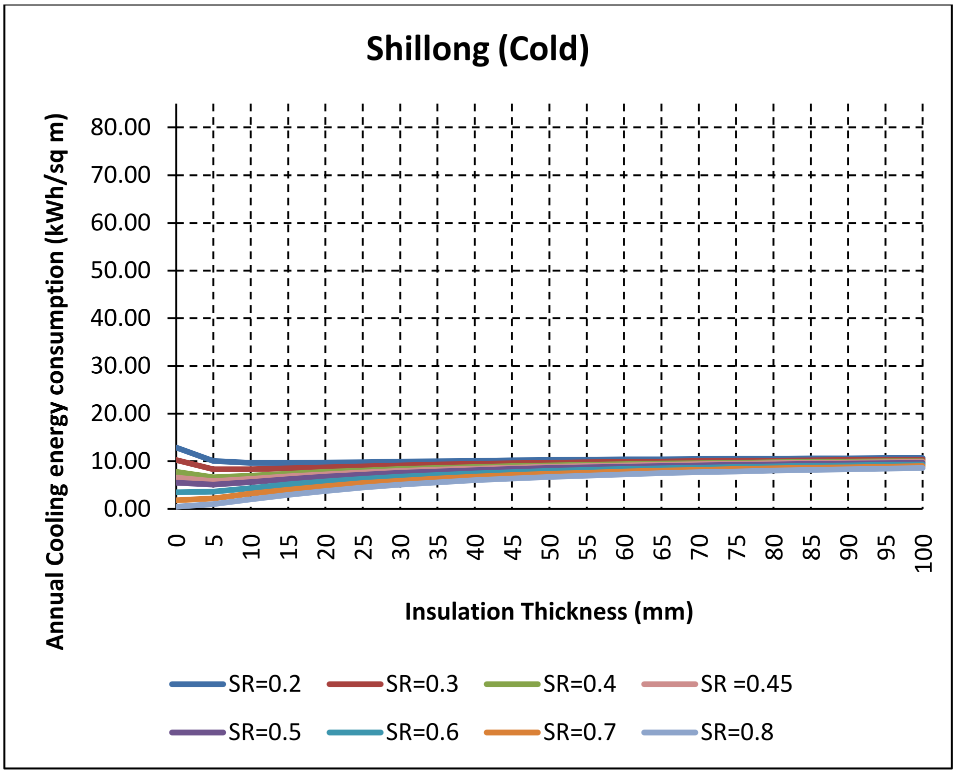


Figure 6.5: Cooling energy consumption varying with roof insulation thickness for different roof SR values, in Cold climate (Shillong), show increase in consumption for roof insulation thickness beyond 5mm, right from roof with SR value of 0.3.

From the results the following can be observed:

- In all the climates except cold (Shillong), adding insulation to a grey roof (roof with SR <= 0.3) provides savings. Further, with the increase in insulation thickness, the incremental savings decrease.
- In case of aged cool roof, (SR 0.45 as specified by building codes), for all the climates except cold (Shillong), increase in roof insulation has minimal affect on energy savings after an insulation thickness of 25 mm (roof assembly R value: 0.845 m^2 K/W). For each 5mm increase in insulation thickness further, the incremental savings is less than 1 kWh / m^2 /year. Hence, increasing the roof insulation above 25mm provides minimal decrease in the cooling energy consumption. However, for cold climate such as Shillong, beyond 5mm thickness of the insulation provides negative savings due to the increase in cooling energy consumption.
- For a cool roof with SR 0.6, the cooling energy consumption decreases with minimal insulation thickness of 10 mm in hot climates such as Ahmedabad (Hot and dry) and

New Delhi (composite), and of 5 mm in moderate climates such as Bangalore and Mumbai. After which, increase in roof insulation thickness is providing minimal or zero savings. In case of Shillong (Cold), the pattern still remains the same, and adding insulation is increasing the cooling energy consumption.

- Interestingly, for roof with a very high solar reflectivity (SR 0.7 & 0.8), the roof insulation act adversely in all the climates. An insulation thickness of 5mm shows savings in cooling energy consumption, after which, increase in roof insulation thickness increases the cooling energy consumption.

Therefore, in all most all the cases and climates, a minimal insulation thickness of 5mm provides the maximum savings in cooling energy consumption, for any roof solar reflectivity (except SR 0.8, for which the cooling consumption straight away increases with the increase in roof insulation thickness, for climates such as Temperate-Bangalore, Warm and Humid – Mumbai, and Cold- Shillong) as compared to an un-insulated roof.

Hence, it is observed that higher is the roof reflectivity, less is savings in cooling energy consumption due to roof insulation, and in extreme cases insulation can be detrimental.

6.3.1 Heating energy consumption

Figure 6.6 and Figure 6.7 show how the heating energy consumption per unit area varies with increasing thickness of roof insulation for roofs with different solar reflectivity values, for New Delhi and Shillong climates respectively. From the five climates analysed in this study, Shillong and New Delhi have relatively harsh winter season as compared to other places, due to which there exists certain heating energy consumption. Cool roof shows heating energy penalty in cold climates like Shillong. The heating energy consumption in building with un-insulated high reflective roof is high compared to a building with grey roof. Further, use of insulation on roof helps in decreasing the heating energy consumption by trapping heat inside the building. Hence, a grey roof with highest amount of insulation shows the least heating energy consumption. This heating energy consumption is high in case of Shillong and can constitute to as high as 90% of overall HVAC energy in the worst case scenario. However, in climate like New Delhi, it's predominantly cooling energy consumption and disadvantage in increase in heating energy consumption has lesser impact.

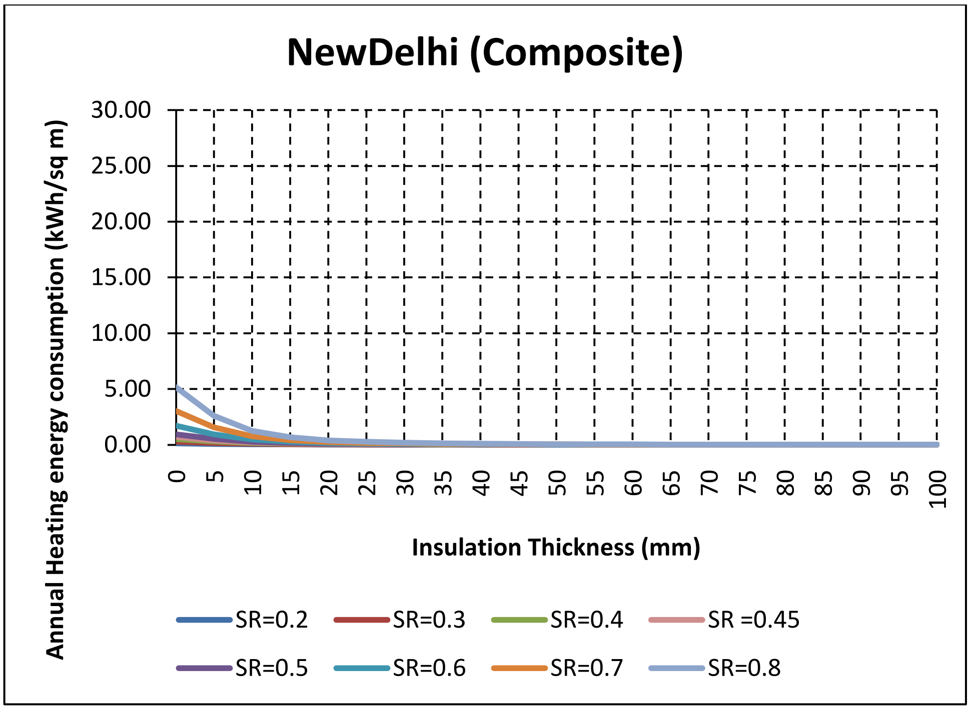


Figure 6.6: Heating energy consumption varying with roof insulation thickness for different roof SR values, in Composite climate (NewDelhi), show very negligible amount of resultant heating, and advantage or roof insulation in decreasing heating consumption.

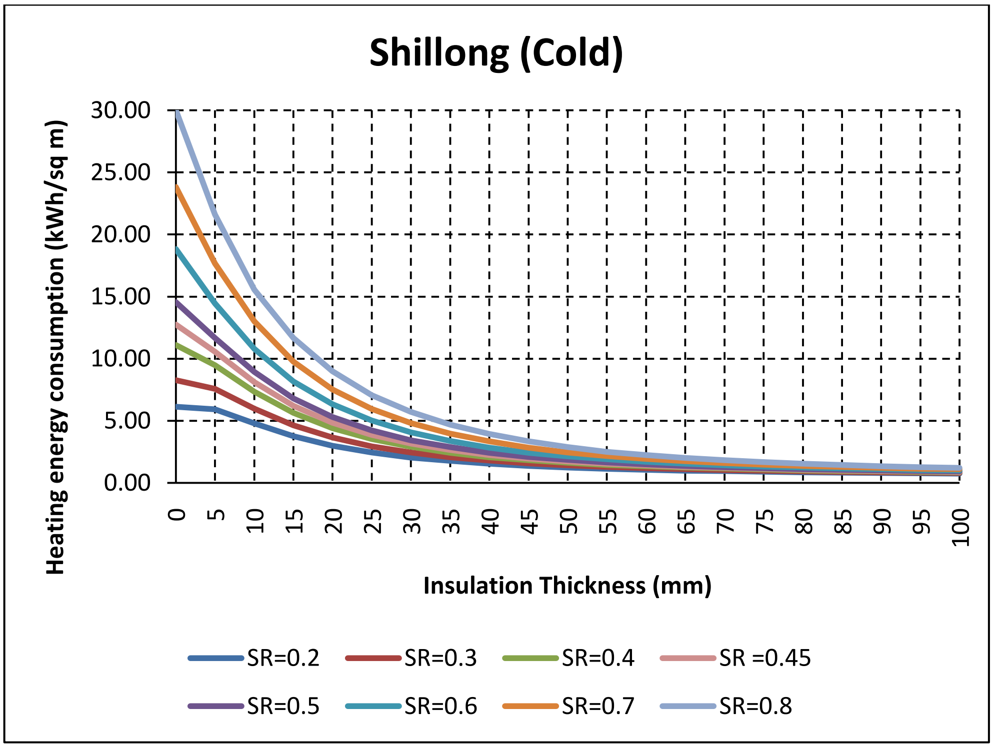


Figure 6.7: Heating energy consumption varying with roof insulation thickness for different roof SR values, in Cold climate (Shillong) showing the advantage of roof insulation in decreasing the heating energy consumption and the disadvantage of cool roof in increasing the heating energy consumption

6.3.2 Overall HVAC energy consumption

Figure 6.8 - Figure 6.12 shows the overall HVAC energy consumption per unit area for varying roof insulation thickness and solar reflectivity value, for different climates in India. As discussed in case of cooling energy consumption, since Indian climatic conditions predominantly have cooling requirements compared to heating, the overall HVAC energy consumption patterns seem more or less similar to the cooling energy consumption patterns in all climates except in Cold.. Expect for the cold climate -Shillong, in all the other climates, increase in roof insulation thickness shows a disadvantage when the roof reflectivity is 0.7 or more. For buildings with cool roofs with SR value 0.6, there are no considerable savings in overall HVAC energy consumption. Moreover in climates like Bangalore for SR of 0.6 too, the overall HVAC energy consumption increased with the increase in roof insulation thickness.

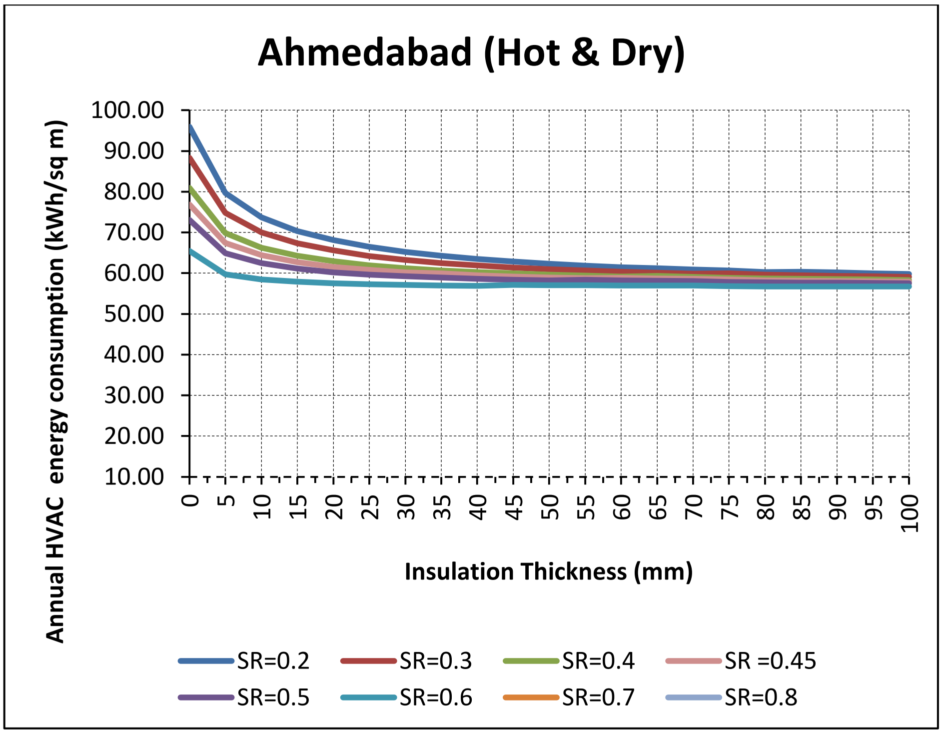


Figure 6.8: HVAC energy consumption varying with roof insulation thickness for different roof SR values, in Hot & Dry climate (Ahmedabad)

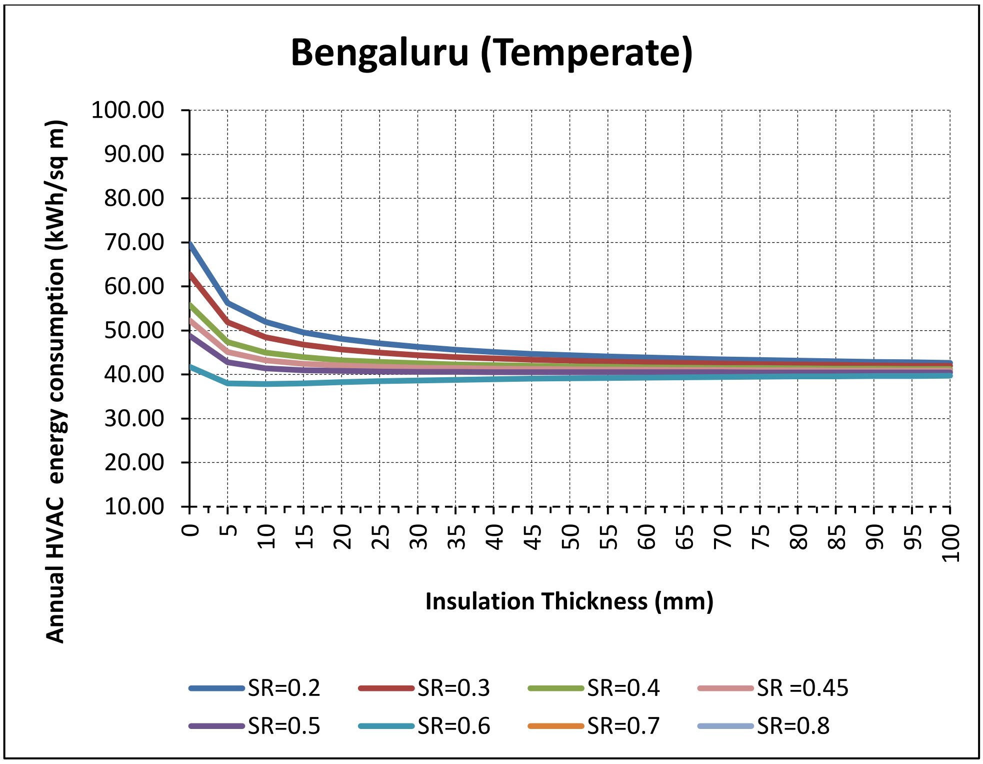


Figure 6.9: HVAC energy consumption varying with roof insulation thickness for different roof SR values, in Temperate climate (Bangalore)

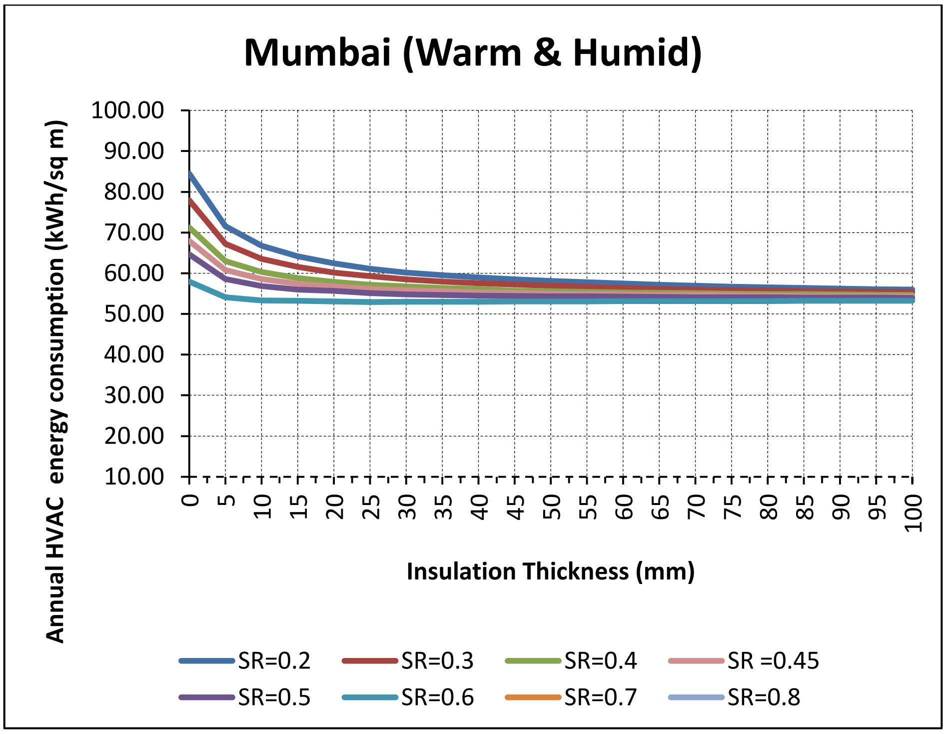


Figure 6.10:HVAC energy consumption varying with roof insulation thickness for different roof SR values, in Warm and Humid climate (Mumbai)

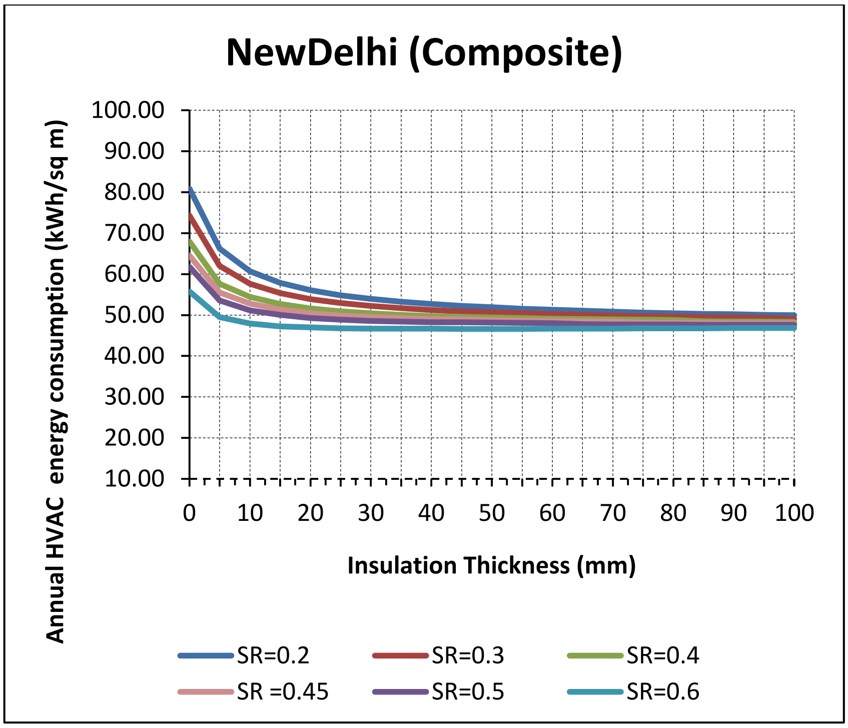


Figure 6.11:HVAC energy consumption varying with roof insulation thickness for different roof SR values, in Composite climate (NewDelhi)

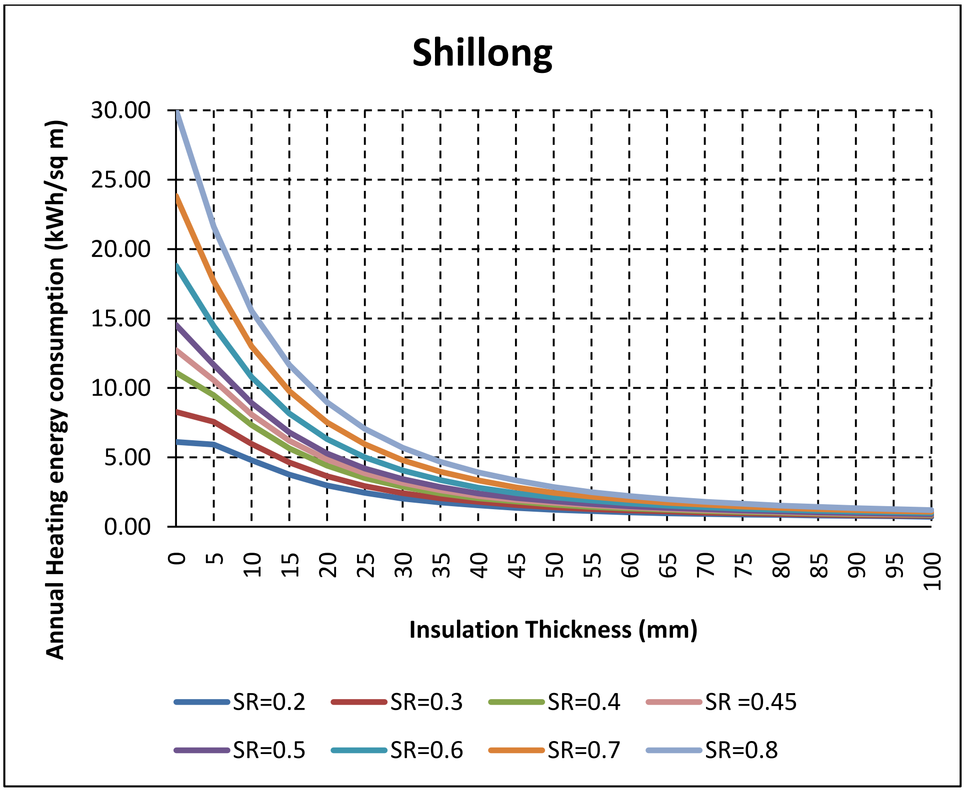


Figure 6.12: HVAC energy consumption varying with roof insulation thickness for different roof SR values, in Shillong climate

6.3.1 Relevance with ECBC India

The Energy Conservation Building Code of India provides compliance options for the building to meet the requirements of the code. As per the prescriptive approach, the building should perform as per the code's requirements specified for building envelope, lighting, equipment and HVAC. According to the prescriptive approach, the building envelope should meet the properties defined by the code. For roof of a day time use building, the code defines a U value (of the complete roof assembly) as 0.409 W/m^2 K, which implies 2.445 m^2 K/W - R value, for buildings in all climatic zones. Further, it specifies that the solar reflectivity of the roof should be greater than or equal to 0.7. From the analysis done in this study, it is observed that use of high insulation in buildings in various climates of India would provide no high benefits. Considering the insulation used for this study having thermal conductivity 0.028W/m K, the code prescribed U value can be achieved with an insulation thickness of 60 mm. However, as observed in the results earlier, the maximum saving in energy consumption is achieved with 5mm roof insulation thickness. Further, since the SR of the roof as prescribed by the code is 0.7 or more, increase in roof insulation thickness can show negative savings in almost all the climatic zones. Hence, the study suggests that the code compliance requirements are to be revisited and revised based on the advantages and the disadvantages in savings that would happen with the use of roof insulation over a cool roof.

6.3.1 Payback analysis for insulation

Table 6.7and Table 6.8show the savings in overall HVAC energy consumption in Indian Rupees (INR) that can be achieved in a year, and the payback period, for a given solar reflectivity of the roof and for varying roof insulation. The thickness of insulation in millimetres (mm), cost of insulation in INR for the given thickness of roof insulation (considering the roof insulation cost as INR 8000 / m^3), and monetary savings in INR in a year and payback period are tabulated for two different roof reflectivity values. Please note that the practically available roof insulation thicknesses are 25mm, 30mm, 40mm, 50mm and 75mm. In the Tables 5A-5B, results for these thicknesses are shown in bold and only these thicknesses are used for deriving the appropriate thickness of roof insulation for a given case. Assuming, 5 years to be a reasonably good payback period, all the cases where the payback period is less than or equal to 5 years has been highlighted to compare the payback period in each climate zone for a given SR value.

Table 6.7: Cost savings per year due to savings in HVAC energy consumption, and a simple payback period, for a roof with SR 0.45.

		Ahmedabad		**Bangalore**		**Mumbai**		**NewDelhi**		**Shillong**	
Insulation Thickness (mm)	Cost of Insulation (INR)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)
5	40	57	0.70	43	0.92	43	0.93	54	0.74	22	1.79
10	80	75	1.07	55	1.47	56	1.43	70	1.14	35	2.26
15	120	85	1.42	59	2.03	63	1.90	79	1.52	44	2.74
20	160	92	1.74	62	2.60	67	2.39	84	1.90	49	3.25
25	**200**	**96**	**2.08**	**63**	**3.17**	**70**	**2.84**	**88**	**2.28**	**53**	**3.79**
30	**240**	**100**	**2.41**	**64**	**3.73**	**73**	**3.31**	**90**	**2.67**	**55**	**4.37**
35	280	101	2.76	65	4.30	74	3.78	92	3.05	56	4.98
40	**320**	**104**	**3.07**	**66**	**4.87**	**76**	**4.22**	**93**	**3.44**	**57**	**5.59**
45	360	106	3.40	66	5.44	77	4.69	94	3.85	58	6.25
50	**400**	**107**	**3.73**	**67**	**6.00**	**78**	**5.14**	**94**	**4.24**	**58**	**6.92**
55	440	109	4.05	67	6.57	78	5.62	95	4.63	58	7.60
60	480	108	4.45	67	7.13	79	6.09	96	5.02	58	8.30
65	520	109	4.78	68	7.70	79	6.55	96	5.41	58	9.01
70	560	110	5.11	68	8.27	80	7.01	96	5.80	58	9.73
75	**600**	**110**	**5.44**	**68**	**8.84**	**80**	**7.48**	**98**	**6.11**	**57**	**10.46**
80	640	112	5.74	68	9.40	81	7.94	98	6.50	57	11.19
85	680	112	6.07	68	9.97	81	8.41	99	6.89	57	11.94
90	720	113	6.40	68	10.54	81	8.88	99	7.28	57	12.69
95	760	113	6.73	68	11.10	81	9.34	99	7.67	57	13.44
100	800	113	7.05	69	11.67	82	9.81	99	8.06	56	14.20

Observations:

- For hot climates such as Ahmedabad and NewDelhi, an insulation thickness of 50 mm is suggested, using with the payback of 5 years can be achieved.
- For Bangalore and Mumbai, little lesser insulation would provide the required payback. Hence, 40mm thick insulation is suggested.
- However, for cold climate such as Shillong, an insulation thickness of 30mm would provide the required savings in cost.

Table 6.8 Cost savings per year due to savings in HVAC energy consumption, and a simple payback period, for a roof with SR 0.6

Insulation Thickness (mm)	Cost of Insulation (INR)	Ahmedabad		Bangalore		Mumbai		NewDelhi		Shillong	
		Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)	Savings /yr (INR)	Payback period (years)
5	40	34	1.16	23	1.77	23	1.73	37	1.07	29	1.38
10	80	42	1.91	24	3.40	28	2.90	47	1.71	46	1.74
15	120	46	2.64	23	5.32	28	4.22	51	2.36	57	2.10
20	160	48	3.34	21	7.56	29	5.47	52	3.05	64	2.51
25	**200**	**49**	**4.06**	**20**	**10.05**	**30**	**6.66**	**54**	**3.71**	**68**	**2.94**
30	**240**	**50**	**4.78**	**19**	**12.81**	**30**	**8.03**	**54**	**4.42**	**71**	**3.39**
35	280	51	5.50	18	15.72	30	9.41	54	5.15	73	3.86
40	**320**	**51**	**6.22**	**17**	**18.82**	**30**	**10.84**	**54**	**5.91**	**74**	**4.35**
45	360	50	7.18	16	22.08	29	12.26	55	6.57	74	4.85
50	**400**	**50**	**7.92**	**16**	**25.47**	**29**	**13.69**	**55**	**7.31**	**74**	**5.38**
55	440	51	8.67	15	28.97	29	15.14	55	8.07	74	5.91
60	480	51	9.42	15	32.61	29	16.59	54	8.82	74	6.46
65	520	51	10.18	14	36.34	29	17.94	54	9.58	74	7.02
70	560	51	10.93	14	40.23	29	19.40	54	10.35	74	7.59
75	**600**	**52**	**11.51**	**14**	**44.12**	**29**	**20.88**	**54**	**11.12**	**74**	**8.16**
80	640	52	12.25	13	48.13	29	22.38	54	11.91	73	8.74
85	680	52	13.00	13	52.17	29	23.84	54	12.68	73	9.33
90	720	52	13.74	13	56.29	28	25.32	53	13.46	73	9.91
95	760	52	14.48	13	60.59	28	26.81	53	14.24	72	10.50
100	800	53	15.23	12	64.92	28	28.33	53	15.03	72	11.10

Observations:

- For SR 0.6, it can be clearly observed that increasing insulation thickness is turning out be a disadvantage in terms of payback
- Still, in this case too, Ahmedabad and NewDelhi are the climates in which insulation would give certain returns. To achieve a payback period of maximum 5years an insulation thickness of 30 mm is suggested in these cities.
- Whereas for Bangalore and Mumbai, where the savings are achieved with minimum thickness of insulations, it is suggested that no insulation should be used in the roof, since this investment would have no sufficient payback.
- Interestingly, Shillong behaves the other way. Due to the heating penalty that happens due to cool roof, high insulation is required. Hence, an insulation thickness of 40mm would also provide a good payback.

Hence, from these observations it can be said that, for high reflectivity roofs, minimum or no insulation is suggested considering the payback on the investment for roof insulation. Especially this is profoundly seen in temperate and warm climates such as Bangalore and Mumbai.

6.3.1 Detailed analysis

In this study, it has been observed that with increase in roof insulation thickness, the cooling energy consumption might increase in case of a highly reflective roof. This performance of the building has been analysed in detail for one specific case of a composite climate such as NewDelhi.

To understand why the energy consumption increases with increasing insulation in case of highly reflective roof, more detailed analysis was done by observing hourly heat flux (heat transfer between roof internal surface and room air) and indoor air temperatures in a specific scenario. A roof with solar reflectivity of 0.8 has been chosen for this analysis. Both the extreme cases: un-insulated roof with R value of 0.309 m^2/ W K and highly insulated roof with R value of 3.876 m^2/ W K are compared, to understand the phenomenon behind this behaviour of the building. Table 8 shows the comparison of monthly energy consumption and the heat flux for these two roofs.

Table 6.9: Comparison of monthly cooling and heating energy consumption in Delhi, and heat flux for roof with R value of 0.309 m^2 K/ W and 3.876 m^2 K/ W

Month	**Average Outdoor Air Temperature**	**Roof without insulation (R value:** 0.309 m^2-K / W, SR: 0.8)				**Roof with insulation (R value:** 3.876 m^2-K / W, SR: 0.8)				
		Positive Heat Flux[W/m2] (from slab bottom to room air)	Negative Heat Flux [W/m2] (from slab bottom to room air)	Heating Electricity Consumption (kWh/m2)	Cooling Electricity Consumption (kWh/m2)	Positive Heat Flux [W/m2] (from slab bottom to room air)	Negative Heat Flux [W/m2] (from slab bottom to room air)	Heating Electricity Consumption (kWh/m2)	Cooling Electricity Consumption (kWh/m2)	Savings/Loss due to insulated roof
January	13	0	-4,706	3.19	0.00	0	-730	0.01	0.22	
February	17	1	-2,904	0.31	0.04	59	-266	0.00	0.93	
March	21	78	-2,061	0.02	0.98	323	-296	0.00	2.16	
April	28	725	-973	0.00	3.20	701	-323	0.00	3.66	
May	32	1,626	-608	0.00	5.76	1,156	-312	0.00	5.61	
June	33	1,919	-450	0.00	6.42	1,209	-297	0.00	5.96	
July	30	1,216	-557	0.00	5.05	1,039	-297	0.00	5.10	
August	30	1,189	-563	0.00	5.37	1,017	-289	0.00	5.41	
September	29	984	-603	0.00	4.88	912	-289	0.00	4.99	
October	25	178	-1,505	0.00	2.33	660	-303	0.00	3.54	
November	19	0	-2,997	0.03	0.32	268	-274	0.00	1.87	
December	15	0	-4,367	1.60	0.00	15	-386	0.00	0.65	
Total	**-**	**7,915**	**-22,294**	5	34	**7,359**	**-4,063**	0	40	

Observations from results in Table 6.9 are:

- The outdoor air temperatures are higher than the indoor setpoint temperature of 25^{o}C, mainly in the summer months, i.e, April- September.
- During these six months (April-September), the positive heat flux in due to un-insulated roof is always greater than that in building with insulated roof. However, through these six months, the negative heat flux (heat loss) through roof is also higher incase of an un-insulated roof. Since, the heat loss is higher, and the heat ingress is regulated due to high reflective roof, the overall cooling energy consumption for these six hot months, in almost equal in both the cases (building with un-insulated roorf and highly insulated roof).
- In rest of the months (January- March, October-December), also in which the cooling requirement is more compared to heating requirement, the heat loss through the un-insulated roof is substantially higher compared to the roof with insulation. Hence, in the former case, the building gets an opportunity of night cooling since most of the times the outdoor air temperatures are lower than the indoor air temperatures. This decreases the heat that is trapped inside the building during unoccupied time and hence decreases the cooling energy consumption.
- The building with un-insulated roof has a capability of loosing heat through the roof, whereas the heat loss through the roof in building with roof insulation is restricted. In all the months the negative heat flux is smaller in insulated roof compared to the un-insulated roof.
- Monthly total heat gain in building through roof in the building with un-insulated roof is higher by 556 W/m^2. Monthly total heat loss through roof in a building with un-insulated roof is higher by 18,231 W/m^2. Hence, the overall cooling energy consumption in the building with un-insulated roof is lower by 6 kWh/m^2, when compared to the cooling energy consumption by the building with insulated roof.

Further, this behaviour has been analysed on an hourly basis to understand the heat flow pattern and the temperatures. After analyzing the daily average outdoor air temperatures, a day on which the outdoor temperature is more than the indoor set point temperature, and when the energy consumption is higher in case of the insulated roof when compared to un-insulated roof, has been selected for the analysis. April 17th is one such day. Table 6.10 , shows the comparison of hourly cooling energy consumption, heat flux , indoor air temperatures and roof surface temperatures. All this analysis has been done for one particular zone, Zone 5, which is the core zone of the perimeter and core model.

Table 6.10: Comparison of hourly cooling and heating energy consumption in Delhi, and heat flux for roof with R value of 0.309 m^2 K/ W and 3.876 m^2 K/ W

Date & Time	Outdoor dry bulb temperature (°C)	Roof without insulation (R value: 0.309 m^2-K / W, SR: 0.8)					Roof with insulation (R value: 3.876 m^2-K / W , SR: 0.8)				
		Cooling energy consumption (kWh/m^2)	Roof inside surface temperature (°C)	Roof outside surface temperature (°C)	Heat flux (W/m^2)	Indoor Air temperature (°C)	Cooling energy consumption (kWh/m^2)	Roof inside surface temperature (°C)	Roof outside surface temperature (°C)	Heat flux (W/m^2)	Indoor Air temperature (°C)
04/17 01:00:00	26	0.0000	28.53	25.66	-0.63	29.04	0.0000	29.30	18.50	-0.71	29.86
04/17 02:00:00	24	0.0000	28.14	24.93	-1.06	28.89	0.0000	29.30	17.04	-0.68	29.85
04/17 03:00:00	23	0.0000	27.74	24.19	-1.47	28.70	0.0000	29.30	15.55	-0.64	29.82
04/17 04:00:00	22	0.0000	27.33	23.56	-1.91	28.51	0.0000	29.30	14.04	-0.62	29.81
04/17 05:00:00	23	0.0000	26.93	23.07	-2.40	28.33	0.0000	29.29	13.33	-0.63	29.82
04/17 06:00:00	23	0.0000	26.55	22.64	-2.87	28.15	0.0000	29.29	13.06	-0.65	29.82
04/17 07:00:00	24	0.0000	26.20	22.64	-3.33	28.01	0.0000	29.28	14.36	-0.69	29.84
04/17 08:00:00	26	0.0000	25.93	23.67	-3.74	27.90	0.0000	29.28	18.98	-0.79	29.90
04/17 09:00:00	29	0.0000	25.86	25.50	-3.81	27.86	0.0000	29.28	25.66	-0.88	29.95
04/17 10:00:00	31	0.0068	26.05	27.67	0.10	25.05	0.0095	29.18	32.61	4.10	25.21
04/17 11:00:00	33	0.0062	26.48	29.81	1.25	25.00	0.0083	29.07	38.16	4.95	25.00
04/17 12:00:00	35	0.0062	27.15	31.77	2.08	25.00	0.0080	29.05	42.05	4.91	25.00
04/17 13:00:00	37	0.0063	27.96	33.42	3.19	25.00	0.0078	29.04	44.33	4.89	25.00
04/17 14:00:00	38	0.0065	28.81	34.59	4.48	25.00	0.0078	29.04	44.96	4.89	25.00
04/17 15:00:00	39	0.0068	29.63	35.28	5.81	25.00	0.0078	29.05	44.46	4.90	25.00

04/17 16:00:00	39	0.0071	30.33	35.26	7.03	25.00	0.0079	29.05	42.72	4.91	25.00
04/17 17:00:00	39	0.0073	30.86	34.54	8.00	25.00	0.0078	29.06	39.58	4.92	25.00
04/17 18:00:00	39	0.0000	31.22	33.45	3.56	28.54	0.0000	29.09	35.63	1.08	28.28
04/17 19:00:00	37	0.0000	31.44	32.22	1.72	29.62	0.0000	29.21	31.69	-0.36	29.61
04/17 20:00:00	35	0.0000	31.35	31.11	1.53	29.68	0.0000	29.26	28.30	-0.55	29.73
04/17 21:00:00	32	0.0000	31.10	30.09	1.22	29.68	0.0000	29.28	25.42	-0.52	29.73
04/17 22:00:00	30	0.0000	30.76	29.16	0.87	29.66	0.0000	29.30	22.58	-0.49	29.73
04/17 23:00:00	29	0.0000	30.35	28.36	0.51	29.62	0.0000	29.31	20.66	-0.49	29.73
04/17 24:00:00	28	0.0000	29.93	27.60	0.21	29.57	0.0000	29.31	19.20	-0.48	29.73
Total	-	**0.0531**	-	-	**20.34**		**0.0651**	-	-	**30.39**	-

From this hourly analysis, following have been observed:

- All most all through the day, outdoor dry bulb temperature is higher than the indoor air set point temperature.
- In case of un-insulated roof the indoor surface temperature varies, where as in case of the insulated roof, more or less a constant temperature has been maintained all through the day, which is greater than the set point temperature.
- Though both the roofs are painted white, since the insulation is placed above deck in case of the insulated roof, the outside temperature of this roof is substantially higher during the day, compared to the un-insulated roof. Whereas, the inner surface temperature of the un-insulated roof is higher during the day, when compared to the insulated roof. Due to this, there is more heat gain into the building without roof insulation.
- However, during nights the indoor roof surface temperature of un-insulated roof decreases when compared to the insulated roof. Hence the heat loss through this un-insulated roof is high, which thereby decreased the start up cooling energy loads in the morning hour of subsequent day, and thus decreasing the overall cooling energy consumption.
- Overall heat flux is more in case of insulated roof when compared to an un-insulated roof.

Related Publications

1. Surekha Tetali, Jyotirmay Mathur, Vishal Garg. "Effect of Cool Roof and Roof Insulation on HVAC Energy Consumption in Office Buildings in Tropical Climate". (Abstract Accepted for Building Simulation 2011. Sydney, Australia. November 2011)
2. Surekha Tetali, Jyotirmay Mathur, Vishal Garg. "Effect of roof insulation in office building with cool roofs in India. (Targeted Journal: Energy and Buildings, Elsevier Publications) (Under Preparation –First draft ready)

References

[1]. Solar radiation handbook (2008), Solar Energy Centre, MNRE, Indian Metrological Department

[2]. R.U Halwatura, M.T.R Jayasinghe. Influence of insulated roof slabs on air conditioned spaces in tropical climatic conditions- A life cycle cost approach. Energy and Buildings 41(2009) 678-686.

[3]. M. D'Orazio, C. Di Perna, E. Di Giuseppe. The effects of roof covering on the thermal performance of highly insulated roofs in Mediterranean climates. Energy and Buildings 42 (2010) 1619- 1627.

[4]. O.T. Masoso, L.J. Grobler. A new and innovative look at anti-insulation behaviour in building energy consumption. Energy and Buildings 40 (2008) 1889- 1894.

[5]. Lollini, Barozzi, Fasano, Meroni, Zinzi. Optimisation of opaque components of the building envelope: Energy, economic and environmental issues. Building and Environment 41 (2006) 1001-1013.

[6]. Ronnen Levinson, Hashem Akbari. Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency (2010) 3.53-109.

[7]. Harry Suehrcke, Eric L. Peterson, Neville Selby. Effect of roof solar reflectance on the building heat gain in a hot climate. Energy and Buildings 40 (2008) 2224-2235.

[8]. A. Synnefa , M. Santamouris a, H. Akbari. Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. Energy and Buildings 39 (2007) 1167-1174.

[9]. Berdahl, P. and S. Bretz. 1997. "Preliminary Survey of the Solar Reflectance of Cool Roofing Materials," Energy and Buildings - Special Issue on Urban Heat Islands and Cool Communities, 25(2):149-158.

[10]. Konopacki, S., L. Gartland, H. Akbari, and L. Rainer. 1998. "Demonstration of Energy Savings of Cool Roofs," Lawrence Berkeley National Laboratory Report No. LBNL-40673, Berkeley, CA.

[11]. Hildebrandt, E., W. Bos, and R. Moore. 1998. "Assessing the Impacts of White Roofs on Building Energy Loads." ASHRAE Technical Data Bulletin 14(2).

[12]. Konopacki, S. and H. Akbari. 2001. "Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin." Lawrence Berkeley National Laboratory Report LBNL-47149. Berkeley, CA

[13]. Parker, D., J. Sherwin, and J. Sonne. 1998b. "Measured Performance of a Reflective Roofing System in a Florida Commercial Building." ASHRAE Technical Data Bulletin 14(2).

[14]. Energy Conservation Building Code of India. Published by: Bureau of Energy Efficiency, Ministry of Power, Government of India.

Chapter 7: Conclusion and Future Work

This thesis analysed cool roof technology for its energy performance in building. The work emphasizes in demonstrating the benefits of cool roof technology, through a field study, analysis of experimental results and simulations. The work also includes the development of an online calculator for cool roofs. Further, a survey of the existing codes, organizations, potential and relevance of cool roofs in Indian context has been performed.

Through the historical study of relevance of the technology in Indian traditional architecture, it was found that cool roof was in practice decades ago which provided cooler terraces and also interiors of the homes. In the present, prevalence of the cool roofs is mainly due to the increased awareness through the products available in the market and their commercial ads, along with other methods such as the building codes and rating systems, which mandate the use of cool roof for all the climates of India. However, there is still a gap between the technology and the user, in making the right choice of product and its implementation technology.

A field installation of various cool roof products has been done to observe the performance of these products over a span of one year. Six different types of cool roof products –white cement paint, ceramic tiles, an aluminium foil, and white cool coatings were installed on site. From the observations through the year, it was found that though the resulted savings due to the white ceramic tiled roof is less compared to the other cool coatings, there is a good payback in the former case, due to its increased life. In case of the aluminium foil it was found that during the peak summer afternoon, the foil very quickly gains and losses heat, unlike the other material which showed constant temperature. During these peaks it has a lesser surface temperature when compared to the other roofs. However, the life and maintenance of the foil is the biggest disadvantage. In terms of savings the cool coating in white, performed the best.

In the analysis that has been performed over the raw data which has been collected in a yearlong monitoring, at the experiment conducted in Satyam Learning Centre, Hyderabad, the overall energy savings due to cool roof has been calculated. From the experiment it has been found that the energy savings ranged between 0.066-0.072 kWh/m^2/day representing 14% to 26% of cooling energy consumption attributed to cooler roofs.

Further, an online calculator (http://coolroof.cbs.iiit.ac.in/) for calculating the energy savings, simple payback and the thermal comfort, due to cool roofs has been developed as a part of this study. This project is intended to help the users (builders, owners, Architects, Engineers, and the research community) of cool roof by providing a quick analysis tool which can show the savings due to cool roof in different scenarios. Amongst many others, the major difference between this tool and the already available calculators is that, this calculator does real time simulations using EnergyPlus engine for all the Indian cities that have weather data available. From the recent user statistics it was found that there are around fiver user per day to this site.

Further, in this work an assessment of cool roof's impact on roof insulation thickness was done, through simulation of cool roof and roof insulation in various combinations. From the simulation results it was observed that the savings achieved by increasing insulation thickness had diminishing returns, and has negligible effect on cooling energy consumption in case of high SR roofs. In some cases, when the roofs are highly reflective (SR of 0.7 and 0.8), adding insulation led to increase in cooling energy consumption. Further, based on these results, this work also suggested that the Energy Conservation Building Code recommendations for the prescriptive method are to be revisited, since the use of extra insulation may lead to decrease savings when the building has a cool roof. .

Hence, on a whole the study is an assessment of the relevance and potential of cool roof technology in India, along with its effect on energy performance of a building. This work can further be extended into an urban level study, to demonstrate the national savings in energy consumption due to cool roof. Further, the performance of both the cool roof and roof insulation can be studied for various scenarios such as – change in schedule, ventilation, etc. This might provide a new set of conclusions, showing that evaluation of the technology at micro level is important, as there would be several factors which affect the performance of a building. A one place reference for all information related to cool roof and its potential in India, that would come to use, both for common man and the decision makers, can be a future target.

Appendix A: Potential Testing Laboratories

There are some other potential laboratories within India which would be capable of the testing of the cool roof products. Some of them are:

- Building Energy Performance Laboratory, Centre for Sustainable Environment and Energy, CEPT University, Ahmedabad
- Devi Ahliya University, Indore
- National Physical Laboratory, NewDelhi
- Jawaharlal Nehru Technological University, Hyderabad

More laboratories which have capabilities to test the cool roof performance, (Reflectance and emittance) within India as listed suggested by ASTM are as listed below:

1. **Shriram Institute for Industrial Research**

Address & Contact	
19, University Rd, Delhi, 110007 India	Tel: 910-112-7667267 Tel: 910-112-7667850 Fax: 910-112-7667676 V. Seth sridlhi@vsnl.com http://www.shriraminstitute.org
Description	
SRI provides analytical services including chemical, physico-mechanical, thermal studies, NDT, analytical method development, microbiological studies in food and drugs, residual analysis, calibration services, toxicological studies, contract research for process/product development, EIA, air, water and soil analysis, irradiation services.	
Products Tested	
ANIMAL AND PLANT PRODUCTS > Food ANIMAL AND PLANT PRODUCTS > Agricultural products (excluding food) ANIMAL AND PLANT PRODUCTS > Animal and fishery products (excluding food), including leather, furs ANIMAL AND PLANT PRODUCTS > Forestry products TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile mill products TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile products, finished products and apparel TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Lumber, wood, cordage, furniture TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Paper, packaging and related products ELASTOMERS AND PROTECTIVE COATINGS > Plastics, rubbers, resins ELASTOMERS AND PROTECTIVE COATINGS > Adhesives (organic resins), glues ELASTOMERS AND PROTECTIVE COATINGS > Paints, varnishes, lacquers, printing inks and related products	

NONMETALLIC MINERALS AND PRODUCTS > Bituminous and other materials, coal, tar NONMETALLIC MINERALS AND PRODUCTS > Cement, asbestos products, concrete, lime, gypsum NONMETALLIC MINERALS AND PRODUCTS > Soil and rock, building stones, aggregates, sand NONMETALLIC MINERALS AND PRODUCTS > Ceramics, clay and clay products NONMETALLIC MINERALS AND PRODUCTS > Glass and glass products NONMETALLIC MINERALS AND PRODUCTS > Semiconductor materials and devices NONMETALLIC MINERALS AND PRODUCTS > Petroleum refinery products, including asphaltic materials, petrochemicals, lubricants NONMETALLIC MINERALS AND PRODUCTS > Petroleum crudes, natural gas METALLIC MATERIALS AND PRODUCTS > Metallic ores, powders METALLIC MATERIALS AND PRODUCTS > Ferrous alloys, steels METALLIC MATERIALS AND PRODUCTS > Nonferrous metals, alloys METALLIC MATERIALS AND PRODUCTS > Stainless alloys including nickel, chromium METALLIC MATERIALS AND PRODUCTS > Primary metals: bar, sheet, pigs, ingots CONSTRUCTIONS > Building constructions including foundations CONSTRUCTIONS > Highways, bridges, tunnels, and other related constructions MACHINERY > Electrical machinery, equipment, supplies, appliances CHEMICALS AND CHEMICAL PRODUCTS > Chemical compounds and allied products (excluding human medicinals) CHEMICALS AND CHEMICAL PRODUCTS > Pharmaceuticals CHEMICALS AND CHEMICAL PRODUCTS > Soaps, detergents, water treatments CHEMICALS AND CHEMICAL PRODUCTS > Fertilizers, feeds, pesticides LABORATORY, SCIENTIFIC, MEDICAL EQUIPMENT > Scientific instruments LABORATORY, SCIENTIFIC, MEDICAL EQUIPMENT > Laboratory apparatus, supplies LABORATORY, SCIENTIFIC, MEDICAL EQUIPMENT > Medical devices LABORATORY, SCIENTIFIC, MEDICAL EQUIPMENT > Computers ENVIRONMENTAL, BIOLOGICAL MATERIALS > Air: indoor and outdoor atmospheres, stack emissions, noise levels ENVIRONMENTAL, BIOLOGICAL MATERIALS > Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process ENVIRONMENTAL, BIOLOGICAL MATERIALS > Soil and rock for environmental uses ENVIRONMENTAL, BIOLOGICAL MATERIALS > Hazardous waste, solid (nuclear and chemical) ENVIRONMENTAL, BIOLOGICAL MATERIALS > Leachates
Lab Services
Building and Welding Inspection, Construction Materials, Environmental Impact, Environmental Simulation, Product Performance
Testing Services
Biological Testing, Chemical Testing, Chromatography, Electrical/Electronic Testing, Electrostatic, Geotechnical Testing, Mechanical Testing, Metrology, Nondestructive Evaluation, Radiation/Ionizing, Spectroscopy, Thermal Analysis, Thermal Fire Testing
Equipment, Testing Capabilities, Applications
GC-MS, LC MS, GC, HPLC with various detectors, IR, UV AAS, CHNSI, UV

condensation, weather meter, auto chemistry system-Orion, MDSC, TGIA-DTA, HDT, Rheocord, DMA for thermal and theological studies of polymers, thermal, mass, pressure, flow, electrical, calibration, NDT, LITM and metallographic studies, environmental audit and analysis, ecotesting, drug pharma, microbiological, toxicological studies, petroleum and residual analysis
Specific Tests Conducted
ASTM E93, ASTM D129, ASTM D130, ASTM D482, ASTM C25, ASTM C114, ASTM D97, ASTM D524, ASTM D665, ASTM D2270, ASTM D892, ASTM D1500, ASTM D3172, ASTM D2172, ASTM D36, ASTM D611, ASTM C169, ASTM C1240, ASTM D1510, ASTM D128
Lab Accreditations/Evaluations
NABL, ISO, DGCA, DGMS, EIA, BIS

2. Central Coir Research Institute [COIR BOARD]

Address & Contact	
Kalavoor P.O. Alappuzha-688522, Kerala, India Kalavoor P.O. Alappuzha-688522, Kerala, India	Tel: 914-772-258094 Fax: 914-772-258415 Dr. Uma Sankar Sarma uss_2000@yahoo.com http://www.ccriindia.org
Description	
C.C.R.I. a premier research institute of COIR BOARD, an autonomous body under Ministry of MS&ME, Govt. of India, has the facilities for testing wide-width tensile properties, grab strength, trapezoid tearing strength, AOS thickness, mass per unit area and deterioration of geotextiles on exposure to light and water as per ASTM standards. Testing of coir pith is done for its conductivity, NPK & CHOS content& phytosanitation. Indentation Hardness, Chloride, Sulphate content of Rubberized Coir mattresses.	
Products Tested	
ENVIRONMENTAL, BIOLOGICAL MATERIALS > Leachates ENVIRONMENTAL, BIOLOGICAL MATERIALS > Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Geotextiles TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile products, finished products and apparel TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile mill products ANIMAL AND PLANT PRODUCTS > Agricultural products (excluding food)	
Lab Services	
Product Performance	
Testing Services	
Biological Testing, Chemical Testing, Chromatography, Geotechnical Testing, Mechanical Testing	
Equipment, Testing Capabilities, Applications	
Testing equipment includes UTM (Universal Testing Machine) and Xeno test for measuring the characteristics of geotextiles as per ASTM standards. The equipment for testing the permeability of geotextiles is also installed and characterization by ASTM standards in progress. Surface characterization is done using FT-IR Spectrophotometer	

and Scanning Electron Microscope. Analysis of coir pith is done using state-of- art equipments viz., Conductivity Meter, [C,H,N,S,O] analyzer, Atomic Absorption Spectrophotometer, UV /Vis Spectrophotometer, HPLC, GC-MS and Colony Counter, Differential Scanning Calorimeter (DSC) and Thermo Gravimetric Analyzer (TGA). The lab is also equipped with Refrigerated Ultracentrifuge, Freeze Drier, BOD Incubators, Laminar Air Flow, Autoclaves, and Muffle Furnace.
Specific Tests Conducted
AATCC1641998, IS14294, IS14293, IS13162, ASTM D1777, ASTM D3776, ASTM D4533, ASTM D4595, ASTM D4632, ASTM D4751, ASTM D4355, IS898, IS8301, IS9208, IS11420, IS12503, IS14596
Lab Accreditations/Evaluations
1. Recognized by Bureau of Indian Standards[BIS] for testing of rubberized coir mattresses. 2. Recognised by Australian Quarantine and Inspection Service [AQIS] for testing of coir pith.

3. Research Testing and calibration laboratory

Address & Contact	
(A Division of Metal Handicrafts Service Centre) Peetal Nagri, Rampur Road, Moradabad, UP, 244001 India	Tel: 915-916-32354,919412530224 Tel: 915-914-60131 Fax: 915-914-60131 Dr. Ravindra Sharma rtclindia@gmail.com http://www.metalcraftsandtest.org
Description	
Research, Testing and Calibration Laboratory (NABL ACCREDITED LAB)is a Division of Metal Handicrafts Service Centre under Ministry of Textiles , Govt. of India provides Testing capabilities for Metal & Alloys like steel, Brass, Copper, Silver, Gold, Bronze, Aluminium Alloy, Zinc Alloy, Solder Metallic & Non Metallic coating testing like Silver , Copper , Nickel ,Powder Coating, Lacquer & testing of Wax and Wood Products, Corrugated Card Board Boxes, Paper Electroplating Bath Solution: Silver, Nickel, Copper, Zinc, Brass Electrolyte The Lab is also providing Consignment inspection & testing, expert advice on test reports, product performance etc.	
Products Tested	
METALLIC MATERIALS AND PRODUCTS > Metallic coatings METALLIC MATERIALS AND PRODUCTS > Primary metals: bar, sheet, pigs, ingots METALLIC MATERIALS AND PRODUCTS > Stainless alloys including nickel, chromium METALLIC MATERIALS AND PRODUCTS > Nonferrous metals, alloys METALLIC MATERIALS AND PRODUCTS > Ferrous alloys, steels METALLIC MATERIALS AND PRODUCTS > Metallic ores, powders NONMETALLIC MINERALS AND PRODUCTS > Soil and rock, building stones, aggregates, sand NONMETALLIC MINERALS AND PRODUCTS > Cement, asbestos products, concrete, lime, gypsum COMPOSITE MATERIALS > Composite Materials CHEMICALS AND CHEMICAL PRODUCTS > Chemical compounds and allied products (excluding human medicinals)	

METALLIC MATERIALS AND PRODUCTS > Metallic components, cast, forged, welded, pressed METALLIC MATERIALS AND PRODUCTS > Metallic products, semifabricated, extrusions, rolled sections METALLIC MATERIALS AND PRODUCTS > Metallic fasteners CHEMICALS AND CHEMICAL PRODUCTS > Soaps, detergents, water treatments ENVIRONMENTAL, BIOLOGICAL MATERIALS > Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process ENVIRONMENTAL, BIOLOGICAL MATERIALS > Hazardous waste, solid (nuclear and chemical)
Lab Services
Environmental Impact, Environmental Simulation, Product Performance
Testing Services
Chemical Testing
Equipment, Testing Capabilities, Applications
Inductively coupled Plasma Emission Spectrometer (ICP-OES)for Toxic & Non Toxic Metallic contents , Non-Metallic Surface Coating Thickness . ED-XRF spectrometer for 24 Elements from Aluminum to uranium and Multi Metallic Coating Thickness , Metallurgical Microscope of 20X -2000X Stereoscopic Microscope , Water Analysis kit, Color Spectrometer, Gloss Meter, Bursting Strength Testers, Automatic Drop Tester, Digital Moisture Meter, Salt Spray Cabinet
Specific Tests Conducted
ASTM:E:1621, ASTM:E:352, ASTM:E:1277, ASTM:E:34, ISO:3497, ASTM:B:568, IS:14126, ASTM:E:1613, US:EPA:3052,3060A, ASTM:E:1645,16CFR1303, ASTM:C:738,AOAC:973, FDA, CALF. PROP. 65, ISO:7086, ISO:6486, BS:6748, IS:101, ASTM:B:117, ISO:99227, ASTM:B:499, APHA/AWWA, IS:3025, IS:228, ASTM:E:350
Lab Accreditations/Evaluations
RTC Laboratory is recognized by Major exporters of Metal Handicrafts in Moradabad & their buyers from foreign countries. Besides it is accredited from National Accreditation Board for Laboratories (NABL)in India

4. The Bombay Textile Research Association [BTRA]

Address & Contact	
Lal Bahadur Shastri Marg, Ghatkoper (W) Mumbai, 400086 India	Tel: 091-022-25003651 Tel: 091-022-25003652 Fax: 091-022-25000459 Dr. Ashok N. Desai btra@vsnl.com, btralibrary@yahoo.co.uk http://www.btraindia.com/director.htm/
Description	
BTRA Test Laboratories undertake textile testing for-Physical/chemical properties–fibre, yarn, fabric [made with natural and man-made fibres and woven /nonwoven/knitted fabrics] and allied products, chemicals/dyestuffs, etc., Microbiological properties for textiles, Technical textiles/composites testing includes geo-textiles, filters and automotive textiles, Polymer properties, Flammability, Ecology testing, tests for washing machine manufacturers, detergent manufacturers, hoteliers, etc.	
Products Tested	

TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile mill products TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Textile products, finished products and apparel TEXTILES AND FIBROUS MATERIALS AND PRODUCTS > Geotextiles COMPOSITE MATERIALS > Composite Materials NONMETALLIC MINERALS AND PRODUCTS > Glass and glass products CHEMICALS AND CHEMICAL PRODUCTS > Pharmaceuticals ENVIRONMENTAL, BIOLOGICAL MATERIALS > Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process
Testing Services
Thermal Analysis, Surface Analysis/Microscopy, Spectroscopy, Mechanical Testing, Geotechnical Testing, Electrostatic, Chromatography, Chemical Testing, Biological Testing, Thermal Fire Testing
Equipment, Testing Capabilities, Applications
DSC, TMA, TGA, FT–IR Analysis, X-ray Diffractometer, UV- Visible Spectrophotometer, GPC, HPLC, HPTLC, GC-ECD/MSD, AAS, Scanning Electron Microscopy, TOC, LOI Meter, V.H. Flammability, Static Honestometer, Colour eye 7000 spectrophotometer, Universal Tensile Tester [up to 10 ton capacity], AFIS, HVI, Yarn Testers for Hairiness/Unevenness/Friction/Tension, Fabric Testers for crimp/wear resistance/wrinkle recovery/permeability, Antibiotic Zone Reader, Colony Counter, UV Inoculation Hood
Specific Tests Conducted
ISO 9237, ISO 9073-4, ISO 9073-3, ISO 9073-12, ISO 9073-11, ISO 9073-10, ISO 9073-1, ISO 105-C03, ISO 105-C02, ISO 105-C01, ISO 105-B02, ISO 105-A03, ISO 105-A02, ISO 105-A01, DIN EN 71-3, DIN EN 14362-2, DIN EN 14362-1, DELPHI DX – 900276, GM 9130P, DIN-EN-12225, JIS L 1902, AATCC 193, AATCC 174, AATCC 163, AATCC 150, AATCC 147, AATCC 144, AATCC 135, AATCC 130, AATCC 128, AATCC 127, AATCC 124, AATCC 118, AATCC 117, AATCC 110, AATCC 107, AATCC 101, AATCC 100, AATCC 97, AATCC 82, AATCC 81, AATCC 79, AATCC 78, AATCC 61, AATCC 30, AATCC 20A, AATCC 17, AATCC 16, AATCC 15, AATCC 8, AATCC 3, ASTM D4884, ASTM D7004, ASTM D6241, ASTM D5141, ASTM D4751, ASTM D4716, ASTM D4595, ASTM D4533, ASTM D4491, ASTM D4439, ASTM D4355, ASTM D4354, ASTM D2905, ASTM D1682, ASTM D76, ASTM E145, ASTM D1059, ASTM D1230, ASTM D1422, ASTM D1423, ASTM D1424, ASTM D1425, ASTM D1777, ASTM D1776, ASTM D2256, ASTM D2591, ASTM D2731, ASTM D3776, ASTM D3786, ASTM D4355, ASTM D4437, ASTM D4491, ASTM D4533, ASTM D4595, ASTM D4632, ASTM D4716, ASTM D4751, ASTM D4772, ASTM D4833, ASTM D4885, ASTM D4886, ASTM D4966, ASTM D4970, ASTM D5034, ASTM D5035, ASTM D5199, ASTM D5261, ASTM D5493, ASTM D5494, ASTM D5494, ASTM D5587, ASTM D5596, ASTM D5733, ASTM D5866, ASTM D5867, ASTM D6241, ASTM D6243, ASTM D6413, ASTM D6512, ASTM D6571, ASTM D6612, ASTM D6637, ASTM D6717, ASTM D6720, ASTM D6767, ASTM F2101, ASTM F2100, ISO 105-C04, ISO 105-C05, ISO 105-C06, ISO 105-C10, ISO 105-D01, ISO 105-E01, ISO 105-E02, ISO 105-E04, ISO 105-N01, ISO 105-N02, ISO 105-P01, ISO 105-X05, ISO 105-X11, ISO 105-X12, ISO BS EN 1049-2, ISO 10993 – 3, ISO 10993 – 4, ISO 10993 – 5, ISO 10993 – 10, ISO 10993 – 11, ISO 11058, ISO 11224, ISO BS EN 12127, ISO 12138, ISO 12947-PT.2/3/4, ISO 12945-1, ISO 12945-2, ISO 12947-1, ISO 12956, ISO 13431, ISO 13438, ISO 139, ISO 13934-1, ISO 13934-2, ISO 13937-1, ISO 13937-2, ISO 13937-4, ISO 16549, ISO 17070, ISO 17202, ISO 17234, ISO 1833 – 3, ISO 1833 – 5, ISO 1833 – 11, ISO 2060, ISO 2061,

ISO 2062, ISO 3696, ISO 3801, ISO 3932, ISO 5079, ISO 554, ISO 6887-1, ISO 6939, ISO 7211-2, ISO 7211-3, ISO 7211-4, ISO 7211-5, ISO 7211-6, ISO 7218, ISO 9862, ISO 9863-1, ISO 9864, FMVSS 302, BS 3119, BS 3120, ASTM D2863, ISO 14184, BS 6806-2, BS 6806-3, DIN 54020, AATCC 112, ASTM E2149, DIN EN 12225, SNV 195 920, MIL STD 8104, RDSO
Lab Accreditations/Evaluations
: National Accreditation Board for Testing and Calibration Laboratories [NABL] - BTRA is accredited as per ISO-17025:2005 STANDARDS

5. **Intertek Caleb Brett India Pvt. Ltd.**

Address & Contact	
Unit No. D1, Udyog Sadan No. 3,MIDC, Central Road, Andheri (E) Mumbai , 400 093 India	Tel: +91-222-8244767Board Tel: +91-225-5704184 Fax: +91-222-8244768 Shailendra L Rane EAMELabs@intertek.com http://www.intertek-cb.com
Description	
Testing, sampling and inspection of: (a)crude oil (b)condensates (c) refined petroleum products (d) lubricants (e) petrochemicals (f)water (g) vegetable oils (h) agricultural commodities (i)metals (j) minerals (k) coal.	
Products Tested	
ANIMAL AND PLANT PRODUCTS > Food ANIMAL AND PLANT PRODUCTS > Agricultural products (excluding food) NONMETALLIC MINERALS AND PRODUCTS > Bituminous and other materials, coal, tar NONMETALLIC MINERALS AND PRODUCTS > Cement, asbestos products, concrete, lime, gypsum NONMETALLIC MINERALS AND PRODUCTS > Petroleum refinery products, including asphaltic materials, petrochemicals, lubricants NONMETALLIC MINERALS AND PRODUCTS > Petroleum crudes, natural gas METALLIC MATERIALS AND PRODUCTS > Metallic ores, powders METALLIC MATERIALS AND PRODUCTS > Ferrous alloys, steels METALLIC MATERIALS AND PRODUCTS > Nonferrous metals, alloys METALLIC MATERIALS AND PRODUCTS > Stainless alloys including nickel, chromium CHEMICALS AND CHEMICAL PRODUCTS > Chemical compounds and allied products (excluding human medicinals) CHEMICALS AND CHEMICAL PRODUCTS > Soaps, detergents, water treatments CHEMICALS AND CHEMICAL PRODUCTS > Fertilizers, feeds, pesticides	
Testing Services	
Biological Testing, Chemical Testing, Chromatography, Optics/Photometry, Spectroscopy	
Equipment, Testing Capabilities, Applications	
ICP, AAS + GF, Gas Chromatograph, FTIR, Vidoephotometer, Xray Machine, UV/Vis Spectrophotometer, Densitometer, Moisturemeter, Potentiometric titrator etc. Methods: ASTM, IP, ISO, UOP, GAFTA, FOSFA, AOCS, IS.	
Specific Tests Conducted	

ASTM D5185, ASTM D4294, ASTM D5134, GAFTA 130, IS 548

6. Subodh Technoligists

Address & Contact	
R 874, M.I.D.C. Rabale, Navi Mumbai, 400708 INDIA	Tel: 912-227-690817 Tel: 912-232-989715 Fax: 912-227-697312 Sudhakar Bonde sudhakar@subodhlabs.com http://www.subodhlabs.com
Description	
Services: Engineering material testing covering Chemical, Mechanical, Metallurgical and Corrosion testing work as per ASTM/BS/DIN/IS/ASME specifications	
Products Tested	
ENVIRONMENTAL, BIOLOGICAL MATERIALS > Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process MARKETPLACE PRODUCTS--CONSUMER AND BUSINESS > Sports equipment, toys, musical instruments MARKETPLACE PRODUCTS--CONSUMER AND BUSINESS > Consumer goods, miscellaneous MACHINERY > Transportation vehicles and equipment including tires MARKETPLACE PRODUCTS--CONSUMER AND BUSINESS > Educational products MACHINERY > Boilers, pressure vessels, pipework MACHINERY > Electrical machinery, equipment, supplies, appliances MACHINERY > Machinery, miscellaneous, implements, engines, turbines METALLIC MATERIALS AND PRODUCTS > Metallic components, cast, forged, welded, pressed METALLIC MATERIALS AND PRODUCTS > Metallic products, semifabricated, extrusions, rolled sections METALLIC MATERIALS AND PRODUCTS > Metallic coatings METALLIC MATERIALS AND PRODUCTS > Metallic fasteners METALLIC MATERIALS AND PRODUCTS > Reactive and refractory metals METALLIC MATERIALS AND PRODUCTS > Stainless alloys including nickel, chromium METALLIC MATERIALS AND PRODUCTS > Primary metals: bar, sheet, pigs, ingots METALLIC MATERIALS AND PRODUCTS > Nonferrous metals, alloys METALLIC MATERIALS AND PRODUCTS > Ferrous alloys, steels COMPOSITE MATERIALS > Composite Materials METALLIC MATERIALS AND PRODUCTS > Metallic ores, powders ELASTOMERS AND PROTECTIVE COATINGS > Plastics, rubbers, resins	
Lab Services	
Building and Welding Inspection, Construction Materials	
Testing Services	
Surface Analysis/Microscopy, Spectroscopy, Mechanical Testing, Chemical Testing	
Equipment, Testing Capabilities, Applications	
Major equipments: GDS Spectrometer (LECO¡VUSA; Computerized UTM; Facility of Electronic Extensometer; Image Analyzes System on Olympus Microscope (Japan); Atomic Absorption Spectrometer (Varian); Corrosion Testing as per NACE Standards	

Specific Tests Conducted
ASTM G99, ASTM G133, ASTM G171, ASTM E2546, ASTM E384, ASTM E92, ASTM D7027, ASTM D7187, ASTM C1624, ASTM C1327, ASTM C1326, ASTM B571, ISO 6507, ISO 14577
Lab Accreditations/Evaluations
Accreditation: Accredited by National Accreditation Board for Testing & Calibration Laboratories (NABL) India as per ISO/IEC 17025 (2005).

7. Central Research and Development Laboratory (CRDL)

Address & Contact	
Hindustan Zinc Limited Post-Zinc Smelter Debari, Pin-313024, Debari Udaipur, Rajasthan, India	Tel: +91-294-2655196 Tel: +91-294-2656612 Fax: +91-294-2655057 M.L. Gupta mohan.gupta@vedanta.co.in http://www.hzlindia.com/crdl.asp
Description	
Central R&D Laboratory is working for process development, process improvements, metal recovery from wastes/by-products & for analytical services. We have excellent lab scale, bench scale & pilot testing facilities for the R&D work supported by accurate & precise analysis with highly sophisticated instruments & experienced manpower. Mineral processing section does research for parameter optimization for grinding, sieving, cyclosizing, flotation for improved metal grade/recovery in the metal concentrate & new flowsheet development. Mineralogy studies are also done. Extractive metallurgy section does research for pyrometallurgical (high temperature), hydrometallurgical (metal leaching-purification), electrowinning, solvent-extraction & bioleaching. This includes recovery/quality improvement projects/process development for recovery of metal values from wastes/by-products. Analytical section has highly sophisticated instruments for working as umpire/referral lab with trained.	
Products Tested	
METALLIC MATERIALS AND PRODUCTS > Metallic components, cast, forged, welded, pressed METALLIC MATERIALS AND PRODUCTS > Metallic products, semifabricated, extrusions, rolled sections METALLIC MATERIALS AND PRODUCTS > Metallic fasteners METALLIC MATERIALS AND PRODUCTS > Metallic coatings METALLIC MATERIALS AND PRODUCTS > Reactive and refractory metals METALLIC MATERIALS AND PRODUCTS > Primary metals: bar, sheet, pigs, ingots METALLIC MATERIALS AND PRODUCTS > Stainless alloys including nickel, chromium METALLIC MATERIALS AND PRODUCTS > Nonferrous metals, alloys METALLIC MATERIALS AND PRODUCTS > Ferrous alloys, steels METALLIC MATERIALS AND PRODUCTS > Metallic ores, powders	
Testing Services	

Chemical Testing, Geotechnical Testing, Spectroscopy
Equipment, Testing Capabilities, Applications
Mineral Processing: Crushing, Grinding, Sizing–including Cyclosizer, Gravity separation, Batch Froth Flotation (Denver, External Air - Outokumpu), Flotation Column (Deister), Closed type mini flotation circuit, 2 TPD pilot plant including all above facilities. Extractive Metallurgy: Leaching reactors, solvent extraction, electrowinning, bioleaching reactors, bioleaching columns, high temperature furnaces (upto 1200oC) Pilot plant including leaching reactors, thickeners, filter press facilities. Analytical: X-Ray Diffraction, X-Ray Fluorescence Spectrophotometer, Atomic Absorption Spectrophotometer, UV-vis spectrophotometer, Mercury analyzer, Karl Fischer apparatus - moist determination, Autotitrator, Wet chemical analysis lab with fuming chambers, hot plates etc. Petromineralogy Lab: Microscopes with image analyzer software for different mineralogical & MOG studies.
Lab Accreditations/Evaluations
ISO 9001, ISO 14001, OHSAS 18001 certified. Recognized from Department of Scientific and Industrial Research (DSIR). Five - S workplace management certified.

Appendix B: List of products, vendors and manufactures

Simple White Paint - Exterior Grade (all water based emulsions)			
Manufacturer	*Product Specification*	*Corporate Office*	*Approximate Cost*
Asian Paints	Apex Ultima (white colour)	Asian Paints Limited Asian Paints House 6A, Shantinagar, Santacruz (E), Mumbai - 400 055. India. Tel: 022 - 3981 8000 Fax: 022 - 3981 8888	
Pidilite	Dr. Fixit Heatshield	Head Office Pidilite Industries Limited Ramkrishna Mandir Road P.O.Box No.17411 Andheri (East) Mumbai - 400059 Phone :(022) 28357000 Fax :(022) 28357008 E-mail :drfixit@pidilite.com	
Dulux	Dulux Weathershield		
Nerolac	Excel Tile guard	Ganpatrao Kadam Marg Lower Parel, Mumbai 400 013 Tel : 022 - 2493 4001/24992500 Fax : 022 - 2491 9439	
Berger	Weathercoat AllGuard/Longlife (white colour)		
Shalimar	Shaktiman Exterior Acrylic Emulsion	Shalimar Paints Limited, 5th Floor, 'C' Wing, Oberoi Garden Estate, Chandivili Farm Road, Chandivili, Andheri (E), Mumbai - 400 072. Phone : 022-28574043 / 6147 Fax : 022-28573725	

(Source: Cool roofs for cooler Delhi: A design manual)

Oikos	Betoncryll Pigmentato	Oikos India Pvt. Ltd. 29, Block -3,Tribhuvan Complex, Ishwar nagar, Mathura Road New Delhi - 110065 Mo: +91 98 107 73731 Ph: +91 11 42603212 - 13 Fax: +91 11 42603212

Tiles/Mosaic

Manufacturer	*Product Specification*	*Contact*	*Approximate Cost*
Kajaria	Stonelo Blanco (Floor Tiles 300x300)	J1/B1 (Extn.), Mohan Co - op Industrial Estate, Mathura Road, Badarpur New Delhi - 110044 Phone : 011 - 26946409 Fax : 91-11- 26946407/26949544 Email - newdelhi@kajariaceramics.com	
Bell	Mont Blanc (Floor Tiles 300x300)	Bell Ceramics Limited, Delhi +91-11-27633852 +91-9717596616	
Somany	Plain White (Floor Tile 300x300)	DEALER NAME - AGGARWAL TRADING CO CONTACT PERSON - MR JAGDISH KUMAR SUMEET ADDRESS - 7660 G T ROAD SHAKTI NAGAR BIRLA MILL CONTACT NO. - 09873437373 CELL NO. - 919873437373.00	

Reflective Roof Coatings

Manufacturer	*Product Specification*	*Contact*	*Approximate Cost*
Thermoshield India Pvt Ltd	High Albedo Roof Coating	Tel: +91 80 2320 79570 Fax: +91 80 2320 7958 Email: sales@thermoshieldindia.com Website: www.thermoshieldindia.com	55 Rs/sqft (excluding water proofing for 2 coats)

(Source: Cool roofs for cooler Delhi: A design manual)

TRUWORTH Impex Pvt.Ltd. An Affiliate of RUSTOLEUM Inc., USA	Solargard Roof Coating	22,Sant Bhavan, Above State Bank of Hyderabad, Marve Road,Malad West, MUMBAI - 400 064 Telephone : 022-32510059 Direct & Telefax: 022-28440992	35 to 55 Rs/sqft
JOTUN Paints	Jotashield Thermo	204 & 205, Ascot Centre, Sahar Road Andheri (East), Mumbai 400 099 Phone numbers: +91 22 28224600 +91 22 28205900(+fax) Fax number: +91 22 28205900	
Unnathi Group	Cool Coat	3, 1st Cross, Netaji Circle, Mathikere Ext. Bangalore - 560054, Email: unnathigroups@gmail.com, info@unnathi.com, unnathicare@gmail.com Phone: 080 - 23604570 Mobile : +91 9986004163, +91 9845554959	
D&D Roof Insulations	Durafoil	Naveen Sangari 09899074143	23 to 30 Rs/sqft
Henkel	Polytex	Greentech Engineers 18,Kariyammana Agrahara Belandur Post Bangalore- 37. Ph:+91-80-65308162,65688685 Fax:+91-80-41262824 Cell: (0)9845190272,(0)9886552322	25 to 30 Rs/sqft (including waterproofing and application)
Thermatek	Heat Resistant Terrace Tiles	ISHAAN INDUSTRIES "An Associate of Parashuram Pottery Works Co. Ltd. Gandevi Road, Bilimora - 396 380 Dist. Navsari, Gujarat. Tel: 02634 284416 Mobile: 9426117277 Email: admin@thermatek.co.in	40 Rs/sqft (only tiles, excluding application)

(Source: Cool roofs for cooler Delhi: A design manual)

Ishaan Industries

http://www.thermatek.co.in/

THERMATEK Heat Resistant Terrace Tile is the core of ISHAAN Brand of products. It is our signature product that not only replicates the benefits of conventional cool roofing product but also incorporates new and improved properties and attributes with major advantages for buildings and homes which suffer daily barrages of solar radiation and absorption through roofs.

- Radiant barrier and sunscreen for your roofing system
- High surface reflectivity value
- Low emissivity
- Superior walkability (lower surface temperature)
- Pest and rot resistant
- Highly dense
- Non-porous
- Impervious
- Less stain absorption

All this discussion leads to some expected insights into the advantages of THERMATEK® which are:

- The best means to counteract the deleterious effects of high heat levels
- The push to lower temperature inside home for thermal comfort
- Proven energy efficiency, environmental responsibility, heat resistance, and long term performance
- Savings on cooling costs
- The way to extend the life of roofs, since a cooler roof would tend to undergo less expansion, and thus experience less wear and tear under the sun
- User friendly installation
- Very cost effective over time because it outlasts conventional roofing and requires little maintenance

Pidilite Industries Ltd.

www.pidilite.co.in

Heat shield

Has been specially developed using advanced materials & technology, making it a high quality all purpose heat insulation coating.

Features & Benefits Heat insulation and energy saving coating:

- High solar reflectance
- Excellent UV resistance
- Higher thickness; hence longer life
- Waterproof and breathable
- Non toxic, water based system, thus Eco friendly.
- Corrosion resistant

Technical Information

Color:	White.
Appearance:	Emulsion.
Thermal Conductivity:	0.029 w / m K.
Elongation:	100%i.
Specific Gravity:	1.03
Surface Dry:	30 mins
Coverage:	3 sq.m per litre per coat

Superior Products International Inc.

www.spicoatings.com

HPC™: High Temperature Coating

Get heat protection that surpasses conventional insulation with HPC™ Coating. HPC™ Coating is a ceramic based, water-borne insulating coating designed to insulate in high temperature situations. Use HPC™ Coating as a base coat/primer or build layers for additional protection.

This insulation method is much different than the traditional "wrap" insulation materials that only slow down the loss of heat (known as an R rating or "heat transfer"). The seven ceramic compounds used create a barrier to catch and hold heat on the surface of the unit—be it pipe, furnace surface, boiler, etc. Unlike wraps that use air as the insulation component, the ceramic compounds in HPC™ Coating resist absorbing heat trying to come off the surface to escape. This traps and holds the heat onto the surface for more effective insulation performance.

Benefits of HPC™ Coating:

- Easy to Apply - Apply directly to hot pipes while operating.
- Insulation - Additional coats immediately reduce surface temperature and loss of heat.
- Long Lasting – Does not absorb humidity or lose insulation value with overcoat of Super Therm®
- Safe - HPC™ Coating is non-flammable and non-toxic
- Coverage – Can be sprayed to fit over any configuration or shape.

Thermo Shield India Private Limited

http://www.thermoshield.com/

Thermo-Shield® Roof Coats are highly efficient, energy-saving, flexible coatings, made from a water-based pure acrylic resin system filled with vacuumed sodium borosilicate ceramic micro spheres of less than 100 microns in size. Each micro sphere acts as a sealed cell and the entire mastic acts as a thermally efficient blanket covering the entire structure. These coatings are non-toxic, friendly to the environment, and form a monolithic (seamless) membrane that bridges hairline cracks. They are completely washable and resist many harsh chemicals. Thermo-Shield® Roof Coats have high reflectance and high emittance as well as a very low conductivity value. Thermo-Shield® Roof Coats greatly reduce thermal shock and heat penetration by keeping roof surfaces much cooler in hot summer weather. They offer UV protection and low VOC's. They display excellent dirt pick-up resistance and retain their flexibility after aging. Thermo-Shield® Roof Coats reduce noise transmission and have an effective use range from -40 Deg C (-40 Deg F) to 375 Deg C (700 Deg F).

Thermo-Shield® is a charter member of the U.S. Government Energy Star Roof Program. The U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA) state the following benefits are derived from the use of reflective coatings:

- Reduction of energy use and cooling costs (up to 40%)
- Downsizing of air-conditioning equipment
- Lowering of the surrounding air temperature in a community
- Decreasing of pollution in urban areas

Aesthetic solutions

http://www.indiamart.com/aestheticsolutions/coating-chemicals.html

Reflective Roof Coating

Cool Coat is two component multiple polymeric system especially for Roofs, to bear foot traffic. Our Cool Coat coating is based on IR reflection & nano technology. It is a coating system with outstanding long-term protection and performance characteristics to restore old, drab, faded roofs to an ethnic & aesthetic finish. Our IR reflection coating Cool Coat not only reflects up to 80% of sunlight but also prevents the growth of moss and algae by the use of active Nanotechnology.

Technology - IR reflection technology & nanotechnology contribute to cooling & Water Proofing of roof & buildings.

Application - Our IR reflection coating can be applied on any surface of any material, in direct exposure to sun.

Features: Our IR reflection coating having following features:

- Most economic one time application saves cost for long 10 years.
- The cool solution for global warming
- Conserves energy, reduces temp by 5 - 14 degree Celsius.

- Passive cooling technique.
- Ensure your buildings cool & watertight.
- Keeps environment pollution free.

Specification:

- Reduces Indoor Temperature by up to 120C.
- Air Conditioning Running Cost Reduces by 40%
- Electricity bills are saved by 40%.
- Construction cost & time is reduced by 50%.
- UV resistant for outstanding durability.
- Protects the roof/wall to develop further cracks by controlling temp variance.
- Can be applied on any type of material metal roofs, wood, concrete, RCC, IPC, Bricks, PVC tanks, aluminum, cement tiles.
- Very Effective on Tin sheds/ Asbestos Sheds/Galvanized cement Sheet.
- Can easily bear good foot traffic so more recommended for Residential & Industrial Roof.
- Minimum life of 10 years over other conventional products.
- Antifungal / anti algae/ anti rust /anti dust effects.
- Eco friendly (inert & non toxic). BREATHABLE & washable.
- Stops the leakage of roof, water storage tank, and swimming pools.

Unique Features

- Reflectivity - up to 80%
- Temp difference obtained - up to 140 C
- Conductivity - Reduced by 50%
- Transmittance - Reduced by 70%

How It Works

- IR reflection coating does not absorb NIR radiation.
- IR reflection coating reflects back the SUN rays (NIR).

- The thin layer keeps itself cool
- Cool Coat layer keeps the substrate cool. It helps maintain temperature below the coating & prevents further crack development by reducing rate of expansion & contraction.
- Most imps, the layer stops heat transmittance.
- Testing Report of IR reflection coating reveals
- Solar Reflectance As High As 88%
- Thermal Emittance As High As 89%
- Water proofing increased by 98 %

Area of Application:

- All new constructed plastered Walls, Industrial RCC flat and sloping roofs, Tanks, Industrial Sheds.
- Existing cementations waterproofing treatments like brick-bat-coba, concrete screeds, below China Mosaic/tiles etc.

Cool Coat is applicable for:

- Masonry walls or facades
- Stone walls
- Asbestos
- Below China mosaic tiles
- Sloping roofs.
- Metal roofs
- Syntax Tanks
- Concrete Tanks
- Exterior RCC surface

Ambiancetech

http://www.ambiancetech.com/heat_shield.html

Technical specifications of the product

PHYSICAL PROPERTIES	STATE	ASTM *
Form	Elastomer	
Appearance	Emulsion	
Volume solids	75%	
Color	Bright white	
Sheen	Flat	
Odor	Nil	
Shelf life	Two years	
Abrasion resistance	6000 cycles	
Weight per litre	900 gms.On wet condition	D-1475
Chemical Properties		
VOC – Evaporation	0 Calculated	
Specific gravity	1.2 ρ / ρH2O (3)	
Viscosity	400 – 500 cP	D-562
Mechanical Properties		
Permeability	1.98 Metric perms @1 mm.	E-96

Accelerated Aging	Excellent	
Tensile strengths	3 kg./cm2	D-828
Reflection Properties		
UV Reflection	90 %	C-1549-04, E903-96
Reflective Index	92 @ 700 nm	E-1980-01
Emittance	0.90 - 0.97	E408-71
Convection coefficient	1.2 @ 32ºC	
Drying Properties		D-3468
Surface drying time	@ 30ºC - 1 hr	
Dry time of water resistance	@ 30ºC - 4 hrs.	
Dry film thickness	110 microns @ single coat	

Other Manufactures/Suppliers

- Ameya Dyechem Pvt.Ltd, - Roof shield A-1 Kashivisheshwar Township,jetalpur Road Vadodara http://www.ameyaindia.in/new/pdf/Roof%20Shield.pdf
- Fosroc Chemicals(India) Pvt.Ltd No.10,'Vishnu Chittam',1st Floor and 2nd Floor Sirur Park B Street,Seshadripuram Bangalore
- Birla White (Grasim Industries Limited), Mumbai Ahura Centre,Ground Floor ,Opp MIDC Office,Mahakali Caves Road,Andheri(E) Mumbai www.birlawhite.com
- Ala Inc Aprtment # 3,Door #15 ,1st Cross Street,Raghava reddy Colony,Ashok Nagar Chennai
- Motley Exim Co.- Cool Roof http://www.motleyexim.com/floor-coating.html
- Monier www.monier.in http://www.monier.in/fileadmin/bu-files/in/pdf_files/component_Leaflet.pdf

Appendix C: Description of input variables of Cool Roof Calculator

- **Location:** This depicts the city in which the performance of the roof is being calculated. The appropriate city is to be selected from the dropdown that is displayed for this field. Weather files in .epw format from the EnergyPlus website shall be used for the simulations. (Note: In-case the required city is not specified in the list of the cities; select the closest city or a city with similar climate.)

- **Building type:** There are five building types specified in this drop down. They are:
    - Office: A 8 hours office schedule (9 am – 5pm)
    - Retail: A schedule for 12 hours , from 10 am- 10 pm
    - Institutional: A 15 hour schedule representing the labs and research centres
    - Residential (AC only in night): A typical home with AC running only during the nights
    - Residential (AC all day): As the name suggests, a residence in which the AC is ON throughout the day.

- **Roof area**: For a conditioned building, please input the total roof area over conditioned spaces and for unconditioned building (that is considered for simulation only in the DETAILED FORM), input the total roof area over the occupied spaces.

- **Roof type (SIMPLE FORM)**: The roof construction type of the building is to be selected in this field. There are five roof types specified in the drop down box. All the roofs are of mass construction with varying roof insulation and external finish.

- **Roof type (DETAILED FORM)**: A layer by layer construction can be defined in this roof type of detailed form. A list of various materials is displayed from which the appropriate roof layer can be selected. Further, for a roof with an insulation layer, the R value of the insulation can be defined.

- **Roof external finish (SIMPLE FORM)**: This specifies the roof external finish properties for the normal roof and the cool roof. Solar reflectance, Infrared Emittance and SRI values that are specified along with the material names help you to select the appropriate or the closest material.

- **Roof external finish (DETAILED FORM):** This specifies the roof external finish properties for the normal roof and the proposed case. Solar reflectance, Infrared Emittance that shall be input, defines the roof coating property. Along with the thermal properties of the roof finish, the cost and life of both the normal roof and the proposed case material are to be input in this form. This help in calculating the simple payback of the proposed case cool roof material.

- **HVAC System (SIMPLE FORM)**: For a conditioned building, the HVAC system that has been designed can be selected here. This drop down provides three HVAC system types. They are:
    - Window AC/Split AC
    - Air cooled chilled water system
    - Water cooled chilled water system

  The system that has been considered in the design or the closest map to that system is to be selected.

- **HVAC Details (DETAILED FORM)**: For a conditioned building, the HVAC system that has been designed can be selected here. This drop down provides three HVAC system types and one case with no system, which means an unconditioned building. They HVAC system types are:
    - Window AC/Split AC
    - Air cooled chilled water system
    - Water cooled chilled water system
    - No System : Unconditioned

  The system that has been considered in the design or the closest map to that system is to be selected. If the designed building is an unconditioned building, “Unconditioned: No system” option is to be selected in the dropdown.

  The performance of the selected HVAC system can also be assigned by specifying an appropriate COP (coefficient of performance) value.

- **Internal loads:** Lighting power density and equipment power density are two inputs in this field that define the lighting and equipment wattage. Total lighting wattage and total equipment wattage divided by the area of the conditioned space provides values of LPD and EPD of that conditioned building. For an unconditioned building divide the total wattages' with the total occupied area.

- **Window area**: The area of fenestration on the external wall in all the four orientations is to be specified in these fields.

- **Electricity rate**: Is the cost of electricity in the city that is selected for simulation

Appendix D: Feedback form on Cool Roof Calculator

Cool Roof Calculator
coolroof.cbs.iiit.ac.in

User Feedback form

- Could you navigate through the site easily and locate the calculator?

  ☐ Yes ☐ No

- Do you think the calculator is useful

  ☐ Yes ☐ No

- Is the interface usable to you

  ☐ Yes ☐ No

  If no, which part of the calculator is problematic?
  Comments: ____
  ____
  ____

- Could you figure out the inputs to be provided in simple and detailed forms, are they easily understandable?

  ☐ Yes ☐ No

  If no, what are the variables/inputs that are not clear?
  Comments: ____
  ____
  ____

- Detail of the inputs requested:

  ☐ Good ☐ Satisfactory ☐ Average

- Detail of the outputs generated:

☐ Good ☐ Satisfactory ☐ Average

- Output format:

  ☐ Good ☐ Satisfactory ☐ Average

- Ease of accessibility of the site:

  ☐ Good ☐ Satisfactory ☐ Average

- Availability of information

  ☐ Good ☐ Satisfactory ☐ Average

- Could you calculate the savings through cool roof for a building

  ☐ Yes ☐ No

- How much time it took to fill the form:

  Form type:

  ☐ Simple ☐ Detailed

  Time took to fill the form: ____________________________

- Visual Appeal:

  ☐ Good ☐ Satisfactory ☐ Average

- Overall impression:

  ☐ Good ☐ Satisfactory ☐ Average

- Time you spent on the website: ____