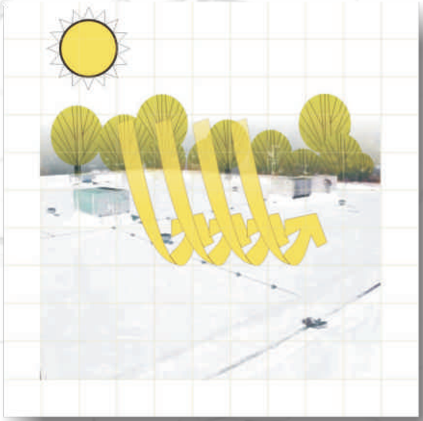
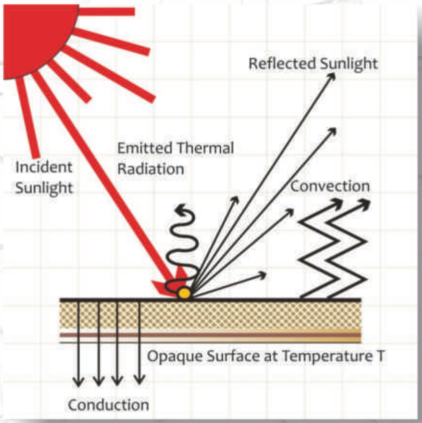
Cool Roofs for Cool Delhi





Chief Minister's Message

Sheila Dikshit
Chief Minister

सत्यमेव जयते

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I am happy that the Bureau of Energy Efficiency has prepared a Design Manual entitled "Cool Roofs for Cool Delhi" which will provide low tech, low cost solutions to citizens of Delhi for cooling their homes and reducing greenhouse gas emissions. Cool Roofs is an innovative effort to reduce cooling costs, energy usage and greenhouse gas emissions by applying reflective, white coating to rooftops, and is one of the quickest and low cost way for reducing our global carbon emissions. The measures suggested in this Manual will provide a solution to urban cities for mitigating greenhouse gas emissions through converted white cool roofs. Delhi can take a lead role in adopting cool roof technology.

I hope that this document will provide a guideline to all citizens of Delhi and will go a long way in combating Climate Change.

Sheila Dikshit
Chief Minister, Delhi

Foreword

The design of the walls and roof of a building are critical both to its visual appeal as well as to its energy consumption. Roofs, which heat up during the day and well into the night, are responsible for about one-fifth of the total heat gain in a building, and consequently their design plays an important role in deciding the air-conditioning requirement for the building.

Cool roofs have the ability to reflect and reject heat because the roofs are prepared with materials which have properties of both high solar reflectance and emittance. Besides reducing cooling load requirements in a building, cool roofs also help in improving occupant comfort level and mitigate the urban heat island effects associated with warm buildings heating up the air around them.

A combination of highly reflective and light coloured and/or vegetative roofs offer a reliable and cost effective measure to cut down upon the heat gain through ceilings during the daytime upto $4^{\circ}C$ thereby reducing the related energy costs. The present manual on Cool Roofs brings out various technical design considerations as applicable for a building located in composite climatic zone of the country.

At the behest of the Hon'ble Chief Minister of Delhi, BEE together with Shakti Sustainable Energy Foundation developed this manual on cool roofs for the composite climatic zone. I am sure that the building owners and users would find this document very useful and that it will assist architects, engineers, building owners and residents to understand the concept and benefits of adopting cool roofs within their buildings.

Dr Ajay Mathur
Director General, BEE

Abstract

This document is a manual on cool roofs that briefly discusses the various technical and design considerations as applicable for a composite climate. The manual addresses architects, engineers, and other building professionals responsible for the performance and construction of buildings. The manual enlists the direct and indirect benefits and energy savings potential of cool roofs. It also discusses various cool roofing materials and their energy performance, application, and maintenance issues. The manual provides a brief summary of available research on cool roofs.

This manual focuses primarily on the light colored reflective roofs, as they are the most viable option for new and existing buildings in Delhi. The focus of the manual is also on the strategy for individual buildings, rather than roads, pavements, and fallow land, which also contribute to the urban heat island effect. The purpose of this document is to assist architects, engineers, building owners, and residents to specify and implement cool roof for their buildings.

Acknowledgments

This document has been produced by Environmental Design Solutions (EDS) for the Bureau of Energy Efficiency (BEE). The Cool Roofs Manual has only been made possible through the efforts of a number of stakeholders and individuals who have staunchly supported the initiative, concept, and production of the document.

First of all we would like to thank Dr Ajay Mathur, Director General (DG), BEE, for his vision of the cool roof initiative and the guidance for the Manual. We are grateful to Mr Sanjay Seth, Energy Economist, BEE, for providing a clear direction for this manual and engaging the stakeholders in the review process. Ms Shabnam Bassi, Energy Engineer, BEE, was immensely helpful in reviewing the document and facilitating the stakeholder review process.

We thank the Lawrence Berkeley National Laboratory (LBNL) team for providing details of cool roof technology and application, and access to the research carried out at the Laboratory. The detailed review by the LBNL team has made this a more concise, technically accurate, and better document. Dr. Tengfang (Tim) Xu made extensive contributions to the development and evolution of this manual – from the first draft stage through the final version – sifting the content as well as the language. Dr Jayant Sathaye provided overall guidance for the tone of the document, supported our efforts through the numerous drafts, and coordinated the review process. We are indebted to Mr Ronnen Levinson for his extensive comments on all aspects of the document – especially the physics of cool roofs. Dr Paul Berdahl provided valuable information on cool roofs maintenance. His specific comments improved the overall accuracy of the document. We also thank Mr DJ Nowak for his insightful observations and comments. Some of the illustrations in this document, though developed internally, are completely based on material and data from LBNL, and in particular, from Mr Ronnen Levinson.

We thank Dr Vishal Garg of International Institute of Information Technology (IIIT) for providing us detailed information on the Case Study (Office Building, Hyderabad) mentioned here. Ms Surekha Tetali of the Building Science Research Centre, IIIT, provided helpful comments to improve the accuracy of the document. Mr Sanjay Prakash of Sanjay Prakash and Associates, provided technical guidance and improved the tone and structure of the document.

Mr Dharmendra, Secretary, Department of Environment, Government of Delhi, reviewed the document and provided valuable information on the current state of green cover in Delhi. Dr Parveen Dhamija and Dr Chandraprakash Gogia, Department of Environment, Government of Delhi, provided immense support and valuable guidance for the project. Ms Mili Mazumdar, , Associate Director, Sustainable Building Science, The Energy and Resources Institute (TERI), reviewed the document and provided critical inputs for making it more appropriate to the regional context. Mr Ravi Kapoor, Senior Pragram Manager, USAID ECO-III Project, reviewed the document – his observations have improved the technical accuracy of the Manual.

Mr Vijay Sehgal, Chief Engineer, ITC Green Center, supported the research and facilitation of the application images used in this document. Mr M Anand, Senior Counsellor, Confederation of Indian Industries – Sohrabji Godrej Green Building Centre (CII-GBC), Hyderabad, graciously agreed to the use of photographs of the CII-GBC 'green roof' for this Manual.

We immensely thank the Shakti Sustainable Energy Foundation / ClimateWorks Foundation team for all their inputs, their keen editing, critical reviews, and constant support. In particular we would like to acknowledge Ms Seema Paul, Ms Tara Parthasarathy, Ms Pallavi Pant, Mr Colin Kelly, and Ms Alpana Jain for their unrelenting efforts.

environmental design solutions

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Contents

List of Abbreviations

ASHRAE American Society of Heating Refrigerating and Air-conditioning Engineers

BIPV Building Integrated Photovoltaics

CRRC Cool Roofs Rating Council

DDA Delhi Development Authority

ECBC Energy Conservation Building Code

GRIHA Green Rating for Integrated Habitat Assessment

IECC International Energy Conservation Code

IIIT International Institute of Information Technology

LBNL Lawrence Berkeley National Laboratory

LEED Leadership in Energy and Environmental Design

PV Photovoltaics

SRI Solar Refelectance Index

TERI The Energy and Resources Institute

UHIE Urban Heat Island Effect

Definitions

Albedo : The ratio of the reflected solar energy to the incoming solar energy (over wavelengths of 0.3 to 2.5 micrometers).

Insolation : The amount of solar radiation that strikes a single location over a given period of time (usually one day) is called insolation.

Solar Absorptance : The ratio of the luminous or radiant flux absorbed by a body to the flux falling on it. Absorptance is sometimes also referred to as absorptivity.

Solar Reflectance : The ratio of the reflected flux to the incident flux.

Solar Reflectance Index : The measure of the ability of a material to reject solar heat, as shown by a small temperature rise.

Thermal Emittance : The ratio of radiation emitted by a surface to the radiation emitted by a black body at the same temperature.

Urban Heat Island Effect : Refers to the higher temperatures experienced in dense urban areas because of heat energy from the sun being absorbed by urban landscape features like paving, streets, parking lots, and buildings.

Section I
How do Cool Roofs Work?

1. Introduction

Anyone who has lived on the uppermost floor of a building in Delhi, or a similar composite climate, may have experienced the discomfort of significantly higher temperatures during the summer months compared to other floors in the building. Many modern buildings in India are constructed of concrete or cinder blocks and are topped with flat, tar-covered roofing. Such surfaces absorb the incident sunlight, transferring it to the interiors of the building. The hot ceiling continues to heat up the space – during the day and well into the night - making the spaces unbearably hot throughout the summer season.

Figure 1, a thermal image[i] of a typical top floor roof on a summer day, clearly shows the large temperature difference between the inside of the roof and other surfaces in the room. While the surrounding spaces are cooler at around 34-36˚C, the ceiling temperature ranges from 39-41˚C. The heavy mass of the concrete roof stores the heat and re-radiates it to the inside. The exposed surface of the roof can get even hotter, with dark surfaces attaining temperatures as high as 80˚C.

At a macro-level, a profusion of hot surfaces results in increased temperatures in an entire urban core. Roofs and other non-reflective, dark, and solid surfaces - like hard paving, concrete terraces, dark horizontal shading elements, roads, parking structures, and even open fallow land - contribute to this warming effect.

This phenomenon, called the urban heat island effect (UHIE), has been well-documented scientifically and can be experienced by anyone traveling from an abundantly planted neighborhood (e.g., Lutyen's Delhi) to a sparsely planted one (e.g., Chandni Chowk). The urban heat island effect is a phenomenon that is characterized by a measured increase in the ambient air temperature in cities compared to their surrounding vegetated and rural areas. Cities can be 1 to 4˚C warmer than surrounding areas.

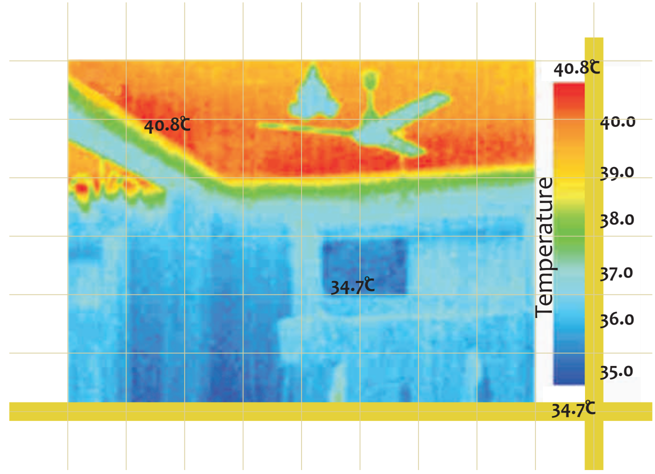


Figure 1 A typical hot ceiling radiating heat inside the space in a residence in Delhi.

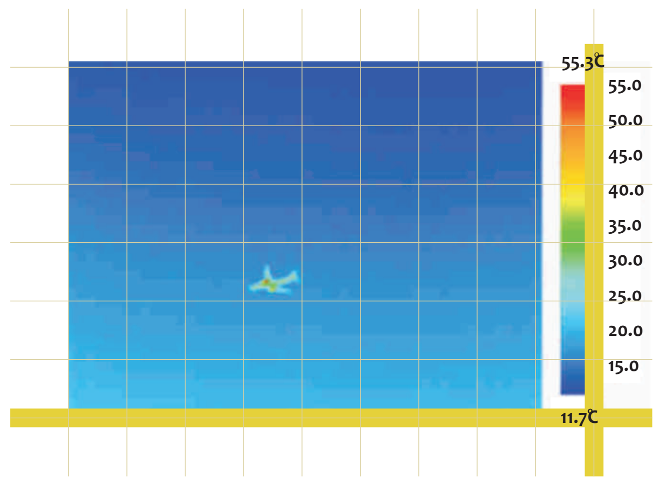


Figure 2 Thermal image of a warm aircraft against a cool sky (Figure courtesy S.M.H. Adil)

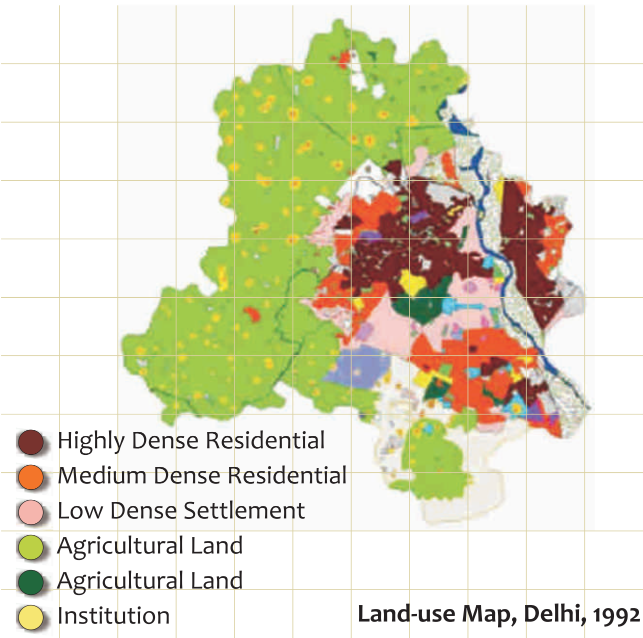
Presently, over 60% of Delhi is built up as residential, commercial, or industrial areas (refer to Table1). A further 10-15% is under roads and other hard paved surfaces, according to data from the Delhi Development Authority (DDA). Given the current spurt in infrastructure growth, new roads, pavements, parking areas, and new residential & commercial areas, the fraction of this hard paved area with non-reflective surfaces is going to increase significantly. Similar growth trends are happening in areas adjoining the city, in the National Capital Region (NCR). This reduction in vegetated area, and the corresponding increase in the dense built-up area will result in more heat radiation being absorbed, and increased incidence of the UHIE, and eventually, an increased demand for air-conditioning.

I thermal imaging involves the use of a special thermal camera, which operates within the thermal infrared spectrum to measure the amount of heat that an object is emitting. in such pictures, temperature is indicated by a colour code, such as dark blue for low temperatures and red for higher temperatures. for example in figure , one can see the hot engine exhaust of a jet, indicated by a warmer red color as opposed to the cooler sky around, indicated by the blue color.

Table1 Current (2010) Land Use Distribution in Percentage, New Delhi

Land Use	% of Land
Residential	45-55
Commercial	3-4
Industrial	4-5
Green/Recreational*	20-21
Public/Semi Public Facilities	8-10
Circulation	10-12

* This does not include green areas under various specific gross land use categories



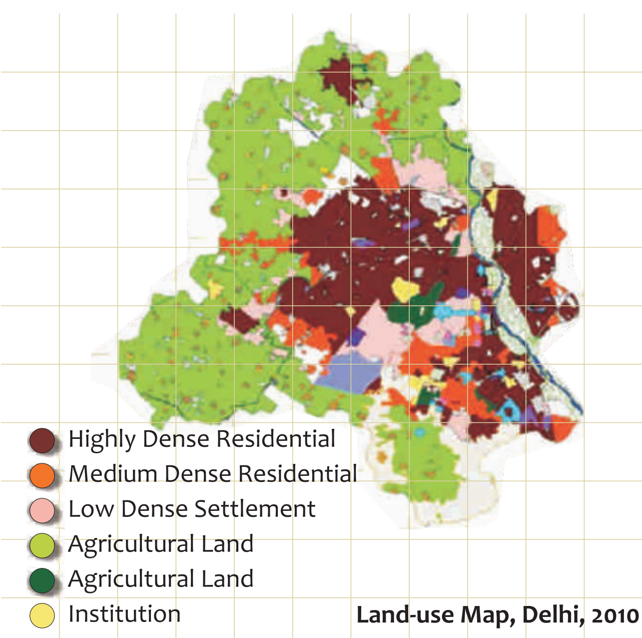


Figure 3 Changes in land use and land cover in Delhi between 1992 and 2004. Agricultural lands, designated in light green, decreased while dense residential areas, in dark red, grew.

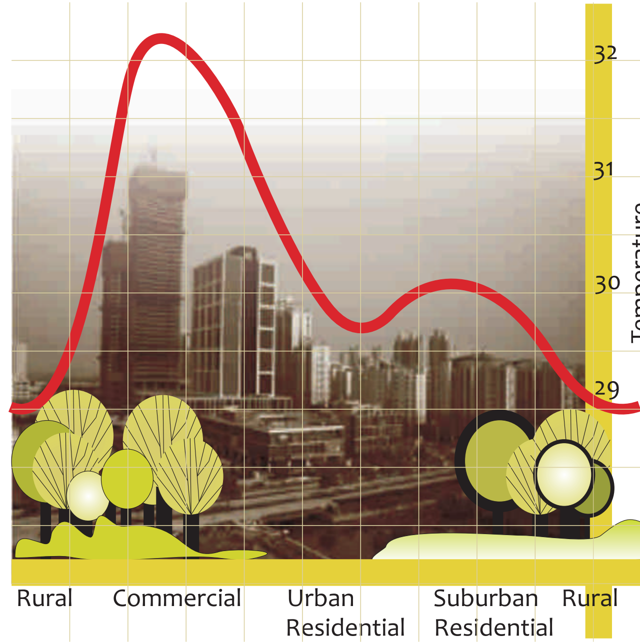


Figure 4 Urban Heat Island Effect
(Figure based on information provided by the Heat Island Group. Retrieved from: *http://eetd.lbl.gov/HeatIsland/HighTemps/)*

While this trend of increased urbanization is inevitable and difficult to contain, a significant part of UHIE can be mitigated with little effort. Some of the key strategies for reducing UHIE are:

1. Expanding and protecting urban tree cover
   a. Planting new trees
   b. Protecting existing green cover
   c. Vegetative Roofing
2. Decreasing roof absorbance
   a. Cool roofing
3. Increasing cool urban surfaces
   a. Increasing pervious paving
   b. Reducing brown (fallow/unused open) land
   c. Increasing light-colored/reflective paving
   d. Increasing water bodies

At an urban, as well as building level, an increase in vegetated areas and water bodies will reduce the impact of the UHIE and increase comfort for the entire microclimate. A combination of highly reflective and light colored roofs and/or vegetative roofs may be used to mitigate UHIE, based on roof location, area, accessibility, and usage.

Increased recognition of the benefits of cool roofing has led to the adoption of cool roof measures in energy codes and the inclusion of cool roofing as part of green building initiatives. Green Rating for Integrated Habitat Assessment (GRIHA), a green building rating program developed by The

Energy and Resources Institute (TERI), and adopted by Ministry of New and Renewable Energy (MNRE), provides credit for cool roofs as a component of their rating system. The LEED® India program of the Indian Green Building Council (IGBC) provides a credit for cool roofs under the Sustainable Sites category (LEED SSc 7.2) in recognition of the importance of urban heat island reduction.

The Energy Conservation Building Code (ECBC) 2007 has a prescriptive requirement for cool roofs (ECBC 4.3.1.1). International energy standards like the International Energy Conservation Code (IECC)[ii] and ASHRAE 90.1-2007 code developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), also credit cool roofs.

ii the 2006 IECC is linked to ashrae standard 90.1 for commercial buildings. it directly offers cool roof credits for residential buildings through performance compliance.

2. What is a cool roof?

A cool roof is one that reflects most of the incident sunlight and efficiently emits some of the absorbed radiation back into the atmosphere, instead of conducting it to the building below. As a result the roof literally stays cooler, with lower surface temperatures, keeping the building at a cooler and more constant temperature. The term, 'cool roof' refers to the outer layer or exterior surface of the roof which acts as the key reflective surface. These roofs have higher solar reflectance than a typical roof surface. The term 'cool roof' encompasses an extensive array of roof types, colors, textures, paints, coatings, and slope applications.

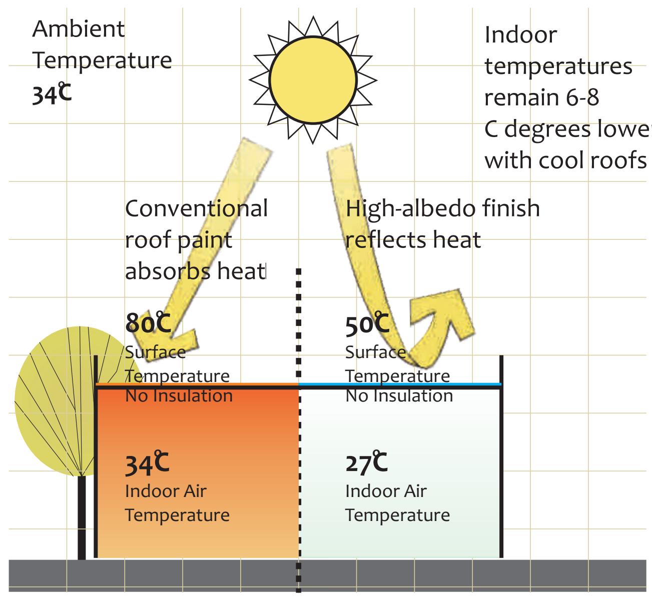


Figure 5 Effect of roof construction on Indoor temperature

Properties of cool roofs

The two primary thermal properties that characterize roofs are solar reflectance and emittance. Surfaces with low solar reflectance, absorb a high fraction of the incoming solar energy. A fraction of this absorbed energy is conducted into ground and buildings, a fraction is convected to the ambient air, and a fraction (termed emissivity) is radiated back to the sky (see Figure 5). For equivalent conditions, the lower the emissivity of a surface, the higher will be its steady-state temperature. Surfaces with low emissivity cannot effectively radiate to the sky and, therefore, get hot.

Solar Reflectance

When solar radiation is incident on an opaque surface, some of the energy is reflected. Solar reflectance is the ratio of solar energy that is reflected by a surface to the total incident solar radiation on that surface. Solar reflectance is measured on a scale from 0 to 1. A reflectance value of 0 indicates that the surface absorbs all incident solar radiation, and a value of 1 denotes a surface that reflects all incident solar radiation. The term 'albedo' is often used inter-changeably with solar reflectance. High albedo or reflective surfaces stay much cooler than low albedo or less reflective surfaces.

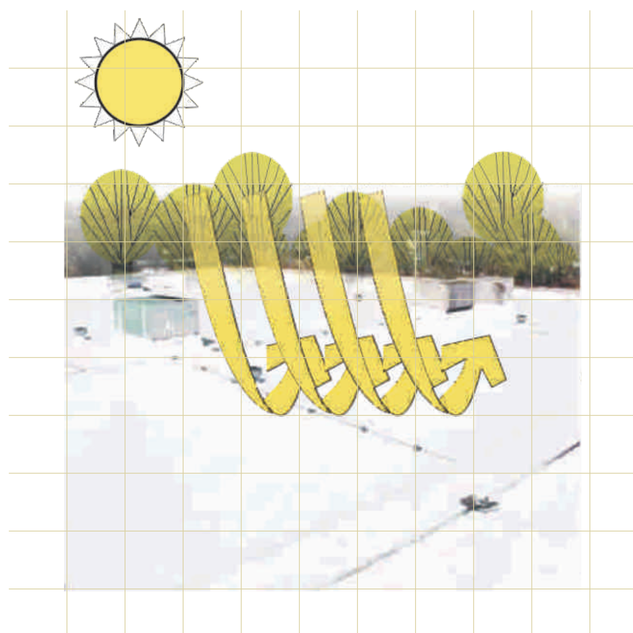


Figure 6 Cool white roof (Source – Cool Roof Rating Council)

Thermal Emittance

Thermal emittance is the relative ability of a material to re-radiate absorbed heat as invisible infrared radiation. Emittance, measured from 0 to 1, is defined relative to a black body with an emittance of 1. Emittance tends to remain constant over the lifetime of a roof.

Energy that is not reflected by the roof is absorbed by it. This absorbed heat will eventually be re-radiated (or lost through conduction) by the roof. A roofing material with higher thermal emittance will re-emit absorbed thermal energy more quickly than a material with a low emittance. A cool roof minimizes the solar heat gain of a building by first reflecting a considerable amount of incoming radiation and then by quickly re-emitting the absorbed portion. As a result, the cool roof stays cooler than a traditional roof of similar construction.

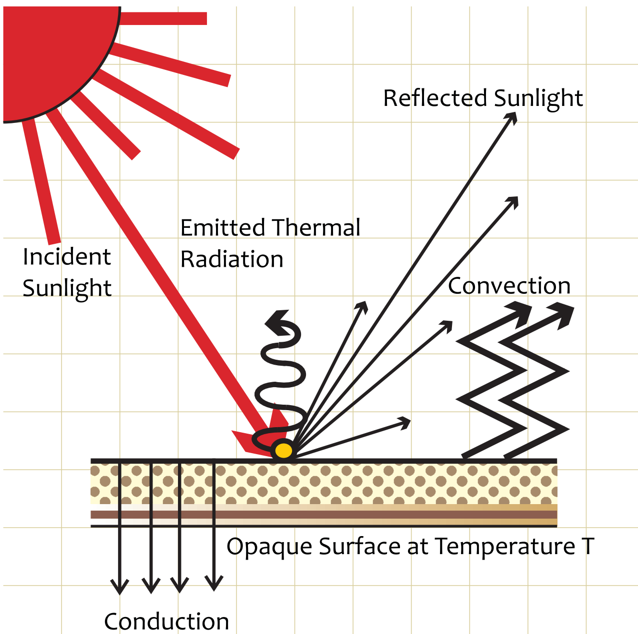


Figure 7 Understanding cool roof and its thermal properties
(Figure based on presentation by Ronnen Levinson, Scientist Heat Island Group, Lawrence Berkeley National Laboratory, EET Division Seminar, June 30 2009).

Solar Reflectance Index (SRI)

Though most roofing materials have a fairly high thermal emittance, in order to accurately determine a roofing product's 'coolness', or its ability to shield the building beneath it from heat, both solar reflectance and thermal emittance must be measured. It is important to note that it is possible for a roofing material to have a very high emittance value and a reflectance value ranging from low to very low, or vice versa, although such materials would typically not be considered cool roofs. A high emittance value alone will not result in a cool roof nor will a high reflectance value alone. The Solar Reflectance Index (SRI), which incorporates both solar reflectance and emittance in a single value, quantifies how hot a surface would get relative to standard black and standard white surfaces.

The Solar Reflective Index (SRI) is a measure of the ability of the constructed surface to reflect solar heat, as shown by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0, and a standard white (reflectance 0.80, emittance 0.90) is 100. Once the maximum temperature rise of a given material has been computed (for example, the standard black has a temperature rise of 50˚C in full sun, and the standard white has a temperature rise of 8.1˚C), the SRI can be computed by interpolating between the values for white and black. Given this definition, it is possible for a material (with both, a high reflectance and a high emittance) to have an SRI greater than 100.

The SRI formula is supported by a significant number of case study analyses by Lawrence Berkeley National Laboratory (LBNL) and is recognized by the industry as an accurate representation of the tradeoff between emittance and reflectance. SRI internalizes an emittance-reflectance tradeoff into a single number simplifying the comparison of roof products.

SRI is calculated according to ASTM E 1980-01. Reflectance is measured according to ASTM E 903, ASTM E 1918, or ASTM C 1549. Emittance is measured according to ASTM E 408 or ASTM C 1371. An easy-to-use SRI calculator developed by Lawrence Berkeley National Laboratory requires the solar reflectance and thermal emittance values to calculate SRI.

According to ECBC cool roof requirement, roofs with slopes less than 20 degrees slope shall have a initial solar reflectance of at least 0.7 and an emittance of 0.75 . ASHRAE 90.1 defines Cool roofs as having a minimum solar reflectance of 0.70 and a minimum thermal emittance of 0.75. The 2007 version of ASHRAE 90.1 adds an alternative of achieving a minimum SRI of 82.

www.coolcolors.lbl.gov/assets/docs/SRI%20Calculator/SRI-calc10.xls

3. Benefits of Cool Roofs

Cool roofs provide numerous benefits at the micro level as well as the community level. Cool roofs conserve energy and enhance thermal comfort because the interior of a building is subject to less thermal flux. They assist in mitigating the urban heat island effect, and when installed comprehensively, can result in lowered ambient air temperatures on an urban scale.

Building Level Benefits

Cool roofs reduce both the energy use and energy demand of a building.

During the cooling season, cool roofs reduce heat conduction through the roof during the day, and hence reduce air-conditioning energy use. During sunny cold winter days, however, cool roofs may cause a marginal increase in heating energy consumption. In Delhi and other composite climate zones, potential heating penalties are a small fraction of cooling-energy savings due to the long cooling seasons and short heating seasons. Moreover, buildings require cooling during the summer season, especially during daytime when the incident solar radiation is intense (and therefore when cool roofs are most effective), while heating is needed during the early morning hours during winters when there is little or no solar radiation present (and therefore when cool roofs are marginally effective or ineffective). Thus, cool roofs are very effective in reducing the summer electricity use with minimal impact on winter heating. In general, savings in annual net utility costs can be expected for most buildings.

Most HVAC systems are designed to meet the cooling loads during peak summer conditions. Cool roofs reduce the peak cooling load and consequently, the system size required to meet this load. As a major portion of the energy savings due to cool roofs is realized during peak hours (when the electricity demand is the highest), its application assumes even more significance as a tool to reduce energy demand.

Research has shown that cool roofs also help increase the life expectancy of roofing systems because extreme cycles of heating and cooling tend to wear out materials as they expand and contract with the temperature. Cool roofs on the other hand, keep the roof a more constant temperature and therefore, tend to last longer.

Neighborhood and City Level Benefits

By reflecting the incident solar radiation back into the atmosphere and reemitting the absorbed portion of the incident radiation as infrared radiation, cool roofs result in cooler air temperatures for the surrounding urban environment during hot summer months. With lower daytime ambient temperatures, buildings and vehicles are confronted by a smaller temperature differential – leading to additional energy savings and subsequently a reduction in harmful emissions from power plants.

While reducing ambient air temperatures, cool roofs also improve air quality by curtailing or eliminating smog formation. Smog is created by photochemical reactions of air pollutants - higher temperatures provide impetus to these reactions. Improved air quality also results in a reduction in heat-related and smog-related health issues, including heat stroke and asthma.

“A Lawrence Berkeley National Laboratory study found that world-wide reflective roofing will produce a global cooling effect equivalent to offsetting 24 gigatons of CO_2 over the lifetime of the roofs. This equates to $600 billion in energy savings.” The study recommends cool roofs as a geo-engineering mechanism to counteract climate change.

Section II
How to Apply Cool Roofs?

4. Cool Roof Materials & Technologies

Cool roofs can be selected from a wide variety of materials and colors, 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. However, the extent of the benefits will correlate to the location of the building (i.e., climate), type and use, as well as to the specific thermal properties of the selected roofing product. For new buildings, the incremental cost of adding cool roofs is minimal, or, at times, none. For existing buildings too, the additional expenses may be insignificant if the retrofit is properly integrated with the re-roofing schedule. Conventional materials for standard roofing are now available with their cool roof counterparts. Table 2 lists the SRI for common roofing materials. White roofs are characterized by a high SRI.

Table 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.

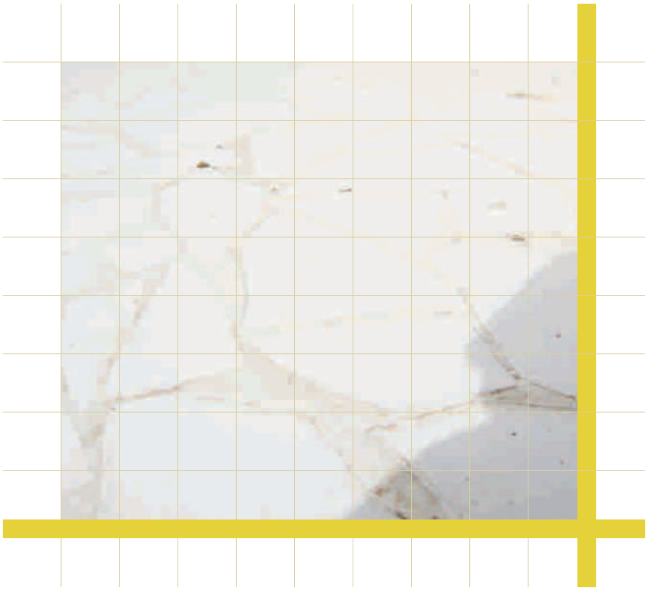


Figure 8 *Broken china mosaic tiles*

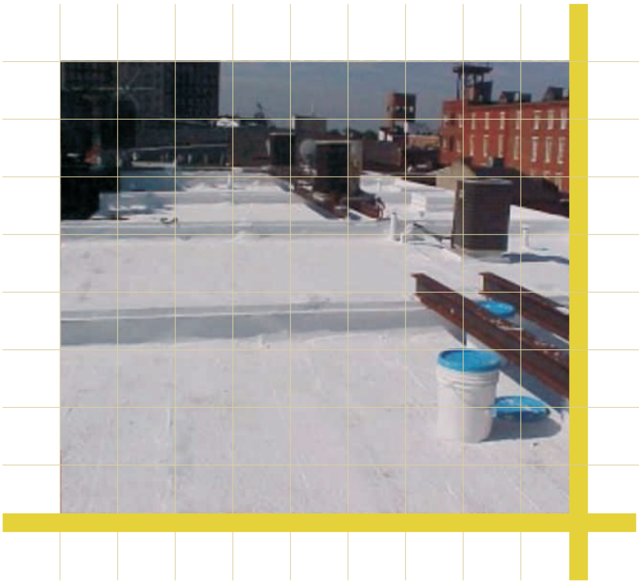


Figure 9 *Lime-washed roof*

Types of Cool Roofs

Roof Coatings

Roof coatings can be divided into two categories: field-applied and factory-applied. Field-applied coatings are applied directly onto the roof surface, either on a new roof assembly or over an existing roof surface and may require an appropriate primer. Factory-applied coatings are applied directly to products at the factory prior to distribution. Examples of factory-applied coatings include coatings applied to metal, and glazes that are applied to tiles.

Specialized white elastomeric coatings are available for low-sloped products and cool color polymer coatings are available for tiles – these can be sprayed on existing roofs.

The white pigment in coatings is typically titanium dioxide. Once applied, the coating is what determines the reflective properties of the roofing product.

Broken China Mosaic Terracing

Well-graded broken pieces of glossy glazed tiles provide an inexpensive and conducive cool roofing option. Broken pieces of glazed tiles (preferably white) are embedded in wet mortar to provide a smooth surface that does not undulate. The joints are then grouted using cement mortar with waterproofing material.

Modified Bitumen

Modified bitumen is bitumen (asphalt or tar) modified with plastic and layered with reinforcing materials then topped with a surfacing material. The radiative properties of modified bitumen are determined by the surfacing material, so a cool modified bitumen product will be finished off with a capsheet or coating to achieve a high solar reflectance.

Reinforced Cement Concrete (RCC)

The ubiquitous roofing solution for Delhi, RCC roof is extensively used in both residential and commercial buildings, and for low- and high-rise structures. These roofs may be topped with elastomeric cool roof coatings or simply finished with broken white glazed tiles.

Slate or Tile

These roofing products are commonly used for residential buildings, or steeper-sloped buildings, and increasingly, for commercial buildings. Slate and tile products are available with solar-reflective surfaces that offer a wide range of cool colors. Additionally, the dense, earthen composition of slate and tile products provides increased thermal mass, yielding additional energy savings not realized through solar reflectance and thermal emittance measures alone. Concrete and clay tiles may be obtained in white, increasing the solar reflectance to about 70 percent (compared to the 20-30 percent range for red tile).

Metal

These roof systems typically are available in white, which raises their solar reflectance to about 65 percent. Unpainted metal should be covered with a white coating to increase its emittance. Metal roofing products can be shaped to look like tiles, or to fit unique curvatures, in addition to a typical standing seam configuration. They come in a variety of factory-applied textures and colors, including darker cool colors with infrared reflective pigments. Metal products can also be coated in cool custom colors to meet a variety of client preferences.

Cool Colours

Technology has enabled the increase of the reflectance of a material by selectively increasing reflectance of non-visible radiation, without altering the reflectance of the visible part of the spectrum (see Figure 10). It is now possible that two identical looking products may vary significantly in terms of thermal reflectance (see Figure 11).

'Cool color' roofing materials are created by integrating pigments that reflect infrared energy, even though their color may still absorb some of the visible spectrum. In this way, roofing products can be both 'cool' and dark colored. This type of infrared reflective pigment has been used in conjunction with a variety of product types, including metal, tile, and coatings, thus broadening the scope of cool roof applicability. While the energy savings of a dark colored cool roof will not be equivalent to that of a white or lighter colored roof, it will deliver more energy savings than its traditional non-cool counterpart.

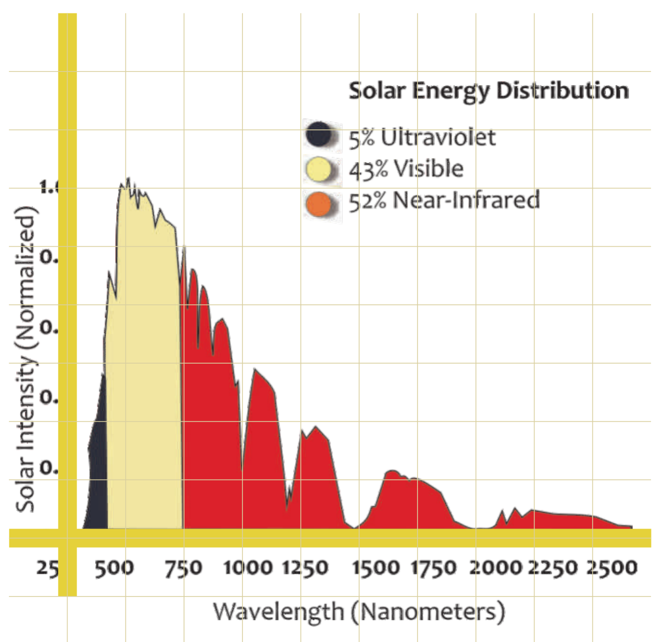


Figure 10 *Graph illustrating that near infrared radiation makes up a large portion of the solar spectrum*

(*Figure based on presentation by Ronnen Levinson, Scientist, Heat Island Group, Lawrence Berkeley National Laboratory, EET Division Seminar, June 30 2009.*)

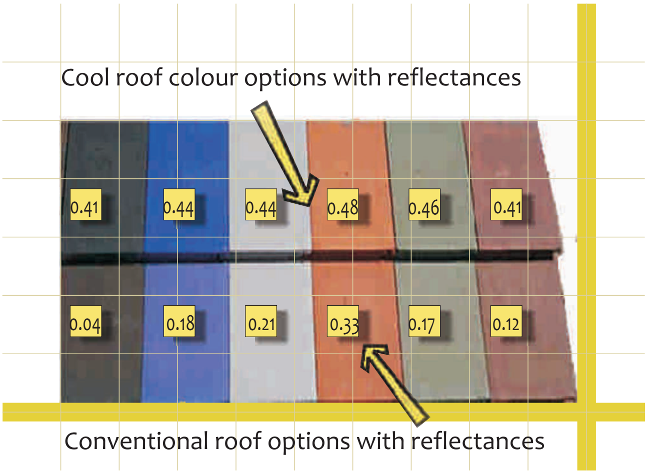


Figure 11 *Cool roof options with corresponding conventional roofing (Figure based on presentation by Ronnen Levinson, Scientist, Heat Island Group, Lawrence Berkeley National Laboratory, EET Division Seminar, June 30 2009.)*

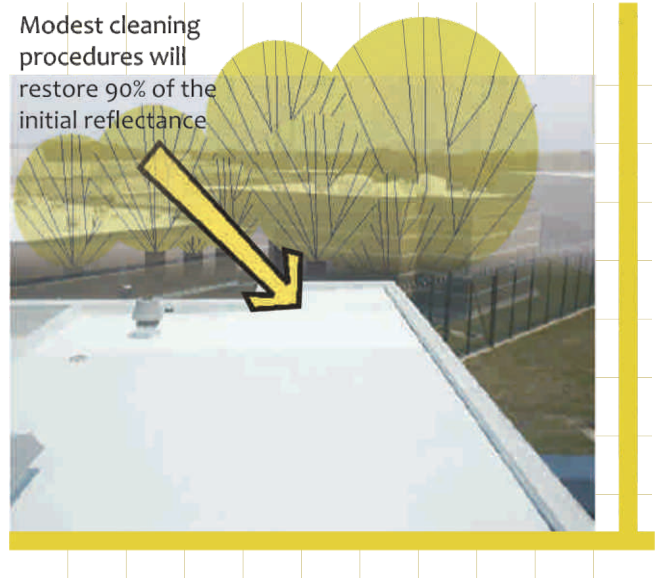
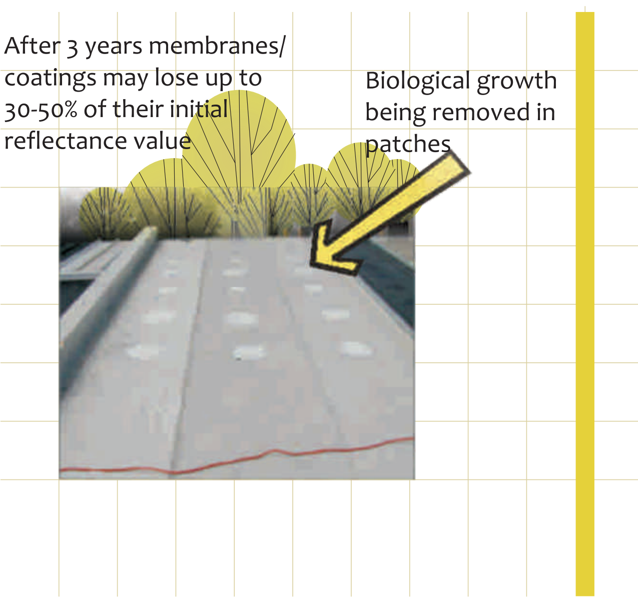


Figure 12 *Cool roof coatings/membranes must be regularly cleaned to prevent biological growth and dirt collection*

Aging and Maintenance

Roofs are exposed to fluctuating weather conditions, solar radiation, and pollution. This may lower the solar reflectance of cool roofing materials.

Studies have indicated that roof surfaces with undulations and low-slopes are more susceptible to lowered reflectivity due dirt accumulation compared to surfaces that are smooth and have high gradients.



Owing to their smooth surfaces, metal, concrete, and clay roof tiles should have less than 20 percent degradation. Specialized cool roof coatings tend to self-clean with sun, rain, and proper drainage and extend service life of underlying roof membrane, but may require re-coating approximately every 5 to 10 years, depending on warranty. The building owner should require a warranty stating that after five years the cool material will remain in place and retain at least 70 percent of its initial reflectivity. Standard maintenance practices as suggested by the roofing manufacturer will keep the cool roof 'cool' for a longer time. It should be ensured that coatings are compatible with the surfaces of roof systems.

5. Cool Roof Coating:Site Application

An office building in Delhi is currently the site for testing the outcome of applying various cool roofing options to a concrete roof. High-albedo paint, glazed tiles, and lime coating have been applied as distinct patches on the roof surface.

A set of data loggers will record the surface temperature of these patches through the summer months. Later, the accumulated data will be analyzed to study and quantify the effectiveness of the reflective coatings. The application procedures outlined in the following figures have been documented at this site.

While application procedures prescribed by the manufacturer may vary from product to product, some processes of cool roof application must always be adhered to:

1. The surface must be properly swept, cleaned and prepared.
2. All cracks and joints on the surface must be reinforced with caulk and polyester fabric strips. All cracks and joints on the surface must be reinforced with caulk and polyester fabric strips.
3. The coating must be applied through an airless sprayer or roller at a rate (or to a thickness) specified by the manufacturer
4. The second coat must be applied after the first coat is totally dry to the touch.
5. Do not apply the cool roof coatings if precipitation is imminent, or likely to occur before all coats are expected to be completely dry.

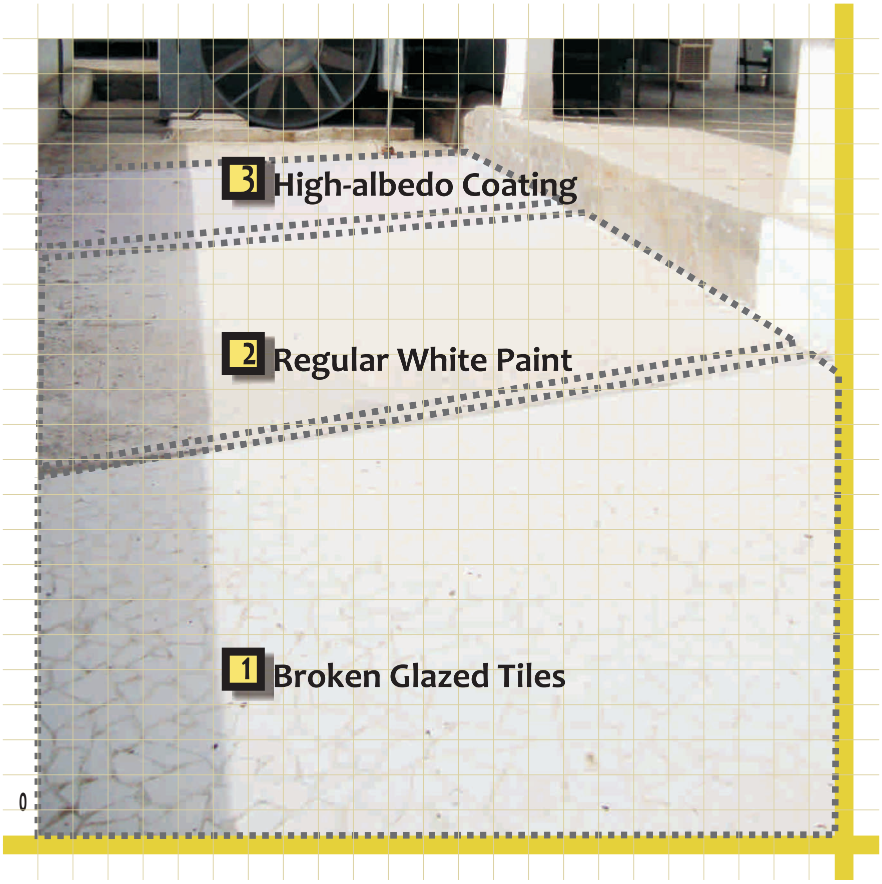


Figure 13 *Photograph showing the layout of various cool roofing options as patches on a concrete roof surface in an office building in Delhi.*

Roof surface ready for the application of broken glazed tiles

Mortar bed being prepared to lay the tiles

Tiles being embedded in the cement-sand mortar

Tiles being set to the same plane

The gaps are filled with white cement slurry

Roof surface with a freshly-set glazed tiles

Figure 14 Broken glazed tiles being set on a roof surface to increase its reflectance

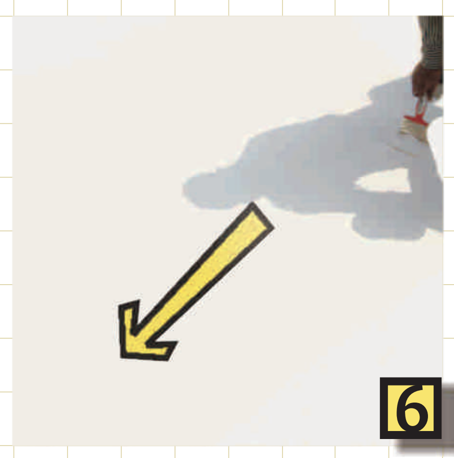
Roof surface ready for the application of cool roof layer

Roof surface being cleaned for application of primer

Primer for elastomeric high-albedo paint

Application of primer at the seams

First coating of elastomeric high-albedo paint



Second coating being applied

Figure 15 Application of cool roof paint to a roof surface that is new or does not need any repairs

Tools for repairing existing roof surface

Blisters on existing roof surface

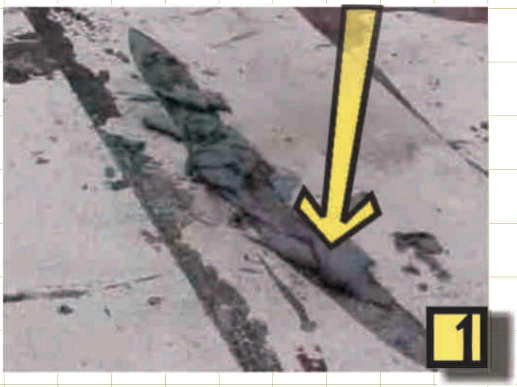
Blisters on existing roof surface

Removing existing reflective coating of roof surface

Peels of reflective coating that have just been removed from the roof surface

Roof surface ready for new coating

Figure 16 An existing cool roof coating being thoroughly removed before applying a new layer of high-albedo paint



Blisters on existing roof surface

Blisters being repaired

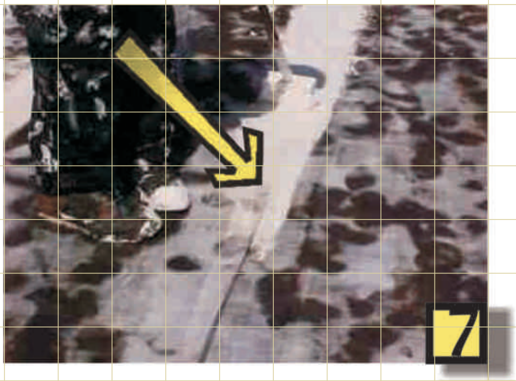
Mesh being laid

Blistered area now ready for cool roof coating application

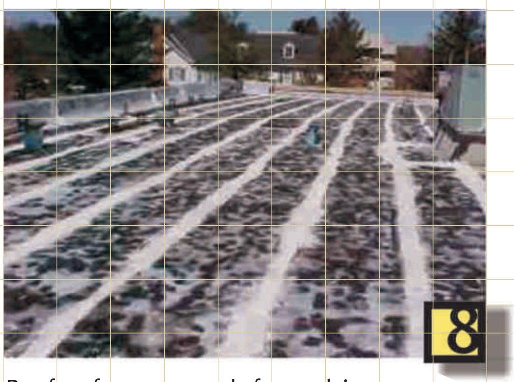
Acrylic seaming of mesh

Acrylic seaming of mesh

Figure 17 Application of cool roof paint to an existing roof surface that needs repairs - I (Source: www.coolroofcontractor.com)



The overlap being brushed into the under-strip with acrylic



Roof surface now ready for applying elastomeric cool roof coating

Edges being sealed with acrylic seaming

End of first cool roof coating

Second coating of cool roof paint

End of final coating

Figure 18 Application of cool roof paint to an existing roof surface that needs repairs - II

(Source: www.coolroofcontractor.com)

6. Case Study:Office Buildings Hyderabad

A demonstration to quantify and record the benefits of cool roofs was conducted at two office buildings in Hyderabad. The study team included the International Institute of Information Technology (IIIT) led by Dr Vishal Garg, and Lawrence Berkeley National Laboratory (LBNL - comprising of Dr Hashem Akbari, Dr Jayant Sathaye, Mr Craig Wray , Dr Tengfang Xu, and Dr Haider Taha), supported by USAID (United States Agency for International Development) and SPM Thermoshield.

Building Parameters

The complex houses two near-identical buildings – this facilitated the study through ensuring identical parametric values for floor area, number of floors, roofing material and system, occupancy and schedules, and cooling systems. This is a two-storey building with a roof area of 700m^2. The roof of one building was coloured black while a white reflective cool roof coating was applied to the roof of the other building.

Monitored Data

Weather towers, temperature sensors, current transducers, and data-loggers continuously monitored the weather, energy-use, and temperature data for the two buildings. The data points monitored weather conditions, building temperatures, and energy use:

Weather
- Outdoor temperature
- Relative humidity

Energy Use
- Whole building electricity use
- Cooling energy use

Building temperatures
- Surface temperature (see Figure 22)
- Heat flux through roof (see Figure 23)
- Roof underside temperature
- Indoor air temperature

Conclusion

The average summertime daily roof surface temperature was reduced by 20 C degrees (Figure 22). Cooling energy savings due to cool roofing (from gray concrete to white roof coating) can vary largely, for example, ranging from approximately 15% to 20% during hot summer days (Figure 23).

Figure 19 *Office Building, Hyderabad*

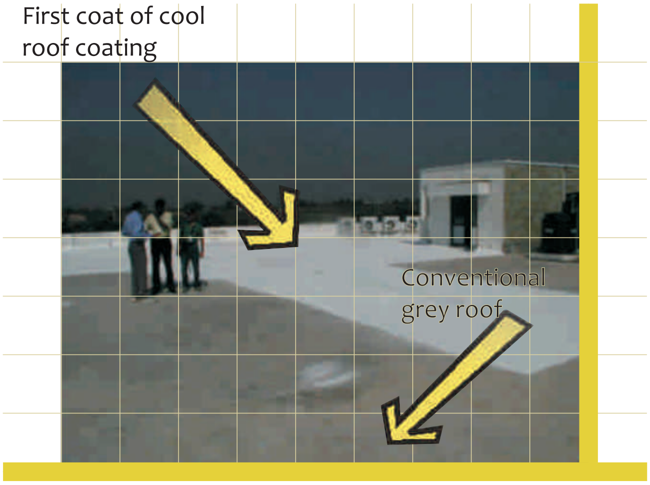


Figure 20 *The first coat of cool roof coating is being applied to a grey surface*

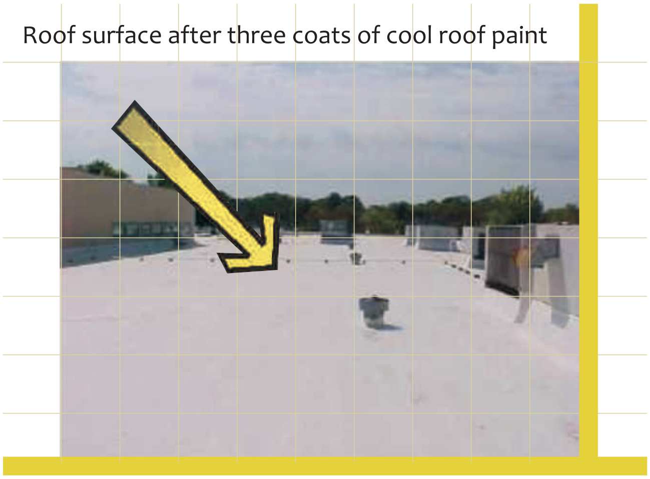


Figure 21 *Roof surface after application of the third coat of cool roof paint*

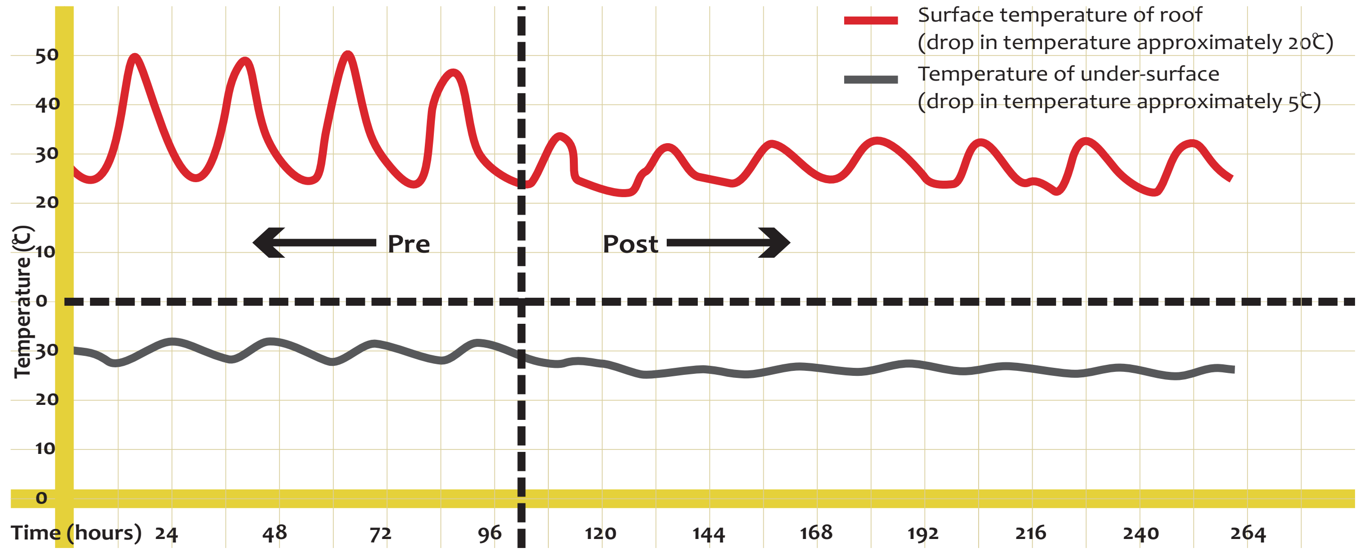


Figure 22 ***Comparison of surface and under-surface temperatures of roof assembly before and after the application of cool roof coating***

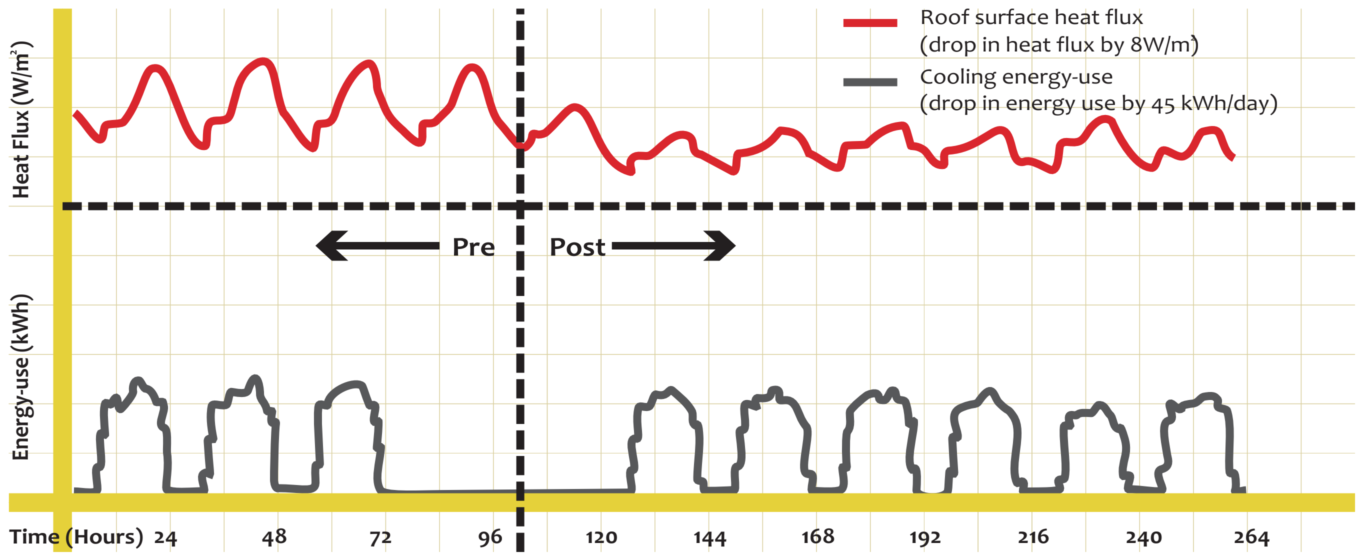


Figure 23 Graph illustrating drop in heat flux and cooling energy-use after the application of cool roof coating

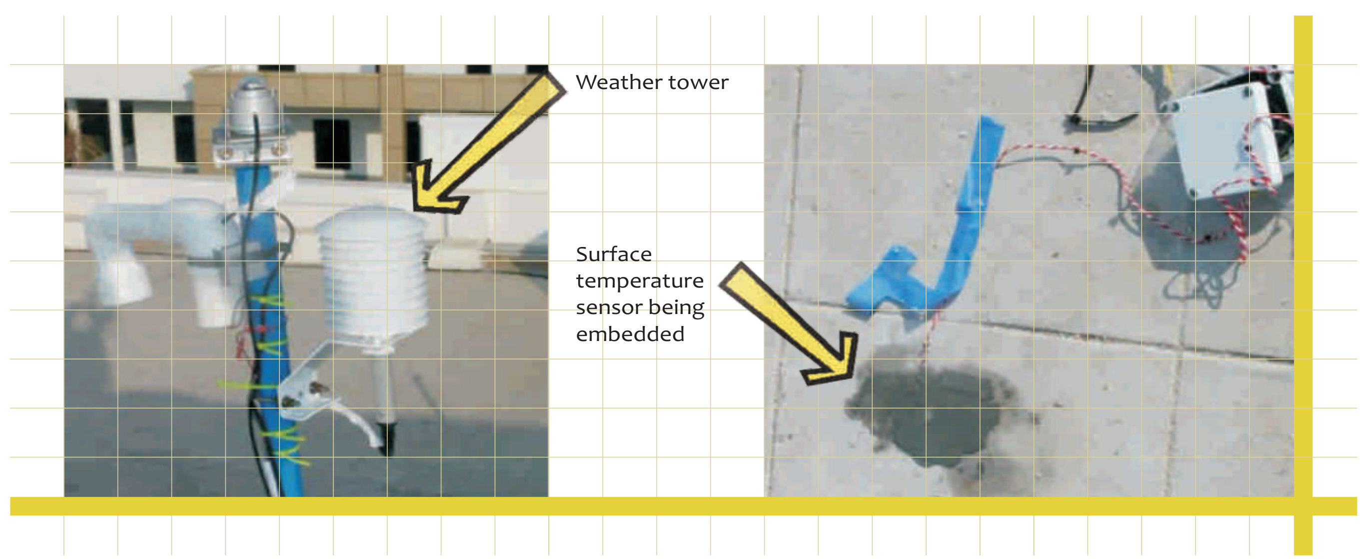


Figure 24 Weather tower and surface temperature sensors being installed on the roof surface

7. Other Strategies for Reducing Heat Influx through Roofs

A cool roof should be chosen based on the slope of the roof, energy savings goals, the project location and climate, local code requirement or green building credits, as well as aesthetic preferences. Designers who are seeking sustainable design credits may also want to consider the cradle-to-cradle aspects of their materials choices, including recycled content, end of life recyclability, and use of toxic materials.

Moreover, the flow of heat from the roof to the conditioned space within a building may be reduced through additional measures like roof insulation, vegetative roofs, and solar panels.

Roof insulation impedes the flow of heat between the roof and the conditioned space, slowing both heating of the building when the roof is warmer than the inside air, and cooling of the building when the roof is cooler than the inside air. Roof insulation is a very effective cooling strategy for conditioned spaces. However, very often, internally generated heat (through people, lighting, and equipment/appliances) may get trapped in an unconditioned insulated building.

Vegetative roofs (also referred to as green roofs), and solar panels installed on roof-tops are very effective in reducing heat transfers through roofs of building and lowering indoor temperatures.

Vegetative Roofs

The process of building construction may involve destruction of green cover. Vegetative roofs, or rooftops with green cover, replace this destroyed vegetated footprint. Vegetative roof systems typically comprise of a lightweight growing medium, plants, and a root repellant layer in addition to the regular components of a roof. The additional components and thickness of the growing medium provides thermal insulation, while the green cover lowers ambient temperatures through evapo-transpiration. However, green roofs may require regular maintenance and involve high first costs.

There are three distinct types of green roofs - intensive, extensive, and modular block.

Intensive vegetative roof systems feel and function like gardens – and may be accessible as parks or as a building amenity. Such systems add a considerable load to the structure of the roof requiring a minimum soil depth of 300 mm. Small trees, shrubs, and other landscape features may add up to an additional load of 400 to 750 kg/m^2 for the building. Such systems are employed for their environmental benefits as well as aesthetic appeal.

Extensive roof systems are primarily built for environmental benefits. They require a soil depth of 25 to 125 mm and may contain a modest green cover comprising of succulents, thick grasses, and hardy plants that are drought-resistant. Additional loads to a building are between 75 and 250 kg/m^2 for the extensive system.

The modular block system is made up of portable units are arranged on a rooftop. The blocks are self-contained, and are typically made of a heavy gauge metal with 100 mm soil depth and a low-growing plant species. A sheet or pad fastened to the underside of the container regulates the flow of water from the unit. Such systems weigh 60 to 90 kg/ m^2.

Benefits

As mentioned already, vegetative roofs 'reclaim' green cover destroyed during the construction process. Establishing plant material on rooftops provide numerous ecological and economic benefits including efficient stormwater management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, and as importantly -- providing a more aesthetically pleasing environment to work and live.

Urban areas are witnessing a rapid increase in impervious surface areas as more and more green covers are destroyed to make way for buildings, pavings, and roadways. Re-introducing a pervious surface that can regulate the stormwater runoff is one of the primary benefits of green roofs. Rapid runoff from roof surfaces is contributing to instances of flooding, erosion. Green roof systems efficiently regulate this runoff and have been shown to initially retain 60-100% of the stormwater they receive – eventually releasing it to the atmosphere.

Figure 25 Green Vegetative Roof – Intensive Roof System

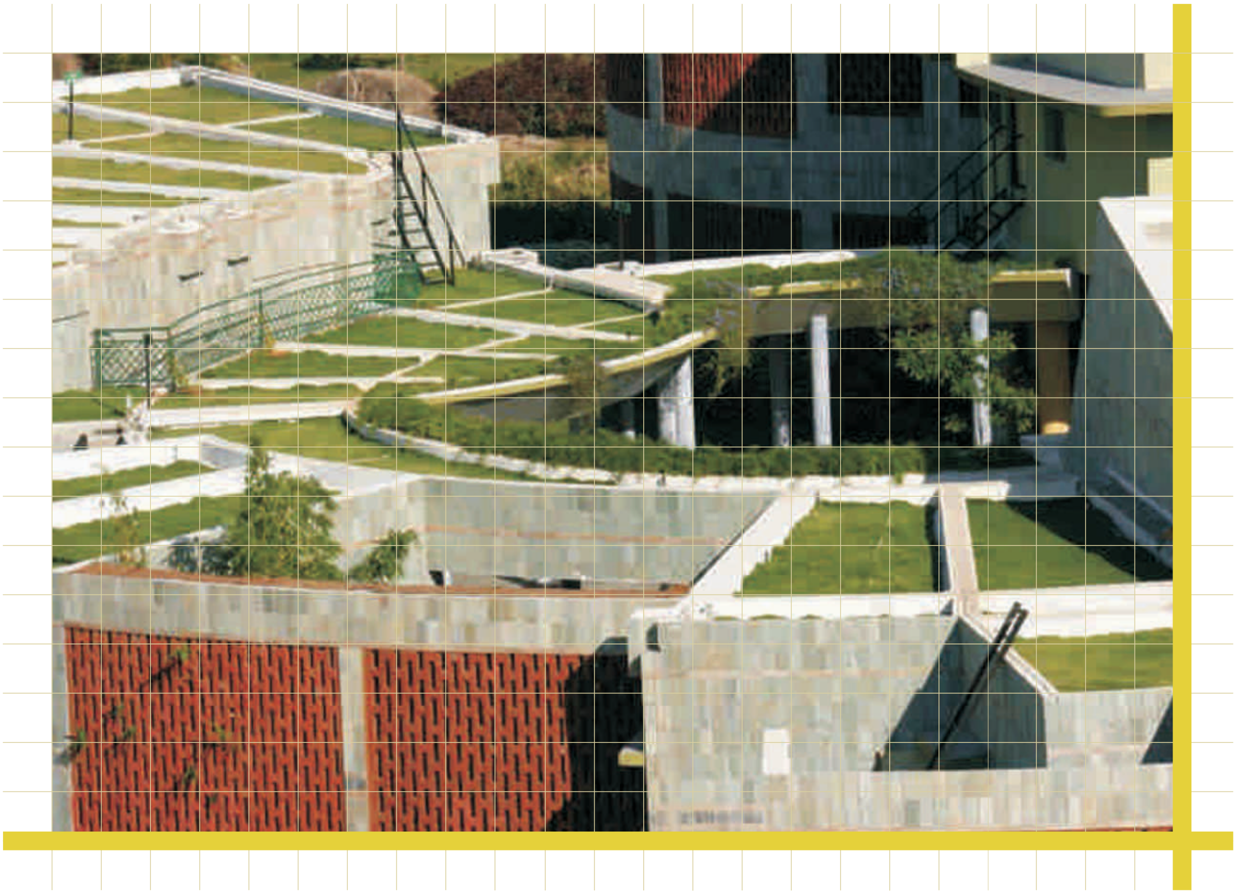


Figure 26 Green Vegetative Roof – Modular Block Roof System (Figure courtesy of CII Green Building Centre, Hyderabad)

Solar Panels

Solar panels harness the energy of the sun through thermal collectors or photovoltaic modules. Such panels produce hot water or electricity while shading the roof. Solar panels are relevant to almost all climatic types, use an abundantly available fuel, and are easy to install.

Solar Collectors

Solar collectors are extensively used for domestic water heating. The most commonly used collector is the flat-plate collector. It is an insulated, weatherproofed box, made of metal or plastic, containing a dark absorber plate beneath a translucent cover (typically tempered, low-iron glass). Copper piping carrying heat exchange fluid travels in an S-shaped pattern between the absorber plate and translucent cover. A collector works on the principle of greenhouse effect[iii].

A mounting area of 5-10 m^2 will be required for meeting the Domestic Hot Water requirements of a 150m^2 home. Collectors may be installed flush with a south-facing roof or rack mounted.

Photovoltaic Modules

Photovoltaic (PV) panels are made of arrays of solar cells that convert solar energy into electricity. Solar cells are made of semiconducting materials. The incident solar radiation on such materials, 'knocks' electrons loose from their atoms – thereby producing electricity[iv]. An array with a solar cell surface area of 1 m^2 is likely to have a power rating in the range of 60-70 W. PV panels may be pole mounted on rooftops.

A relatively recent innovation in the application of PVs for building use is the Building Integrated Photovoltaic (BIPV). This technology integrates the PV solar cells and the roofing material into one product. It is now possible to purchase interlocking concrete tiles, slates, or shingles – with built-in solar cells and plug-in connectors that can simply be wired together during installation.

Benefits

Few power-generation technologies have as little impact on the environment as photovoltaics. Silently producing electricity from light, PVs produce no hazardous waste or air pollution. It does not rely on combustion of fossil fuels – instead using the 'cleanest' and most abundantly available fuel – sunlight.

When installed as pole- or rack-mounted panels, roof-mounted PVs and solar collectors shade the roof below, lowering the surface temperature of the roof.

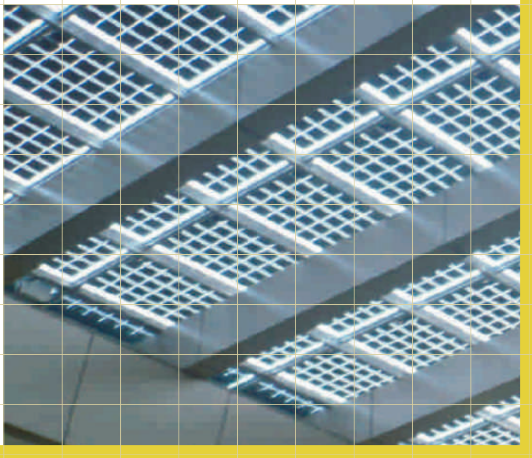


Figure 27 *Ceiling with Building Integrated Solar Panels*

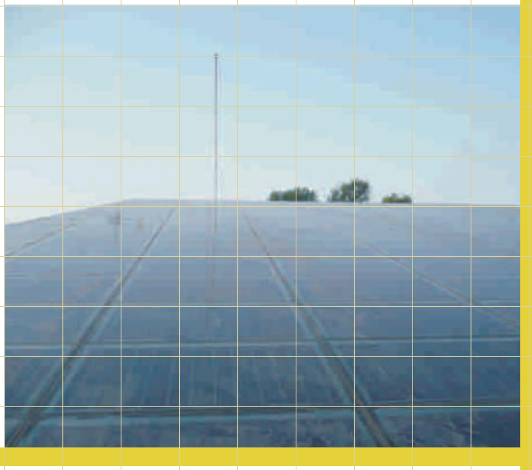


Figure 28 *Roof with solar panels*

iii the greenhouse effect refers to the phenomenon where short wavelengths that form the visible part of the solar spectrum pass through a transparent or translucent medium. this incident energy is absorbed by the medium and re-radiated as infrared radiation. the longer wavelengths of the infrared radiation get 'trapped' by the medium as heat.

iv the process of converting photons (light) to voltage (electricity) is called the photovoltaic effect.

8. Cool Roof FAQ

What is a cool roof?

Cool roofs are highly reflective and emissive materials that stay 25-35 Centigrade degrees cooler in the summer -- thereby reducing energy costs, improving occupant comfort, cutting maintenance costs, increasing the life of the roof, and contributing to the reduction of urban heat islands and associated smog.

How cool is a cool roof?

During the summer, a typical dark roof is 80-100˚C at peak, while cool roofs peak at 37 to 50˚C.

What happens to sunlight reflected from a cool roof?

On a clear day about 80% of sunlight reflected from a horizontal roof will pass into space without warming the atmosphere or returning to Earth.

Can I paint my roof white or a cool color?

There are specialized white elastomeric coatings available for low-sloped products and cool color polymer coatings available for tiles that can be sprayed on existing roofs. However, white roofs will typically perform better than their cool color counterparts (see Table).

Do cool roofs stay cool?

The solar reflectance of cool roofs does decrease over time, primarily due to factors like dust accumulation and microbial growths. These factors can may also increase the thermal emittance of certain materials, like metals. Counter-processes like wind and rain may periodically 'wash' or clean the surface. Eventually an equilibrium will be established amidst all such processes effecting the solar reflectance and thermal emittance of a cool roof. Steady state values for these two parameters are reached within a couple of years. Stable values for solar reflectance and thermal emittance may be obtained after three years of installation through measurements on site.

Are green roofs cool? What about thermally massive, super-insulated, and/or ventilated roofs?

There are a variety of roofing assembly technologies that can reduce the flow of heat into a building, including but not limited to solar-reflective, thermally emissive surfaces; vegetative cover (green roofing); thermally massive construction; super-insulation; and ventilation.

We reserve the term “cool roof” to refer to one that stays cool in the sun by virtue of high solar reflectance and (preferably) high thermal emittance.

Would it be possible to reduce the impact of the greenhouse effect by painting roofs of buildings white to reflect sunlight in the same way the polar icecaps do? Does a paint exist that would mimic the reflective properties of snow?

Painting roofs white would reflect more sunlight and it might also compensate for global warming. The Global Rural Urban Mapping Project (GRUMP), undertaken by the Earth Institute at Columbia University in New York, shows that roughly 3 per cent of the Earth's land surface is covered with buildings.

The Earth has an albedo of 0.29, meaning that it reflects 29 per cent of the sunlight that falls upon it. With an albedo of 0.1, urban areas absorb more sunlight than the global average. Painting all roofs white could nudge the Earth's albedo from 0.29 towards 0.30. According to a very simple "zero-dimensional" model of the Earth, this would lead to a drop in global temperature of up to 1 Centigrade degree, significantly countering the effects of global warming that has taken place since the start of the industrial revolution. Most existing flat roofs are dark and reflect only 10 to 20% of sunlight. Resurfacing the roof with a white material that has a long-term solar reflectance of 0.60 or more increases its solar reflectance by at least 0.40. Akbari et al. estimate that so retrofitting 100 m^2 of roof offsets 10 tonnes of CO^2 emission.

Do cool roofs cost more than conventional roofs?

Initial material costs are comparable with traditional roofing materials - some cool products cost less than traditional materials, some cost up to 20% more. Cool protective coatings can be reapplied every 7-10 years, and increase the longevity of the roof structure under it. Combining these maintenance savings with an average 20 percent savings on air conditioning costs make cool roofing a better bargain over the long term.

Can Cool Roofs lower the temperature on a larger city level?

Cities can be 2-8˚warmer than surrounding environments due to the large areas of dark surfaces, consisting mainly of roads, parking lots and dark-colored roofs. Cool roofs help mitigate the intensity of the UHIE by reducing heat absorption and transfer to the surrounding air. Lower ambient air temperatures resulting from cool roof applications also reduce the production of smog, a process accelerated by warmer temperatures.

9. Calculating Energy Savings

Buildings with lightly colored, more reflective roofs can use up to 40 percent less energy for cooling than buildings with darker roofs.
To calculate the possible savings in energy provided by a cool roof, there are two roof calculators that estimate energy savings.

DOE Cool Roof Calculator

The US Department of Energy Cool Roof Calculator provides an estimate of cooling and heating savings for small to medium size facilities that purchase electricity with a demand charge.

DOE Cool Roof Calculator

[http://www.ornl.gov/sci/roofs%2Bwalls/facts/CoolCalcEnergy.htm]
A similar calculator for the Indian context is currently being developed.

Cool Roof Calculator, Centre for IT in Building Sciences, IIIT Hyderabad

This calculator uses the Energy Plus simulation tool to predict savings through cool roofs. The tool compares two buildings that are identical in all aspects other than roof specification. The inputs to this calculator include building constants (height/ width/ length), schedules (light/ people/ plug loads), glazing size and orientation, roof insulation level, system efficiency, project location (New Delhi/ Mumbai/ Kolkata/ Chennai/ Hyderabad) and solar reflectances of the standard and proposed cases.

The results show the percentage change in cooling energy.

IIIT Hyderabad Cool Roof Calculator
[http://coolroof.cbs.iiit.ac.in/calculator.html]
The table below indicates the pay back period for applying cool roof technology to some common roofing options prevalent in India.

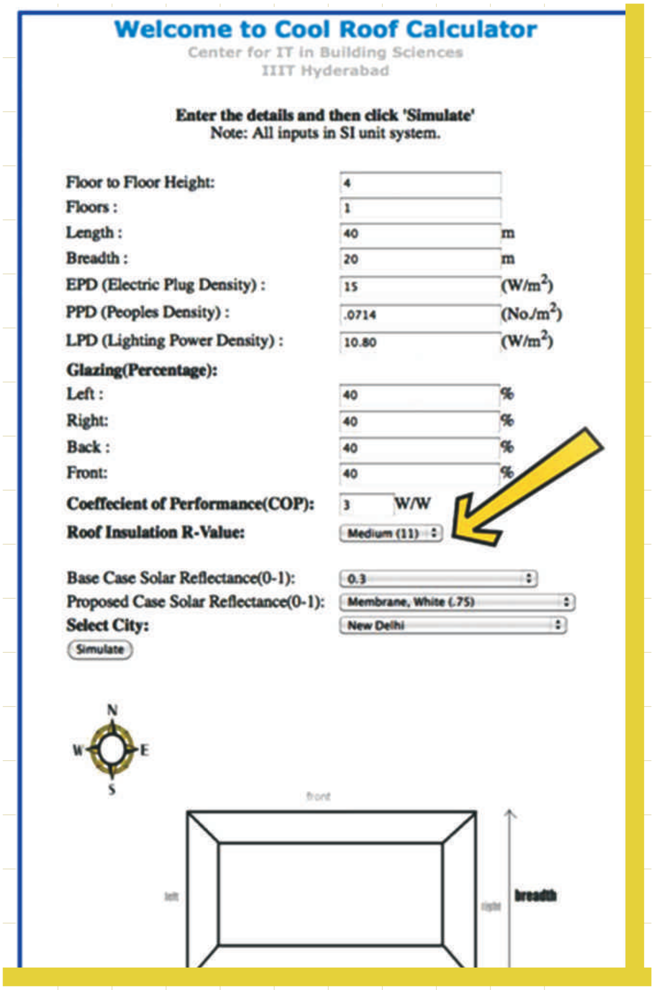


Figure 29 A screenshot of the web-based Cool Roof Calculator developed by IIT, Hyderabad

Table 3 Green Vegetative Roof – Modular Block Roof System
(Table courtesy of Centre for IT in Building Science, IIIT, Hyderabad)

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

Section III

Where can Cool Roof Products be Found?

10. Products and Vendors

Table 4 below includes a list of vendors for cool roof products like white paint, china mosaic tiles, and reflective roof coatings. This is not an exhaustive list of manufacturers – more information will soon be posted on the Bureau of Energy Efficiency website (http://www.bee-india.nic.in/). Moreover, the product specification listed here are based on information provided by the manufacturers, and may not be supported by standardized laboratory test procedures.

Table 4 Cool roofing vendors and products
(Table compiled through direct interaction with manufacturers / product brochures / online listings)

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)	129 Park Street Kolkata 700017 Mobile: +91 33 2229 9724 Fax: +91 33 2249 9009 / 9729 Ph: 2229 6005 / 06 / 16	
British Paints		No.19, D. D. A. Commercial Comlex, Kailash Colony Extension, New Delhi, Delhi - 110 048 (India) Ph: +91-11-29240394 / 29240395 Mobile: +91-9350632236, Fax: +91-11-29233390	
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	

Simple White Paint-Exterior Grade (all water based emulsions)

Manufacturer	Product Specification	Corporate Office	Approximate Cost
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)
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
Dolphin Floats Pvt Ltd, India [Reflectivity: 0.790 Emissivity: 0.982 SRI: 100]	Modified acrylis waterproofing coatings [Seal-n-Cool]	Mr. Alok Telang / Mr. Adish EL-25/5, First And Second Floor,MIDC, Bhosari, Pune, Maharashtra - 411 026, India http://www.dolphinfloats.co.in/modified-acrylic-waterproofing-coatings.html Tel: +(91)-(20)-27121859 Mobile: +(91)-9373989767	15/sq ft 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	

Reflective Roof Coatings

Manufacturer	*Product Specification*	*Contact*	*Approximate Cost*
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)

Bibliography

Websites:

1. http://heatisland.lbl.gov/CoolRoofs/
2. http://www.coolroofs.org/
3. http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_products
4. http://www.epa.gov/
5. http://www.ornl.gov/sci/
6. http://wrcc.sage.dri.edu/
7. http://www.sustainable.doe.gov/
8. http://www.lava.net/~colorcom/energymatters.html
9. http://www.fsec.ucf.edu/
10. http://eetd.lbl.gov/l2m2/cool.html
11. http://www.coolroofs.org/documents/IndirectBenefitsofCoolRoofs-WhyCRareWayCool.pdf
12. http://eetd.lbl.gov/HeatIsland/CoolRoofs/
13. http://www.swenergy.org/casestudies/arizona/tucson_topsc.htm
14. http://www.coolroofs.org/codes_and_programs.html
15. http://www.consumerenergycenter.org/coolroof/faq.html#faqs-05
16. http://www.energystar.gov/ia/partners/product_specs/eligibility/roofs_elig.pdf
17. http://www.energy.ca.gov/2005publications/CEC-400-2005-006/chapters_4q/3_Building_Envelope.pdf (Section 3.4)
18. http://www.energy.ca.gov/title24/coolroofs/
19. http://www.fsec.ucf.edu/
20. http://www.hrt.msu.edu/greenroof/
21. http://www1.eere.energy.gov/solar/photovoltaics.html
22. http://www.rerc-vt.org/solarbasics.htm

Articles:

1. Ministry of Environment and Forests, White paper on pollution in Delhi with an action plan. New Delhi: Government of India Ministry of Environment and Forests; 1997.

2. Akbari, H. (2008). Global Cooling: Increasing Solar Reflectance of Urban Areas to Offset CO2. In press, Climate Change.

3. Features and Benefits of Cool Roofs: The Cool Roof Rating Council Program, Journal of Green Building [http://www.coolroofs.org/documents/JGB_V3N2_a02_vanTijen.pdf] Volume 3: Number 2, Spring 2008.

4. Akbari, H. (2008). Evolution of Cool-Roof Standardsin the US, volume 2, pages 1-32, Advances in Building Energy Research

5. Akbari, H. (2008). Global Cooling: Increasing Solar Reflectance of Urban Areas to Offset CO2March 2008, Climate Change.

6. Features and Benefits of Cool Roofs: The Cool Roof Rating Council Program, Journal of Green Building [http://www.coolroofs.org/documents/JGB_V3N2_a02_vanTijen.pdf] Volume 3: Number 2, Spring 2008.

7. Akbari, H. (2008). Evolution of Cool-Roof Standards in the US, volume 2, pages 1-32, Advances in Building Energy Research.

8. Levinson, R., H. Akbari Evolution of Cool-Roof Standards in the US, Page 17-23, Advances in building energy research 2008 , Volume 2 Published by EarthScan.

9. Levinson, R., H. Akbari and P. Berdahl. 2009. Measuring solar reflectance—Part I: defining a metric that accurately predicts solar heat gain. Submitted to Progress in Solar Energy.

10. Konopacki, S., L. Gartland, H. Akbari and L. Rainer (1998) Demonstration of Energy Savings of Cool Roofs, LBNL-40673, Lawrence Berkeley National Laboratory, Berkeley, CA

11. Akbari, H., T. Xu, H. Taha, C. Wray, J. Sathaye V. Garg (2010). Using Cool Roofs to Reduce Energy Use, Greenhouse Gas Emissions, and Urban Heat-island Effects: Findings from an India Experiment. Lawrence Berkeley National Laboratory Final Report.

References

1. DDA Master Plan (off downloads)

2. http://www.dda.org.in/greens/greens_default.htm

3. http://www.epa.gov/heatisland/mitigation/index.htm

4. US Green Building Council, LEED-NC for New Construction, Reference Guide, Version 2.2, First Edition, October 2005, 95.

5. International Resouces Group (USAID ECO-III Project), Energy Conservation Building Code Users Guide (Bureau of Energy Efficiency, 2009), 25. Retrieved from: http://www.emt-india.net/ECBC/ECBC-UserGuide/ECBC-UserGuide.pdf.

6. Hashem Akbari and Ronnen Levinson, Status of Cool Roofs Standards in the United States, (Lawrence Berkeley National Laboratory, 2008), 6-7. Retrieved from: http://escholarship.org/uc/item/5cg147dp.

7. Budikova, Dagmar (Lead Author); Mryka Hall-Beyer and Galal Hassan Galal Hussein (Topic Editors). 2010. "Albedo." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth November 21, 2006; Last revised January 24, 2010; Retrieved March 17, 2010]. http://www.eoearth.org/article/Albedo

8. Akbari, H. (2008). Global Cooling: Increasing Solar Reflectance of Urban Areas to Offset CO2. In press, Climate Change. Retrieved from: http://heatisland.lbl.gov/CoolRoofs/

9. http://www.hrt.msu.edu/greenroof/

10. Dave Renetzky, HNTB Corporation, Vegetative Roof Systems, EWRI Currents (The Newletter of the Environment & Water Resources Institute of the American Society of Civil Engineers), Volume 7, Number 3, Fall 2005. Retrieved from: http://email.asce.org/ewri/VegetatedRoof.html

11. http://www.rerc-vt.org/solarbasics.htm

12. US Department of Energy, Energy Efficiency and Renewable Energy, October 2008. Retrieved from: http://www1.eere.energy.gov/solar/photovoltaics.html

13. Global Rural Urban Mapping Project, Earth Institute News Archive, Columbia University, March 2005. Retrieved from: http://www.earth.columbia.edu/news/2005/story03-07-05.html

14. Akbari, H., S. Menon, and A. Rosenfeld. 2008. "Global cooling: increasing solar reflectance of urban areas to offset CO2," Climatic Change. Retrieved from: www.energy.ca.gov/2008publications/CEC-999-2008-031/CEC-999-2008-031.PDF

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