COOL IT

THERMALLY-EFFICIENT ROOFS

THE COOL, THE INSULATED AND THE GREEN

Most Indian urban homes use layered roofing assemblies, typically a concrete base topped with waterproofing and finishing materials like tiles, bricks or stone. However, these roofing assemblies are often not designed for thermal efficiency and tend to absorb and retain solar heat.

This heat gain leads to rising indoor temperatures that compromise thermal comfort – particularly for vulnerable communities – and elevated outdoor temperatures that intensify the urban heat island effect.

Roofs must be reimagined using strategies that act across all layers-above, on, and below the roof surface. Building on traditional practices, modern methods combine reflectance, insulation, and green barriers to create nuanced, thermally efficient solutions.

Studies and field evidence show that these strategies can reduce indoor temperatures, improve thermal comfort, lower surface temperatures, cut energy use for space cooling, and reduce GHG emissions and waste heat release into the environment.

Introduction

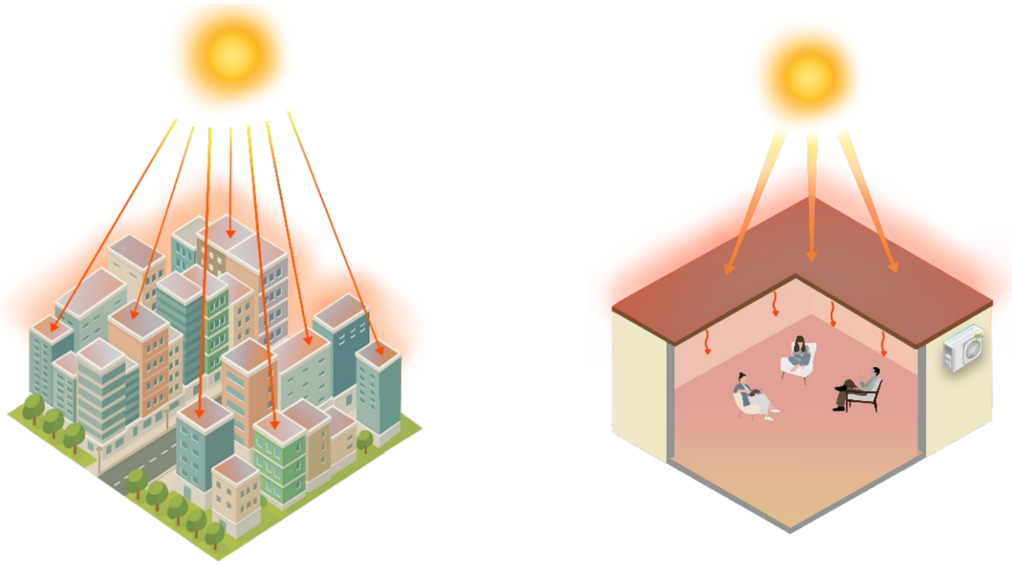
As the world grapples with rising temperatures, urban areas are emerging as epicentres of extreme heat. A decadal analysis by Centre for Science and Environment (CSE) across nine Indian cities found that six of them had over 80 per cent of their land area under heat stress. This phenomenon is driven by multiple factors like loss of blue-green cover, urban morphology and anthropogenic activities — but one key factor that stood out was the role of materials in shaping urban thermal conditions. For instance, in Pune, a variation of 7.33°C in land surface temperature (LST) was recorded within the city, with the highest temperatures concentrated in informal settlements that largely use metal and cement sheets as roofing materials.[1]

The role of roofing materials is especially critical in Indian cities, where they remain predominantly heat-trapping. As per the 2011 Census, 51.94 per cent of urban households use concrete, 15.9 per cent use GI/metal/asbestos sheets, 5.39 per cent use burnt bricks, and 7.93 per cent use stone or slate.[2] Materials like concrete, bricks and stones absorb a substantial amount of solar radiation during the day and release it slowly at night, turning buildings into persistent heat traps. Meanwhile, metal and cement sheets — common in low-income settlements — rapidly transmit heat indoors, making living conditions unbearable during peak summers. This is particularly true for homogenous roofs.

Most Indian homes feature layered roofing assemblies (*see Figure 1*), typically comprising a structural base of concrete or brick topped with finishing layers such as cement mortar, tiles or stone. These materials, especially when dark-coloured and exposed, intensify heat by absorbing solar radiation, raising the roof's surface temperature, and facilitating indoor heat transfer. This brings to light two critical concerns. First, such materials raise ambient air temperatures and contribute to the urban heat island effect. Second, they significantly

Figure 1: Conventional roofing assemblies and their heat absorption

Such assemblies absorb a lot of heat and lead to an increase in both the ambient air temperatures (left) and indoor air temperatures (right)



impact indoor thermal comfort, particularly for vulnerable populations.

This dynamic can be explained by how roofing surfaces interact with solar radiation. All incoming solar radiation is either reflected, absorbed, or transmitted through the surface. In most Indian homes, roofs are constructed using layers of high thermal mass materials, such as concrete or brick, topped with dark, exposed surfaces. These layers absorb intense solar radiation through the day. Without a reflective or insulating layer, this heat moves slowly through the roof, raising indoor temperatures during the day. At night, the stored heat is gradually released both indoors and into the surrounding atmosphere, prolonging discomfort inside homes and keeping ambient outdoor temperatures elevated. This continuous cycle contributes both to indoor heat stress and the urban heat island effect.

How can roofs help?

Indoor and outdoor heat stress can be addressed by intervening at the roof level. Improving thermal comfort requires strategies that either block, reflect or slow down the transfer of heat through the roof. These strategies involve specific material choices and design interventions that act as a protective layer within the roofing assembly.

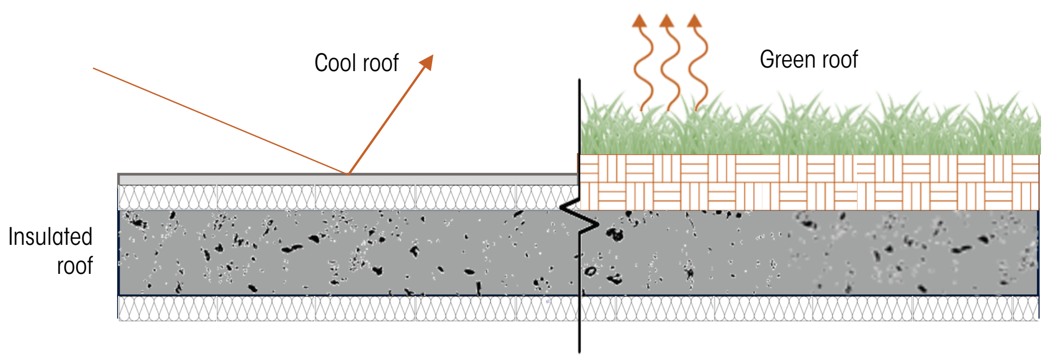
There are three key approaches to achieve this (*see Figure 2*):

- Cool roofs, which reflect incoming solar radiation using materials or coatings that prevent heat from being absorbed in the first place.
- Insulated roofs, which add a barrier layer on the roof surface that slows down the transfer of heat into the building, helping maintain cooler indoor temperatures.
- Green roofs, which add a layer of vegetation that provides both insulation and cooling through evapotranspiration, a natural process where plants release water vapour, using up heat energy and cooling the surrounding air.

These three approaches — reflecting heat, resisting its transfer, and dissipating it through greening — can also be used in combination to create layered protection against extreme heat, making buildings significantly more thermally comfortable and resilient.

Figure 2: Reducing heat gain

The three approaches to reduce heat gain into the building from the roof



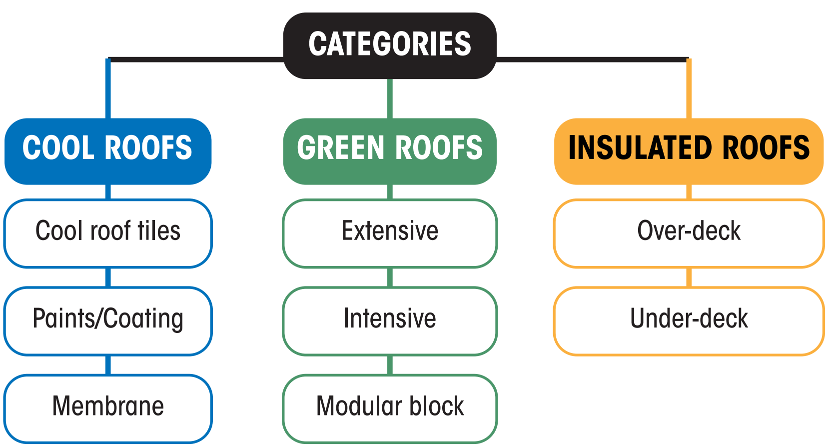
What are cool roofs, insulated roofs and green roofs?

While the term **'cool roof'** is often used broadly to refer to roofing systems that reduce heat gain in buildings, the Energy Conservation Building Code (ECSBC), 2024, defines a cool roof as one with a top layer made of materials that have high solar reflectance and high thermal emittance. These surfaces, typically light in colour, are designed to reject solar heat back to the environment. **Green roofs**, termed as 'vegetated roofs' in the ECSBC, are defined as thin layers of living vegetation installed on top of conventional flat or sloping roofs.[3]

Insulated roofs, while not explicitly defined in the ECSBC, are discussed in the National Building Code (NBC) of India, which describes thermal insulation as a treatment that limits heat gain or loss through the building envelope. In the context of roofing, this involves inserting materials with low thermal conductivity (such as expanded polystyrene, polyurethane foam, or mineral wool) within the roofing assembly to reduce heat flow into the interior.[4]

Figure 3: The three categories of thermally-efficient roofs

Cool, green and insulated



Together, cool (reflective) roofs, insulated roofs and green roofs form part of the broader thermally-efficient roofing strategies that cities and building codes are beginning to adopt to mitigate extreme heat.

Why do cool, insulated and green roofs matter?

In addition to local pilots and state level schemes, cool roofs, insulated roofs and green roofs have found a place in national building regulations and have become a compliance requirement. According to the ECSBC 2024, roofs must meet thermal performance standards either through insulation or surface treatment. Roofs may comply with the maximum assembly U-factors specified for different building categories.

Additionally, the code states that "All roofs that are not covered by solar photovoltaics, or solar hot water, or any other renewable energy system, or utilities and services that render it unsuitable for the purpose, shall be either cool roofs or vegetated (green) roofs."[5] For qualifying as a cool roof, roofs with slopes less than 20° shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75, whereas for qualifying as a vegetated roof (green roofs), roof areas shall be covered by living vegetation of >50 mm high.[6] This makes it a compliance requirement for roofs to meet specific thermal performance standards, either through high reflectivity, insulation or through vegetation.

Similarly, the Eco-Niwas Samhita 2024, India's residential energy conservation code mandates a maximum U-value of 1.2 $W/m^2 \cdot K$ and encourages the use of both cool and green roofs as passive design strategies to enhance thermal comfort and reduce energy demand.[7] Together, these frameworks are pushing thermally efficient roofing — insulated, reflective or vegetated — into the mainstream of climate-responsive building design in India.

This regulatory push is rooted in growing evidence that these strategies significantly reduce heat stress. Numerous studies have demonstrated the impact of reflective, insulated, and green roofs in lowering indoor and surface temperatures, improving thermal comfort, and reducing energy demand for cooling. They are an effective alternative with multiple advantages over conventional roofing materials.

- **Lower indoor temperatures improving thermal comfort**: Cool, insulated and green roofs can reduce indoor temperatures and improve thermal comfort, especially for households without air conditioning. Insulated roofs help reduce the transfer of external heat indoors. A study carried out in Tamil Nadu found that for a metal (galvanized iron sheet) roof insulated with mineral wool, the variation between the indoor ambient temperature and outdoor ambient temperature ranged from 7-9 degrees during peak summers.[8] A study in Nagpur's rural and peri-urban areas analysed the indoor temperature difference resulting from the application of a reflective coating over a traditional roof, and found the difference ranging from 2-4.4 degrees.[9] Another study investigated the cooling potential of green roofs in mild warm climate and found reductions up to 4.4 degrees compared to bare concrete roof.[10]

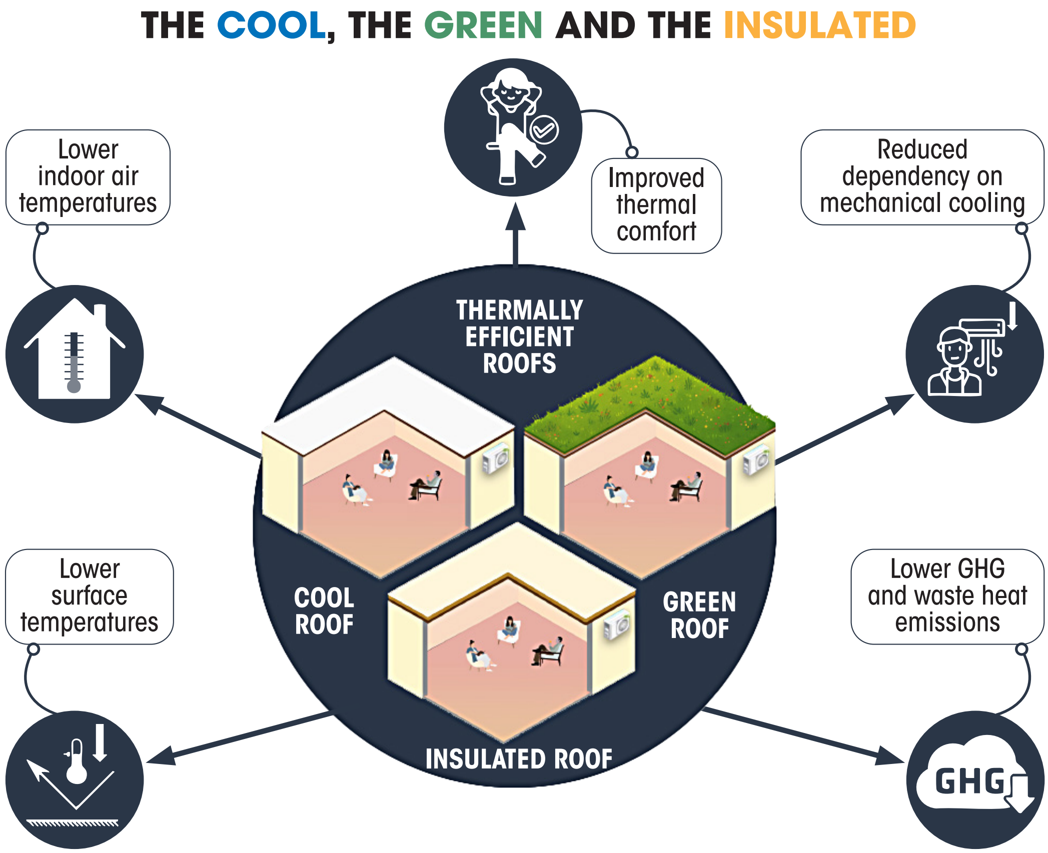
- **Reduced energy consumption**: By decreasing heat gain, cool, insulated and green roofs lower the need for fans, air coolers and ACs, cutting down energy consumption and reducing the load on power grids. Roof insulation significantly cuts energy use by slowing down heat transfer. A study carried out in the warm and humid climate of Perundurai, Tamil Nadu found a reduction in energy consumption of over 38 per cent when hollow clay tiles were used for insulation over RCC slabs.[11] Another study conducted for cities spanning across four climatic zones reveals that average energy saving achieved using reflective cool roofs for temperate, tropical, hot-dry and composite climatic zones are 32.8 per cent, 35.7 per cent, 15 per cent and 25.01 per cent, respectively.[12] Similar studies carried out for green roofs have reported cooling load reductions of up to 50.2 per cent in temperate climates, and average reductions of 10 per cent and 14.8 per cent in hot-humid and hot-dry climates, respectively.[13]

- **Surface temperature reduction and UHI contribution:** Conventional roofing materials, due to their heat-absorbing nature and widespread use in cities, contribute significantly to the urban heat island effect, leading to urban temperatures becoming higher than surrounding rural areas. Studies show that reflective cool roof strategies can lower roof surface temperatures by up to 20 degrees[14] and a green roof can bring down roof surface temperatures by 20.5 degrees[15], thereby limiting heat transfer to indoor spaces and the surrounding environment.

  Insulated roofs, while not affecting surface temperature, slow down heat transfer into buildings, improving indoor comfort and reducing reliance on mechanical cooling.

- **Climate impacts:** A study conducted for the metropolitan region of Hyderabad to examine the potential of GHG emission reduction from the application of cool roofs found an annual direct CO_2 reduction of 11-12 kg CO_2/m^2 of flat roof area associated with reduced cooling energy use.[16] Similarly, for green roofs, a study found an annual reduction of 9.5 kg CO_2/m^2 of roof area.[17]

Figure 4: Benefits of thermally-efficient roofs



Understanding thermally-efficient roofs: Their categories and how they work

In buildings, particularly single-storey structures or top floors of multi-storey buildings, roofs are a major contributor to heat gain, often accounting for half the total amount of heat entering the structure.[18] This is due to their large surface area and direct exposure to solar radiation. Solar radiation falling on the roof surface is either absorbed, reflected or transmitted. Thermally-efficient roofs work by minimising heat gain either by reflecting solar energy, by providing insulation, or through evaporative cooling.

Cool roofs

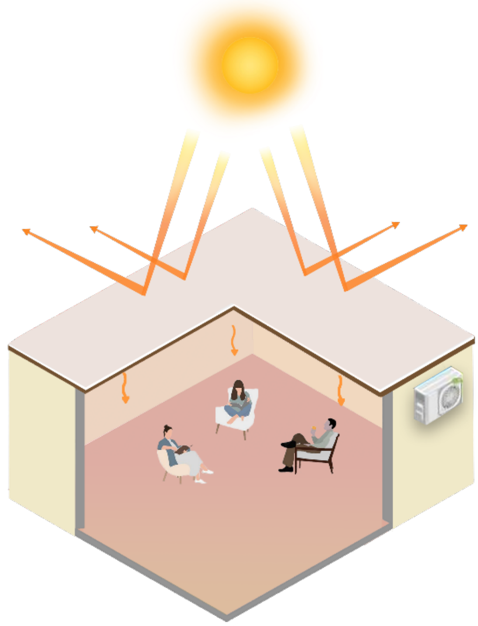
Reflective cool roofs use materials or coatings with high solar reflectance (albedo) and high thermal emittance, allowing them to reflect a large portion of incoming solar radiation and release absorbed heat efficiently.[19]

- **Solar reflectance or albedo** is the ratio of solar radiation reflected by a surface to the solar radiation incident upon it. It is measured on a scale of 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.[20]

  Solar radiation consists of a spectrum of wavelengths: ultraviolet (UV), visible light and near-infrared (NIR). Materials that reflect a greater proportion of this full spectrum, particularly the high-energy NIR range, are more effective in reducing heat gain. The colour of the material plays a key role in determining its solar reflectance. Generally, light-coloured surfaces reflect more solar radiation than dark-coloured ones, especially in the visible spectrum. For example, white or light grey surfaces have much higher albedo values than black or dark surfaces, which tend to absorb more heat. However, advances in material technology have enabled the development of cool colour roofing materials. These are made using special pigments that reflect a significant portion of infrared radiation (the heat carrying part of the spectrum) even if they appear dark to the eye. As a result, even roofing products in darker shades can achieve high solar reflectance and contribute to reducing heat gain.

Figure 5: Cool roofs and their reflectance

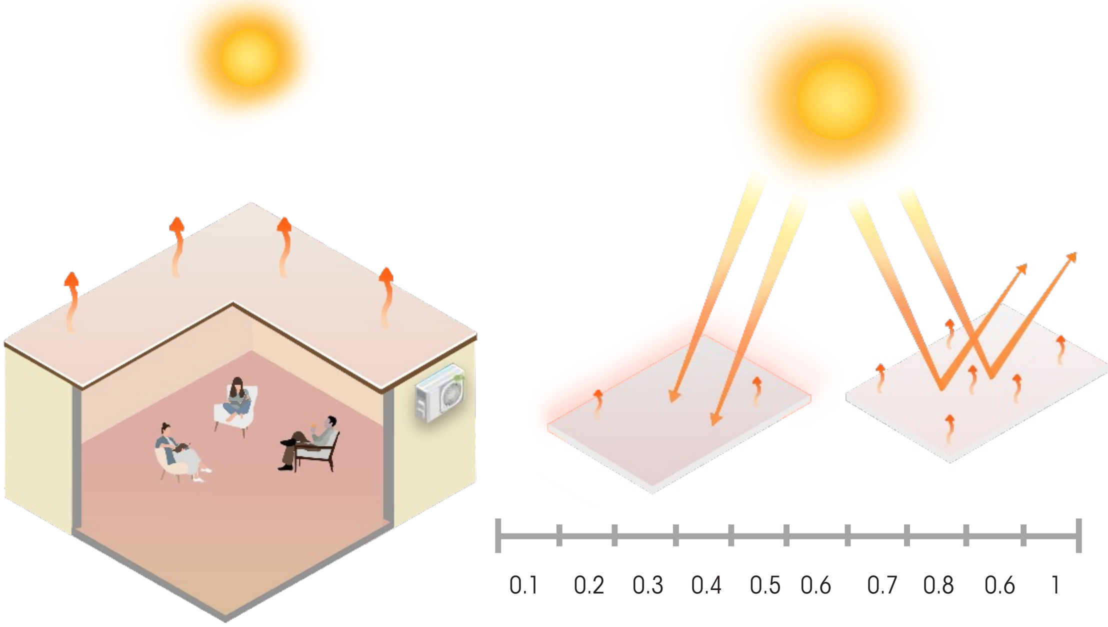
They have higher reflectance: they absorb less solar radiation compared to a standard grey roofing assembly



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 as the ratio of the radiant flux emitted by a body to that emitted by a black body at the same temperature and under similar conditions.[21] Materials with high emittance values (closer to 1) cool down more effectively after heating. Low-emittance surfaces, on the other hand, tend to retain heat for longer periods, making indoor spaces uncomfortable. An effective cool roof balances high solar reflectance and high thermal emittance to stay cooler during the day and release absorbed heat quickly, preventing it from transferring into the building at night.

Figure 6: Thermal emittance of cool roofs

They have high thermal emittance (closer to 1), and thus, can cool down more effectively



- **Solar reflectance index** is the measure of the constructed surface's ability to stay cool in the sun by reflecting solar radiation and emitting thermal radiation. It is defined such that a standard black surface (initial solar reflectance 0.05, initial thermal emittance 0.90) has an initial SRI of 0, and a standard white surface (initial solar reflectance 0.80, initial thermal emittance 0.90) has an initial SRI of 100.[22] A higher SRI (closer to 100) indicates higher ability to reflect incident heat (measured in solar reflectance value) and release absorbed heat.

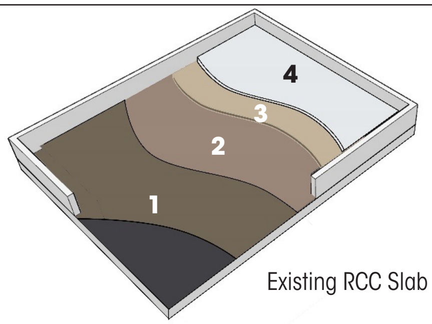
Many reflective roofing products available in the Indian market such as paints, coatings and tiles display these three performance indicators on their labels: solar reflectance, thermal emittance and the SRI value. These parameters help buyers evaluate how well a material will perform in rejecting solar heat and improving indoor comfort.

Types of cool roofs

Cool roofs can be classified into three types:

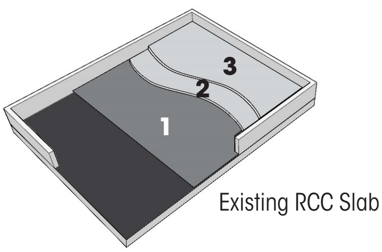
Cool roof (reflective) tiles: Cool roof tiles are special roofing materials such as China mosaic, white, cool colour, or other light-coloured tiles applied to new or existing roofs to reduce heat build-up. They are weather-resistant and more durable than coatings or paints, which may require frequent reapplication.

Table 1: Reflective tiles

Reflective tiles (₹420-₹750/sq m)	
Appropriate for:	
Typology: • Sloping roof • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Warm and humid • Composite
Pros • Weather resistant • Good reflective properties • Less expensive to install	**Cons** • Maintenance required to keep it clean and retain reflective properties • Heavy, hence structural evaluation is necessary for tiles
	Construction detail for cool roof tiles (China mosaic) as seen in demonstration projects in Surat and Indore[23] 1. Waterproofing layer over slab (4-5 mm) 2. Plain cement concrete (PCC) (50 mm) 3. Cement mortar bedding (20-25 mm) 4. Broken China mosaic tiles fixed with white cement

Cool roof paints/coatings: These are liquid-applied reflective coatings made from materials such as lime wash, acrylic polymers, or other plastic-based technologies[24]. Cool-coloured polymer coatings are also available that reflect infrared radiation while retaining darker shades. These coatings are easy to apply, suitable for both new and existing roofs, and cost-effective.

Table 2: Cool roof paints/coatings

Paints/coatings (₹130-₹170/sq m)	
Appropriate for:	
Typology: • Sloping roof • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Warm and humid • Composite
Pros • Less costly as compared to other cool roof options • Easily applicable • Acts as waterproof membrane • Not damaged by freezing temperatures	**Cons** • Can be damaged through human movement and objects • Requires periodic application for maintaining reflecting properties • Water-based coating cannot be applied in winter and rainy season
	Construction detail for cool roof paint/coating as seen in demonstration projects in Surat and Indore[25] 1. Base coat over clean and prepared roof 2. Two coats of reflective paint over base coat 3. Final coat of polymer-silicon-based water-repellent transparent film

Cool roof membranes: These involve the use of prefabricated materials such as thermoplastics like PVC (polyvinyl chloride) or modified bitumen-based sheets that are laid over existing roofs to enhance solar reflectance.[26] Designed to improve the solar reflectance index (SRI) of the roof surface, these membranes provide a durable and low-maintenance cool roofing solution, especially effective on flat or low-slope roofs.

Table 3: Cool roof membranes

Thermoplastic membrane (₹460-675/sq m)	
Appropriate for:	
Typology: • Sloping roof • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Warm and humid • Composite
Pros • Weather-resistant • Good reflective properties • Light weight • Low installation cost	**Cons** • Toxic properties • Susceptible to water retention problems
Modified bitumen membrane	
Appropriate for:	
Typology: • Sloping roof • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Warm and humid • Composite
Pros • Excellent water proofing protection • Ultraviolet protection	**Cons** • Higher installation cost • Hazardous during installation

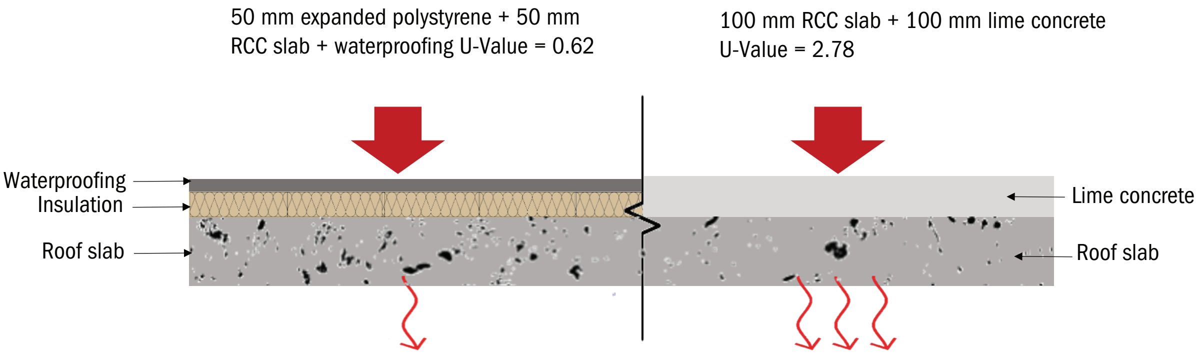
Insulated roofs

Insulated roofs work by reducing the rate at which heat enters a building through the roof, rather than reflecting it like cool roofs or cooling it through vegetation like green roofs. This is achieved using materials that resist heat flow. The effectiveness of this resistance is measured by the thermal transmittance, commonly referred to as the U-factor.

- **U-factor (thermal transmittance)** is the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. U-value is expressed in $W/m^2 K$.[27] A lower U-factor means better insulation, as it allows less heat to pass through the roof. By limiting heat flow, insulated

Figure 7: How insulation works

Insulating materials have lower U-value (thermal transmittance) reducing heat transfer indoors, as compared to RCC slabs without insulation



roofs help maintain stable indoor temperatures and reduce the need for artificial cooling.

Types of insulated roofs

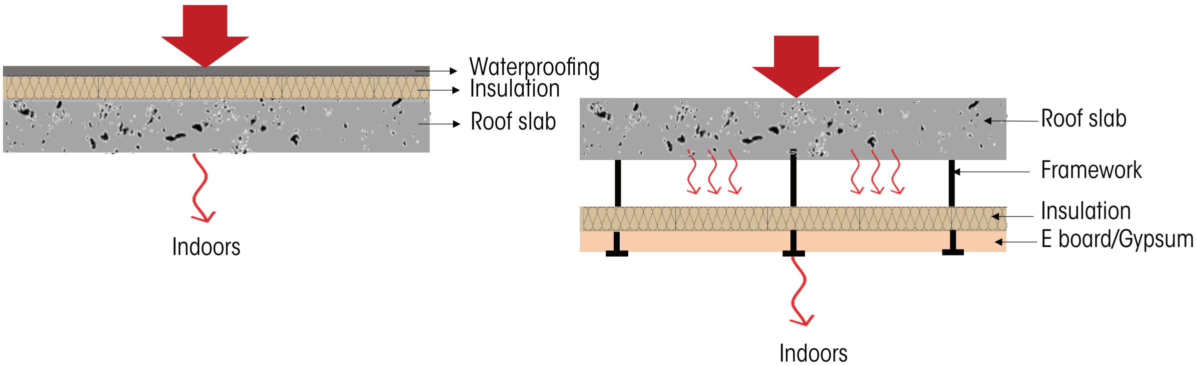
Based on the placement of the insulating layer, insulated roofs are broadly classified into:

Over-deck insulation: In this system, the thermal barrier is provided over the RCC roof to substantially reduce the amount of heat reaching the RCC slab, preventing the slab from getting excessively heated up. An over-deck insulation system also protects the waterproofing system from damage due to thermal stress caused by continuous variation in diurnal and seasonal temperatures. It also acts as protection against mechanical damage to the waterproofing.[28]

Under-deck insulation: In this system, the thermal barrier is installed below the RCC slab to reduce the amount of heat entering the indoor spaces. However, since the heat first passes through the slab before being resisted by the insulation, it can still raise the temperature of the indoor environment to some extent. As a result, under-deck insulation is generally considered less effective in preventing heat gain than over-deck insulation.[29]

Figure 8: Types of insulated roofs and how they work

a) Over-deck and b) under-deck roofing showing reduction in indoor temperatures by cutting down transfer of solar radiation through the roof



SOURCE: https://lloydinsulations.com/wp-content/uploads/2022/05/LIL-Products-PUF-PIR_Slab_for_building_insulation_Res18.pdf

The various materials commonly used for roof insulation are[30, 31]:

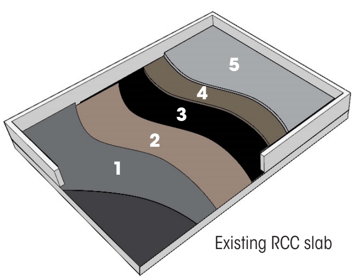
- **Extruded polystyrene sheet (XPS):** XP sheets are lightweight, rigid foam insulation materials used to reduce heat transfer and improve energy efficiency. They are most effective when applied as over-deck insulation, providing a continuous thermal barrier while also resisting moisture ingress.

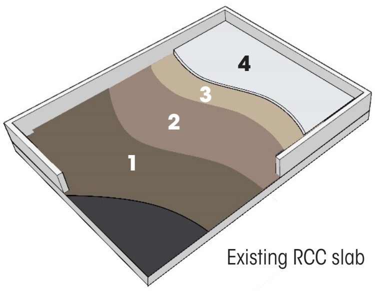
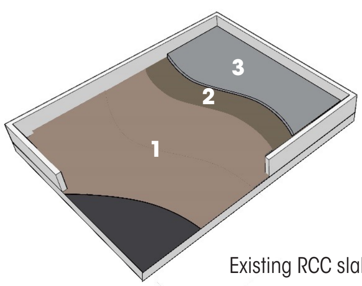
- **Cellulose fibre**: This is an eco-friendly insulation material made from recycled paper and cardboard, processed into soft, fibrous particles. It offers good thermal insulation, comparable to XPS, and is also fire-resistant and biodegradable, making it a sustainable and safe choice for building insulation.

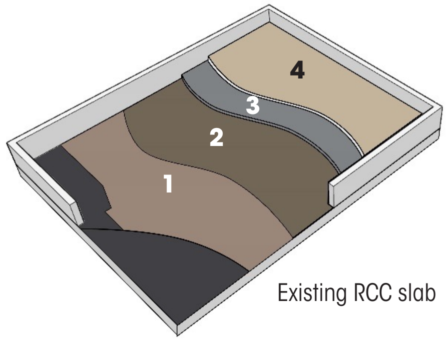
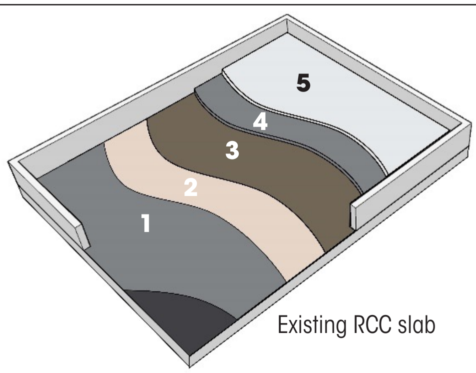
- **Thermocrete:** Thermocrete is made by mixing small thermocol (XPS) balls into regular cement concrete, creating tiny air pockets that reduce heat transfer. It is typically applied *in-situ* over terraces before adding the final cement finish, offering an integrated insulation within the roof slab.

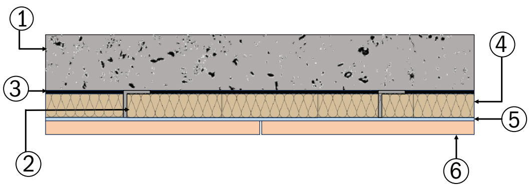
- **Lime concrete:** Lime concrete is made by mixing lime with *surkhi* (crushed brick powder) and broken brick pieces as aggregate. Natural additives like jaggery, gallnut, and *bael* fruit are sometimes mixed in the water while preparing the concrete to enhance water resistance. It is typically topped with tiles or another finishing layer for added durability.
- **Hollow terracotta tiles:** These reduce heat transfer through air cavities that act as natural insulators. These tiles can be further enhanced by adding a reflective finish such as ceramic tiles or China mosaic on top, which helps in solar reflectance and limits heat absorption.
- **Glass Wool:** Glass wool, often known as fiberglass, is produced by spinning or drawing molten glass into thin fibres that have a wool-like texture. These fibers are then held together with a binder and shaped into forms such as rolls, slabs, or loose-fill materials. Along with its effective thermal insulation capabilities, glass wool also offers sound insulation and resistance to fire.[32]

Table 4: Types of materials used for roof insulation

<table>
<tr><th colspan="2">Paints XPS sheet (₹275-₹695 (20-50 mm)</th></tr>
<tr><th colspan="2">Appropriate for</th></tr>
<tr><td>Typology:
• Flat roof
• Existing roof
• New roof</td><td>Climate:
• Hot and dry
• Warm and humid
• Composite</td></tr>
<tr><td>Pros
• Highly durable
• Light weight</td><td>Cons
• Comparatively expensive to hard materials
• Cannot put much load due to softer inner core</td></tr>
<tr><td>
</td><td>Construction detail for roof insulation using XPS sheet for demonstration projects in Surat and Indore[33]
1. Cement mortar bedding (20-25 mm) over slab
2. XPS sheet (50 mm)
3. Vapour barrier plastic membrane (1.5 mm)
4. Water proofing layer (4-5 mm)
5. Indian Patent Stone (IPS) (Cement: Sand: Aggregate- 1:2:4) (50 mm)</td></tr>
</table>

Cellulose fibre	
Appropriate for	
Typology: • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite
Pros • Low maintenance • Environment-friendly • Fire-resistant	**Cons** • Heavy, hence structural evaluation is necessary
 	Construction detail for roof insulation using Cellulose fibre for demonstration projects in Indore[34] 1. Waterproofing layer (4-5 mm) over slab 2. Cellulose fibre blended with cement mortar (Cellulose fibre: Cement: Sand – 1:2:4) 75 mm 3. IPS (Cement: Sand: Aggregate- 1:2:4) (50 mm) 4. Ceramic powder slurry 5. Hydrated lime slurry: 2 coats
Thermocrete insulation	
Appropriate for	
Typology: • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite • Warm and humid
Pros • Environment-friendly; sourced from waste packaging (thermocol) • Relatively cheaper • Low maintenance	**Cons** • Heavy, hence structural evaluation is necessary
 	Construction detail for roof insulation using Thermocrete for demonstration projects in Surat and Indore[35] 1. Thermocrete (Cement: Sand: EPS balls- 1:1:4) over slab 2. Cement mortar bedding (20 mm) 3. Waterproofing (4-5 mm) 4. IPS (50 mm)
Lime concrete/brick lime jelly	
Appropriate for:	
Typology: • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite

Pros • Less expensive to install • Highly durable to weather conditions • Environment-friendly	**Cons** • Heavy, hence structural evaluation is necessary
	Construction detail for roof insulation using lime concrete for demonstration projects in Surat and Indore[36] 1. Lime concrete layer (Hydrated lime: Sand: Broken brick chips- 1:1:2) 2. Cement mortar bedding (20 mm) 3. Mangalore tiles finish
Hollow terracotta tiles	
Appropriate for	
Typology: • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite
Pros • Fire-resistant • Recyclable • Energy-efficient • Low maintenance • Highly durable to weather conditions	**Cons** • Heavy, hence structural evaluation is necessary for concrete tiles • Clay tiles are fragile
	Construction detail for roof insulation using hollow clay tiles for demonstration projects in Surat and Indore[37] 1. Cement mortar bedding over slab (50 mm) 2. Hollow clay tiles 3. Water proofing (4-5 mm) 4. Cement mortar bedding 5. China mosaic tiles fixed with white cement
Glass Wool	
Appropriate for:	
Typology: • Flat roof • Sloping roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite

Pros	Cons
• Light in weight • Easy to install, saves labour cost and time • Made from recycled glass thus environment friendly • Fire resistant • Good acoustic insulation properties	• Not suitable for damp locations • Irritant to skin and respiratory system, care must be taken while installing
	Construction detail for roof insulation using glass wool[38] 1. Existing RCC slab 2. GI/Aluminium channels 3. Adhesive layer 4. Glass wool insulation (25-50 mm) 5 Vapour barrier 6. Finishing material (eg. Gypsum board)

Traditional materials

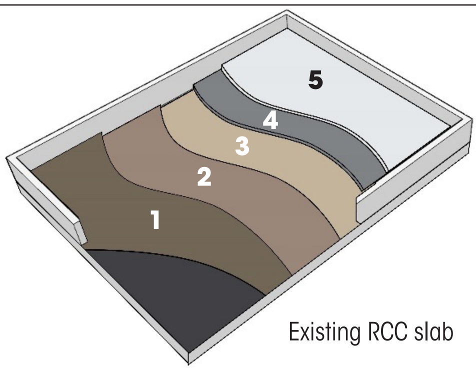
- **Inverted earthen pots:** Burnt clay pots are placed in an inverted position over the roof slab, with lime or cement concrete filled between them. The trapped air inside the pots acts as an insulating layer, reducing heat transfer into the building. A waterproofing layer, such as ceramic tiles, is typically laid over the setup to seal and protect the roof.

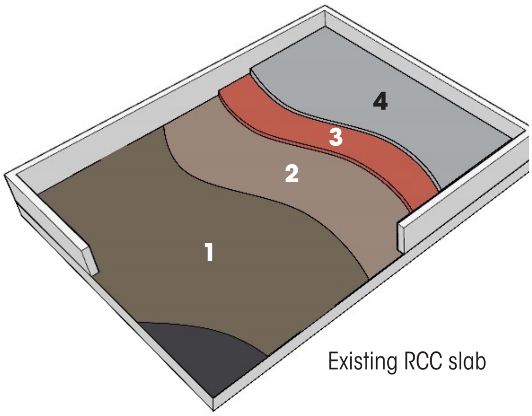
Inverted earthen pots being used for roof insulation in a demonstration project in Indore.

Source: https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/thermal_comfort_handbook_volume_ii.pdf

- **Mud phuska:** This involves applying a layer of puddled clay mixed with chopped straw (*bhusa*) and cow dung over concrete (RCC) roofs. The straw and cow dung help bind the clay while creating tiny air pockets, which act as natural insulators.

Table 5: Traditional materials used for roof insulation

Inverted earthen pots	
Appropriate for	
Typology: • Flat roof • Existing roof • New roof	**Climate:** • Hot and dry • Composite
Pros • Wide accessible; can be sourced locally • Low maintenance • Highly durable to weather conditions	**Cons** • Heavy, hence structural evaluation is necessary
	Construction detail for roof insulation using inverted earthen pots for demonstration projects in Surat and Indore[39] 1. Waterproofing over roof slab (4-5 mm) 2. Inverted earthen pots fixed with cement mortar 3. Indian patent stone (50 mm) 4. Cement mortar bedding (20-25 mm) 5. China mosaic tiles fixed with white cement
Mud phuska	
Appropriate for	
Typology: • Flat roof • Existing roof • New roof	**Climate**: • Hot and dry • Composite
Pros • Environment-friendly • Energy-efficient • Low-cost and easily available solution	**Cons** • Heavy, hence structural evaluation is necessary



Construction detail for roof insulation using mud phuska[40]

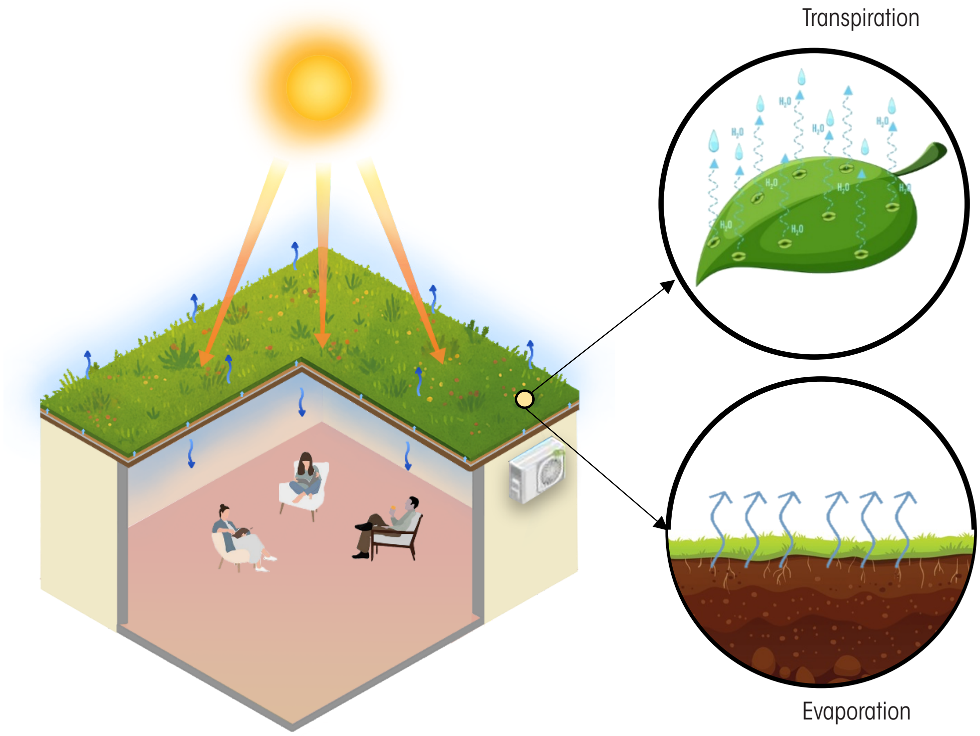
1. Waterproofing layer over roof slab
2. Layer of compacted mud phuska (clay + straw + cow dung)
3. Clay tiles
4. Cement finishing

Green roofs

Green roofs involve adding a layer of vegetation over a waterproof membrane. They remove heat from the air through the process of evapotranspiration, provide shade and insulation, and reduce temperatures of the roof surface and the surrounding air.[41] Plants absorb water through their roots and emit it through their leaves. This movement of water is called transpiration. Evaporation, the conversion of water from a liquid to a gas, also occurs from the soil around vegetation and from trees and vegetation as they intercept rainfall on leaves and other surfaces. Together, these processes are referred to as evapotranspiration, which lowers temperatures by using heat from the air to evaporate water.[42] In addition to cooling the air, the soil and vegetation layer also act as an insulating barrier, slowing down heat transfer into the building and helping maintain more stable indoor temperatures.

Figure 9: Green roofs

They reduce temperatures both indoor and ambient through the process of evapo-transpiration



Types of green roofs

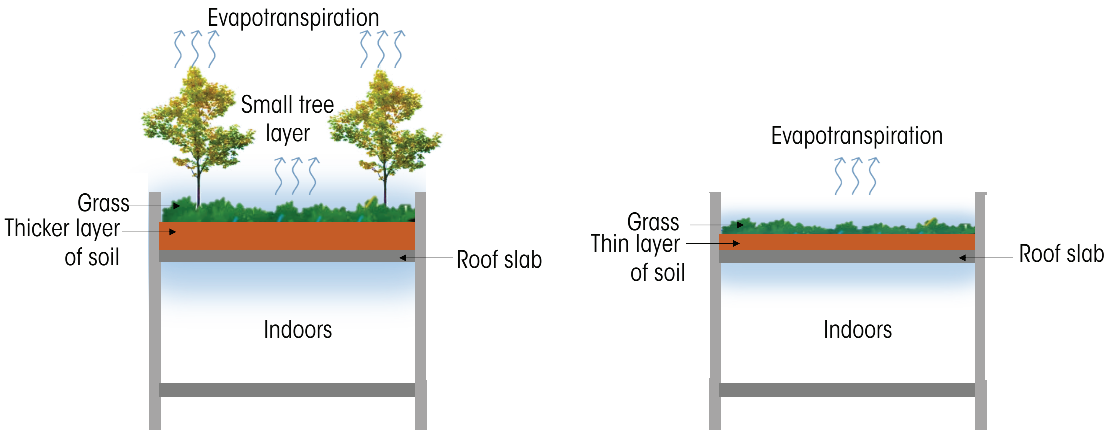
Green roofs can be broadly classified into two categories:

- **Intensive green roofs:** They include lawns, flower beds, shrubs and even small trees on rooftops. These systems require a deeper growing medium, typically more than 300 mm, and add considerable structural load.[43] Because they can support a variety of plants and allow human access, they are often designed as rooftop parks, recreational spaces or community gardens.

- **Extensive green roofs**: Extensive roof systems are lightweight, low-maintenance installations designed that support hardy, drought-resistant plants such as

Figure 10: Intensive and extensive green roofing

The illustrations show how the reduction in indoor and ambient air temperatures happens



SOURCE: https://www.researchgate.net/figure/A-schematic-structure-of-an-extensive-green-roof-and-an-intensive-green-roof-and-the_fig1_330287102

succulents, grasses, mosses, climbers, etc. They require a shallow soil depth typically between 25 to 125 mm.[44] These systems are not meant for regular human access but offer strong ecological value by improving insulation, reducing runoff and enhancing biodiversity.

- **Modular block:** There is also the modular block system which consists of portable, self-contained units which interlock, arranged on a rooftop.[45] These blocks are typically made of heavy-gauge metal, filled with around 100 mm of soil, and planted with low-growing, hardy vegetation. A pad or drainage sheet attached beneath each unit helps regulate water flow. This system is ideal for retrofits, allows easy maintenance, and offers design flexibility.[46]

Figure 11: Modular block green roofing

The system is easy to retrofit and can be maintained easily

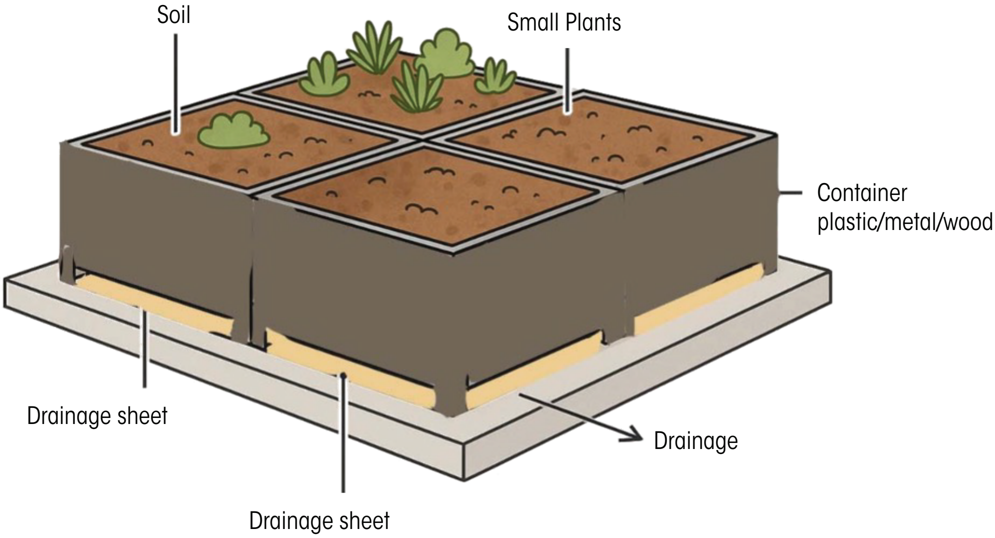


Table 6: Types of green roofs

Green roofs	
Appropriate for: Sloping roof, Flat roof, Existing roof, New roof	
Intensive green roofs	**Extensive green roofs**
Pros • Greater diversity of plants and habitats • Better insulation properties • Can simulate a wildlife garden on the ground • Diverse utilisation of roof, versatile in nature **Cons** • Greater weight loading on roof • Need for irrigation and drainage systems, hence, greater need for energy, water, materials etc. • Higher cost • More complex systems and expertise required, regular maintenance required	**Pros** • Light weight • Suitable for large areas • Suitable for roofs with 0-30 degree slope • Low maintenance • Minimal need for irrigation and drainage • Often suitable for retrofit project • Can leave vegetation to develop spontaneously • Relatively cheap **Cons** • Limited choices of plants • Usually, no access for recreation or other uses
Modular block green roof system	
Pros • Require a relatively shorter installation period • Modular design, hence parts are interchangeable • Can be effectively applied in an existing building	**Cons** • Types of plants may be limited

TWO CASE STUDIES FROM PUDUCHERRY

CSE documented the application of cool and green roofs used individually or in combination in innovative ways, along with the surface temperature differences they achieved. Two case studies were carried out in Puducherry, which experiences long and oppressive summers with high humidity and temperatures often crossing 40 degrees. These conditions push many residents to rely on air conditioning for relief. However, in both the cases that were studied, enhanced thermal comfort was achieved through the application of thermally-efficient roofs, reducing, if not completely eliminating, the need for mechanical cooling.

Ovoid Studio

Integrating a green roof over a metal structure

- Building use: Office
- Construction type: Single-storey, brick walls
- Roof material: Galvanized iron (GI) sheet with green roof (studio); plain GI sheet (workshop)

Ovoid Studio demonstrates how even heat-prone roofing materials like galvanized iron can be adapted for thermal comfort through innovative green roof design. The office building, which originally had a galvanium (galvanized iron, GI) roof, was retrofitted with a green roof system. To prepare the assembly, the GI sheets were first layered with a PVC sheet to prevent rusting. Over this, a geo-fabric layer, which is a permeable woven material that retains water and blocks root intrusion was installed. This geo-fabric was modified by stitching pocket-like compartments filled with soil, into which a trailing variety of money plant was planted. These plants eventually spread across the roof surface, forming a dense green cover.


The Ovoid office with GI sheet roofing layered with green roof (left). Pockets woven into geo-fabric filled with soil (right) act as media for the vegetation, laid over the roof

An integrated irrigation line was installed to ensure adequate watering during dry spells. This green roof significantly reduced surface temperatures. Measurements taken from the underside of the green roof during noon showed temperatures of around 32-33 degrees, compared to 50-53 degrees recorded beneath the adjacent plain GI sheet roof on the workshop side. This reflected a stark 18-20 degree temperature difference, underscoring the green roof's cooling effect even over metal sheets, which are otherwise highly conductive.

Sharanya residence

Green roof and cool roof – use of white-coloured tiles

A double-storeyed residence in Puducherry has incorporated multiple heat mitigation strategies across its roof surfaces, including extensive green roofing and white-coloured tiles. Surface temperatures were recorded during an April afternoon to compare the effectiveness of these interventions. Measurements taken from the green-roofed areas showed surface temperatures ranging between 31-33 degrees, while areas covered with white tiles recorded slightly higher temperatures of 34-35 degrees.

In contrast, the exposed dark concrete sections of the roof reached much higher temperatures, ranging from 42-44 degrees. These readings indicate a surface temperature reduction of 10-11 degrees due to the green roofing and 8-9 degrees due to the white tiles, compared to bare concrete. The results demonstrate the tangible benefits of combining reflective and vegetative strategies to improve rooftop thermal performance in warm and humid climates.

The Sharanya residence with intensive green roofing and white-coloured tiles over roofs

What can be done to popularise thermally-efficient roofs?

Encourage adaptation at state and municipal levels

Cool, green and insulated roofs are increasingly being recognised in national codes and frameworks. The Energy Conservation Building Code of 2024 mandates cool or vegetated roofs for commercial buildings, and the Eco Niwas Samhita for residential buildings recommends similar measures. These strategies are also being introduced in city-level heat action plans (HAPs) — such as Delhi's, which recommends cool roofs as a heat mitigation measure.

However, both building codes and HAPs are largely voluntary and unevenly enforced. Their real impact will depend on formal adoption at the state and municipal levels. Making these codes mandatory and embedding them into building bye-laws and climate resilience strategies is essential to mainstreaming climate-responsive roof design.

Ensure that group housing schemes lead by example

Large-scale housing programmes like the Pradhan Mantri Awas Yojana (PMAY) offer a crucial opportunity to incorporate cool, insulated and green roofing strategies at scale. Under the urban component, as of June 2024, 1.18 crore houses have been sanctioned, 1.14 crore grounded for construction, and 83.67 lakh houses completed. Similarly, under the Pradhan Mantri Awas Yojana-Gramin (PMAY-G), 2.94 crore houses have been sanctioned and 2.62 crore completed as of June 12, 2024.[47]

Among these, low-rise housing, particularly in rural areas, offers the highest potential for roof-based cooling interventions. These layouts have greater roof exposure and experience more intense indoor heat stress, making roofing solutions even more critical. Integrating the ECSBC and Eco Niwas Samhita into PMAY construction can demonstrate leadership and ensure long-term thermal comfort for economically weaker sections.

Prioritise existing low-income settlements

In existing low-income and informal settlements, roofing is often done with thin sheets of metal, tin or asbestos, materials that rapidly transmit heat indoors. These areas are among the most vulnerable to extreme heat. As demonstrated by Ahmedabad's pilot of painting 3,000 low-income households with reflective coating[48] and other projects carried out in cities like Bhopal, Jodhpur and Surat by the Mahila Housing Trust (MHT)[49], targeted interventions can deliver measurable improvements in thermal comfort.

Similar programmes must be scaled up nation-wide, with focused implementation in heat-vulnerable cities and settlements. While cool roofs have taken the lead in such efforts, other strategies such as insulation and green roofs also hold significant potential and should be explored through pilot programmes.

Ahmedabad's pilot programme where 3,000 low-income households were painted over with reflective paints

Credit: https://coolroofs.org/documents/2023-CRRC-Annual-Meeting-Charlotte-Steiner.pdf

Bridge the awareness gap

Despite the benefits and emerging policy frameworks, awareness about cool, green and insulated roofs remains low among homeowners, builders, contractors and even local authorities. Many are unaware of low-cost, locally available options or the long-term energy savings these solutions can bring. Outreach, IEC campaigns, training workshops and demonstration projects are critical for bridging this gap and building trust in these strategies.

This is especially important in informal housing markets where decisions are often made by masons and contractors on the ground. The Delhi Heat Action Plan recognises this challenge and recommends capacity building and training programmes for residential communities, local masons, and relevant stakeholders to promote roof cooling solutions[50]. Under the Ahmedabad Heat Action Plan, outreach strategies like poster and banners in the regional language have been adopted and put up throughout the city to promote and raise awareness on cool roofs.[51] Similar efforts need to be adopted widely to ensure that awareness and technical know-how permeate to the last mile of implementation.

Posters/banners in regional languages in Ahmedabad promoting and spreading awareness on cool roofs

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