Passive Cooling Strategies for Sustainable Buildings

OZONE CELL
MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

Government of India

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Acknowledgments

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- **Mr. Aditya Narayan Singh,** Director (O), Ozone Cell (MoEF&CC)

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार

सत्यमेव जयते

भूपेन्द्र यादव
BHUPENDER YADAV

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

MESSAGE

India's growing economy, together with increasing income, rapid urbanization, and tropical climate are significantly boosting the demand for cooling. Addressing this need by integrating climate-friendly technologies and sustainable practices, such as energy-efficient cooling systems, green roofs, reflective materials is essential for reducing environmental impact and enhancing energy efficiency.

A balanced approach that integrates both passive and active cooling technologies can reduce dependence on mechanical cooling, thereby reducing impacts on energy systems and the climate. An effective building envelope is vital for sustainable cooling, as it boosts energy efficiency by minimizing heat gain and loss, which in turn lowers the need for active cooling systems.

Affordable and sustainable building design principles, including optimizing energy efficiency through passive solar design, using locally sourced and eco-friendly materials, and incorporating low-maintenance, durable features, further contribute to reducing long-term costs and environmental impact. Integrating these technologies and practices contribute to a more energy-efficient and environmentally responsible approach to cooling.

The Report on “Passive Cooling Strategies for Sustainable Buildings” provides scientific and technical insights into space cooling, making it a valuable resource for adopting sustainable and energy-efficient technologies in building sector.
I congratulate the team members for the preparation of this Guidebook.

(Bhupender Yadav)

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सत्यमेव जयते

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भारत सरकार
पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST
& CLIMATE CHANGE

Message

The need for space cooling in buildings is growing due to increasing urbanization, with rising temperatures making cooling essential for maintaining comfort, health, and productivity. Sustainable cooling practices, climate-friendly technologies, and an effective building envelope are integral for energy-efficient buildings, as they work together to minimize heat gain, reduce reliance on mechanical cooling, and reduce the overall environmental impact.

Passive cooling techniques are crucial for India's diverse and extreme climate, as they helps to maintain indoor temperatures and alleviate the strain on the energy grid caused by high temperatures. A sequential approach to addressing space cooling needs by first reducing heat gain through passive cooling techniques before relying on active cooling systems, mitigates the increasing demand for active refrigerant-based cooling in the country. Incorporating passive cooling techniques into building design especially in urban areas, which grapple with rising temperatures and heat islands, minimizes energy consumption, enhances energy efficiency, and reduces long-term costs and greenhouse gas emissions.

The Report on "Passive Cooling Strategies for Sustainable Buildings" emphasizes sustainable building practices, focusing on passive cooling techniques and retrofitting of existing buildings, covering advanced insulation and renewable energy integration, to enhance energy efficiency and urban sustainability. It is a valuable resource material and ensuring its availability to a wider audience would certainly enhance its practical application.

I compliment the team associated with the preparation of this informative Report.

(Leena Nandan)

Dated : September 10, 2024

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LiFE Lifestyle for Environment

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EXECUTIVE SUMMARY

Cooling requirements are cross-sectoral and essential to economic growth, affecting various sectors such as residential and commercial buildings, cold chains, refrigeration, transportation, and industries. The India Cooling Action Plan (ICAP), launched in 2019, provides a long-term vision for addressing these cooling needs. It aims to reduce cooling demand by 20-25% and refrigeration demand by 25-30% by the year 2037.

Space Cooling in Buildings is one of the six thematic areas under ICAP, focusing on promoting the adoption of sustainable cooling technologies for both new constructions and retrofitting existing buildings. The goal is to advance environmentally friendly cooling solutions that enhance energy efficiency and reduce the impact on the ozone layer. The future of space cooling in buildings will greatly benefit from a two-pronged approach. First, by reducing the need for active cooling through a foundation of energy efficiency strategies, and second, by addressing the reduced cooling demand with advanced, efficient cooling technologies. In alignment to this approach, one of the key recommendations of ICAP is to promote wider penetration of climate responsive built spaces to bring indoor temperatures within acceptable thermal comfort band through passive cooling thus reducing cooling load.

Consistent with this strategy, the report on “Passive Cooling Strategies for Sustainable Building” was developed to provide insights into sustainable building practices, focusing on three main areas: passive cooling techniques, retrofitting strategies, and the use of sustainable materials.

The first section delves into passive cooling methods, which leverage natural elements like shade and airflow to keep indoor spaces comfortable with minimal electricity use. The second section focuses on retrofitting existing buildings to boost energy efficiency and enhance urban sustainability, including advanced insulation and the integration of renewable energy sources. The final section emphasizes the importance of choosing appropriate building materials.

Providing practical recommendations and insights into sustainable building practices, this guidebook is an essential resource for architects, construction professionals, and policymakers committed to advancing sustainable cooling solutions in the country.


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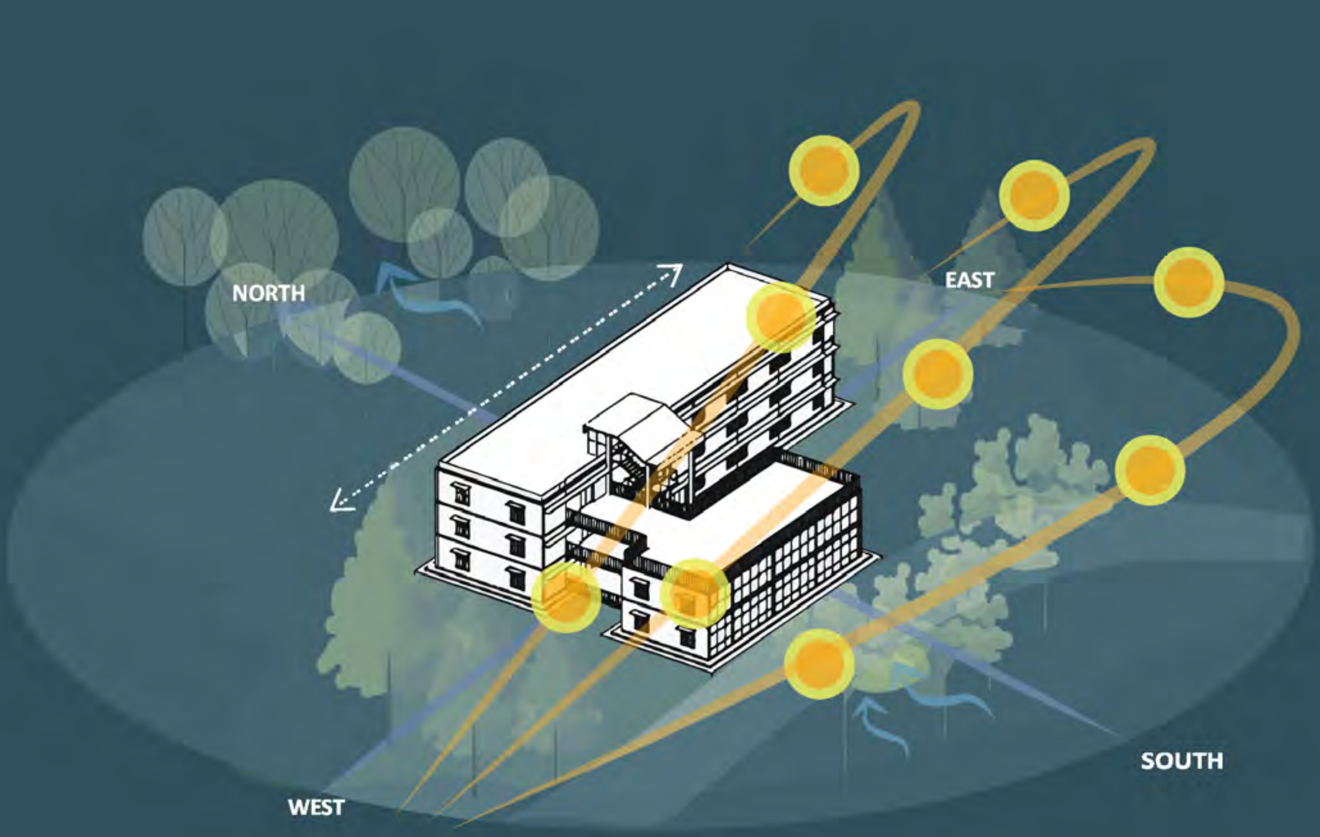
1

PASSIVE COOLING STRATEGIES

This chapter explains how passive cooling methods can keep buildings comfortable without relying on electricity. Passive cooling uses natural elements like shade, air, and building materials to reduce indoor temperatures. By designing buildings with passive cooling in mind, we can create spaces that stay cool on their own, lowering energy bills and reducing environmental impact.



1.1 How Buildings Gain and Lose Heat

Buildings naturally interact with the temperature outside through their walls, roofs, and windows. In hot weather, they can absorb heat from outside, making the indoor space warmer. Conversely, in cooler weather, heat can escape from inside the building. By understanding how heat moves in and out, we can design homes that stay cooler naturally, reducing our reliance on air conditioning. Factors like sunlight coming through windows and air leaks also affect this process. Buildings exchange heat through three main ways: conduction (heat traveling through materials), convection (warm air moving around), and radiation (heat transferred through rays) (**Fig 1.1**). Understanding and managing a building's heat exchange through passive methods is crucial for creating energy-efficient buildings, supporting HCFC phase-out in India, and maintaining comfortable indoor environments.

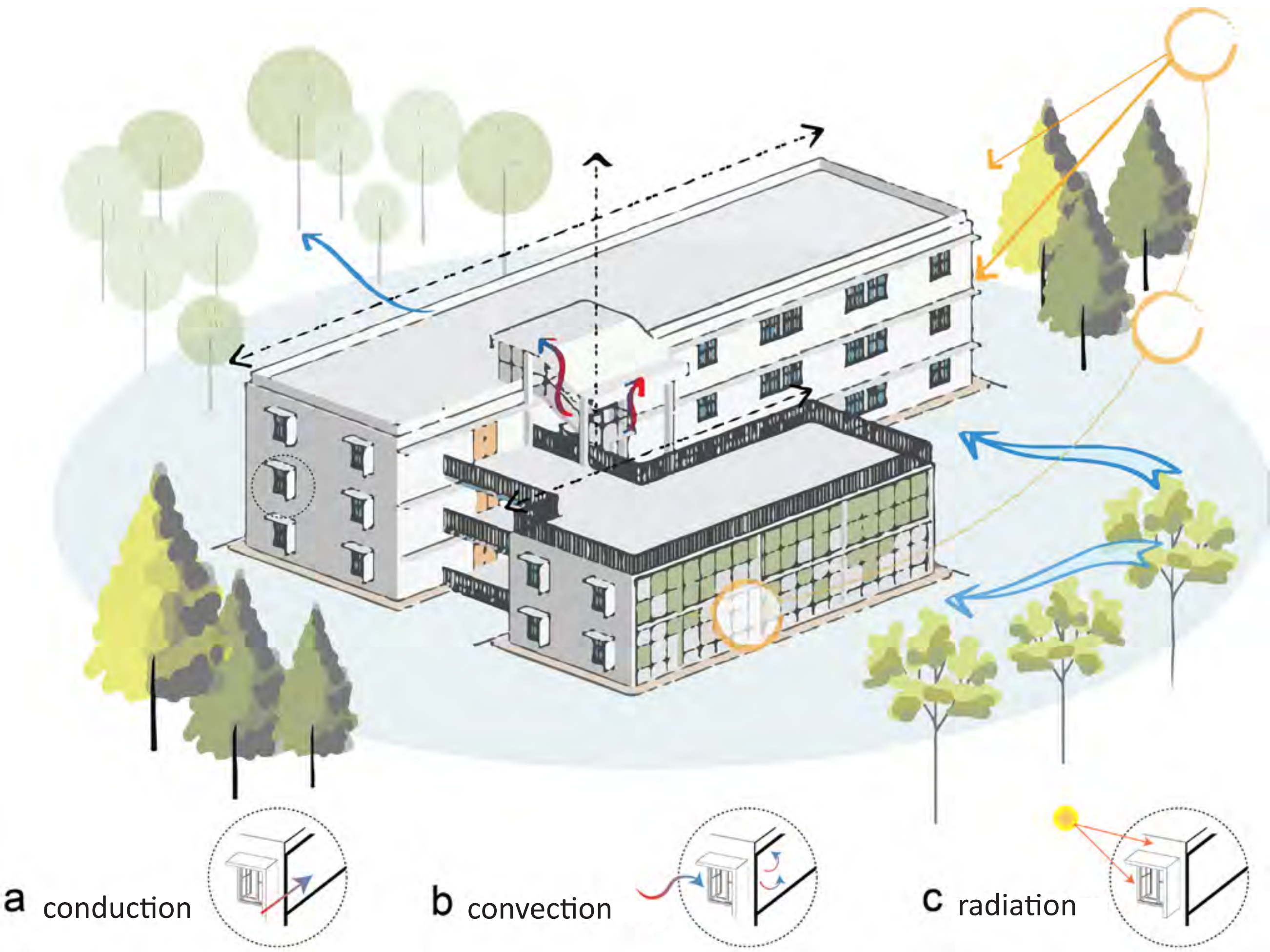


Figure 1.1 Overview of heat exchange between the building and its surroundings

1.2 Passive Cooling Systems

Passive cooling focuses on informed design choices that help keep indoor spaces cool by harnessing natural forces. These techniques are tailored to the building's location, climate, and design. The goal is to minimize heat entering the building and keep it comfortable without mechanical systems.

There are three main strategies for passive cooling (**Fig 1.2**):

Heat Protection - Blocking heat from entering the building.

Heat Modulation - Controlling how much heat the building absorbs.

Heat Dissipation - Releasing excess heat from the building.

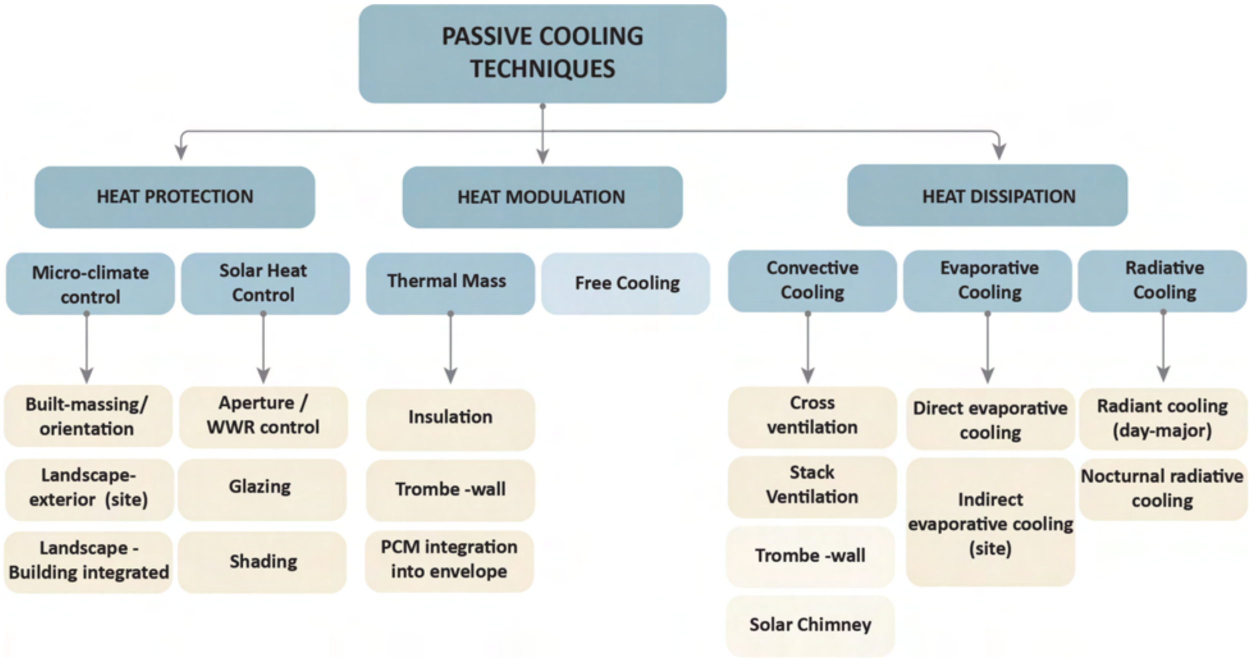


Figure 1.2 Passive Cooling Techniques (Bhamare, Rathod, and Banerjee 2019)

1.2.1 Heat Protection

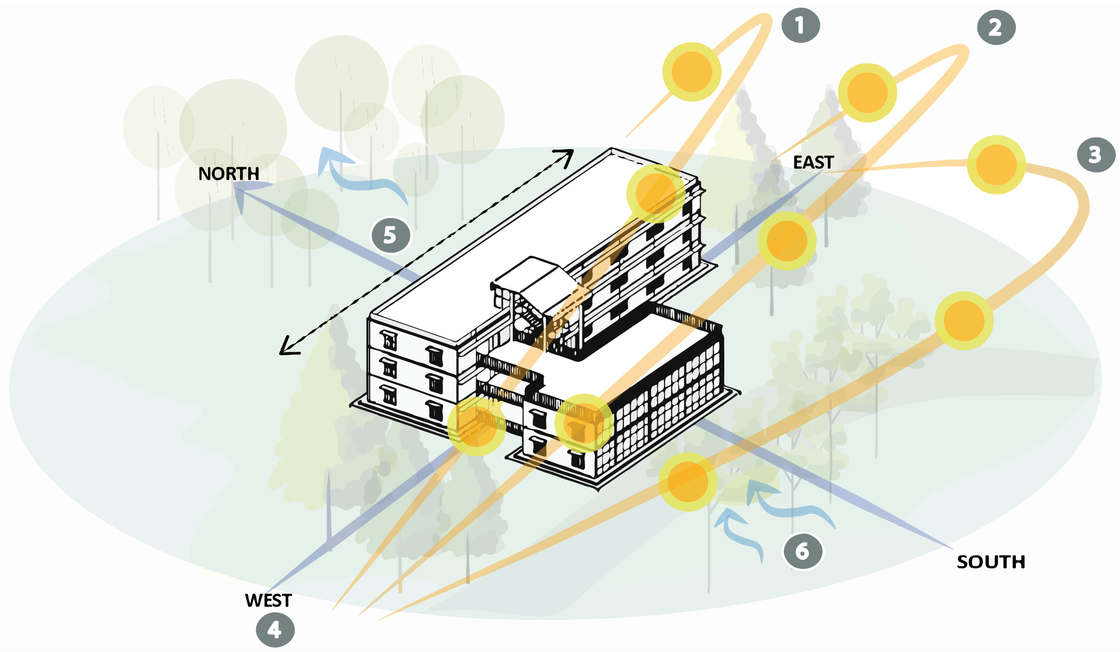
The first step is to prevent heat from entering the building. This can be done by making smart decisions during the design phase:

- **Building Orientation:** Positioning a building so the longest sides face north and south can reduce the amount of direct sunlight, helping to keep the building cooler (**Fig 1.3**).
- **Landscaping:** Planting trees and shrubs around a building provides natural shade, reducing heat gain. Trees help cool the air and block sunlight, creating a more comfortable environment (**Fig 1.4**).
- **Shading:** Using overhangs, awnings, or natural shade from trees helps block direct sunlight, reducing heat inside the building (**Fig 1.5**).

1.2.2 Heat Modulation

This strategy involves using materials that help regulate indoor temperatures:

- **Thermal Mass:** Materials like stone or concrete absorb heat during the day and release it at night when it's cooler. This helps maintain a comfortable indoor temperature without the need for air conditioning (**Fig 1.6** and **Fig 1.7**).
- **Insulation:** Proper insulation slows down the transfer of heat, keeping buildings cooler in the summer and warmer in the winter (**Fig 1.8**). For example, cool roofs or a light-coloured roofing material reflect sunlight, reducing heat absorption and keeping the building cooler (**Fig 1.9**).



1 SUMMER SOLSTICE
Summer Sun Extreme
June 21

Sun at a higher angle, North to E-W axis.
Glare free daylight on North facade, minimal solar radiation fall at high angle.
Easy South facade shading.

2 AUTUMN-EQUINOX
Average Sun position
September 22

Sun is most inclined.
S-E to S-W inclined move.
Shading patterns and PV tracking need to be quantified over these inputs.

3 WINTER SUN-PATH
Winter Sun Extreme
December 22

Sun at low angle, South to E-W axis.
Solar radiation penetrate South facades at a low angle during winter.

4 **East and West facades** continue to receive uniform, **strong solar radiation** at a low angle through the year.

5 To **minimize western and eastern direct solar exposure** and strong solar gain, the **N-S (north-south) stretched orientation** in the built mass is preferred.

6 The N-S stretch also helps building orientation to get in the natural major wind-flow path (summer to monsoon time major wind flow direction is from South-west, South prevalently in Indian Sub-continent.

Figure 1.3 Building orientation utilizing the advantages of reduced solar gain and favorable wind flow

1 Shading
Evergreen, closely spaced trees for shading west facade.

2 Natural Lighting
Trees should be at a distance from the northern side to allow daylight.

3 Plantation-wind-flow
Plantation for funneling wind from the building.

4 Shading
Evergreen trees spaced distantly for shading east facing walls.

5 Heat Gain
Deciduous trees provide solar access during winter along with deep verandahs on south side for sunlight.

6 Flexible shading device
Creepers for shading verandahs, interior spaces as per season.

7 Reduced Albedo
More of green covering reduces Albedo Effect.

8 Green Roof
More indoor cooling and additional insulation.

Figure 1.4 Landscape and Natural vegetation enhancing Passive cooling strategies

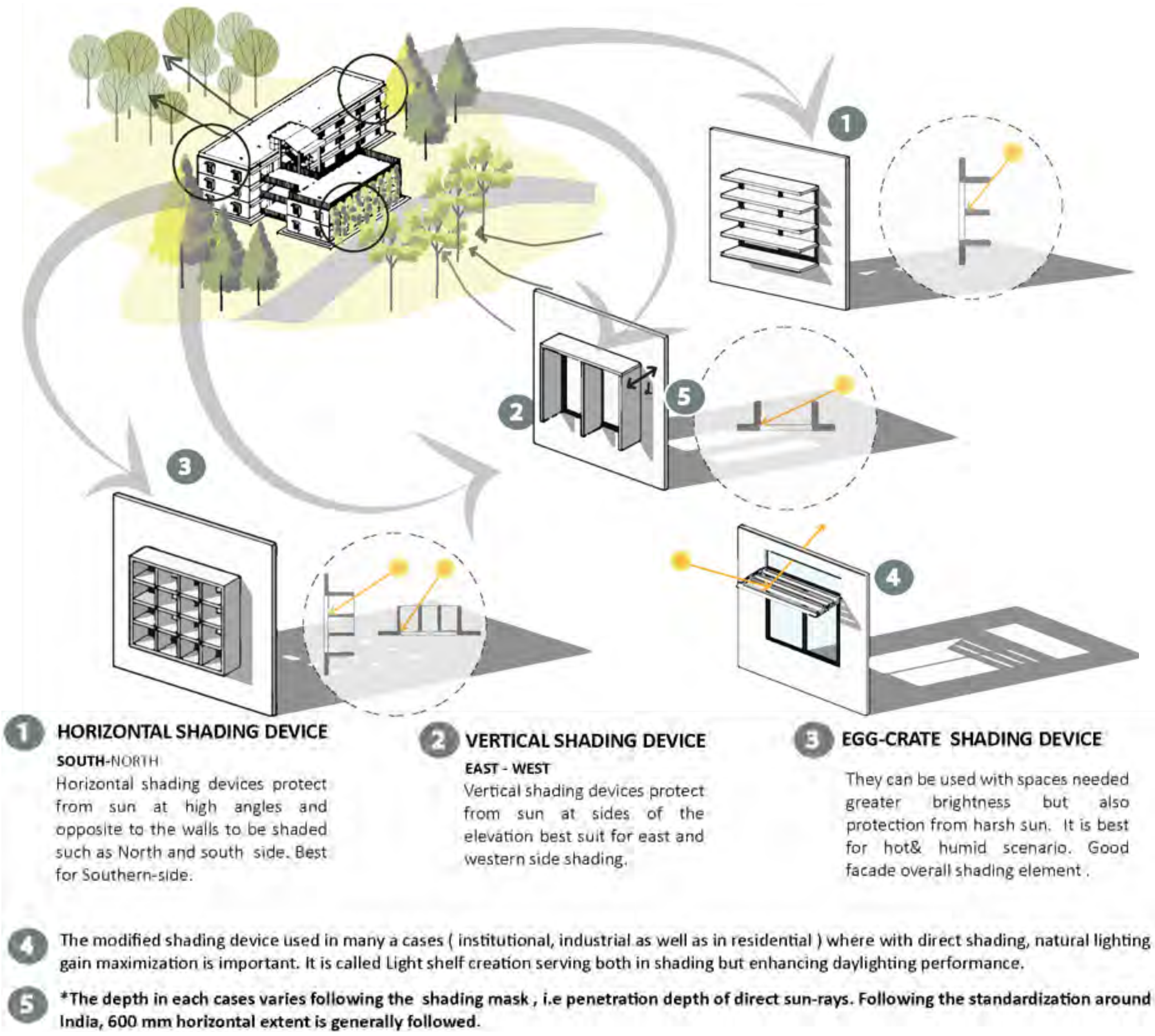


Figure 1.5 Shading Device design in building façade in Indian context

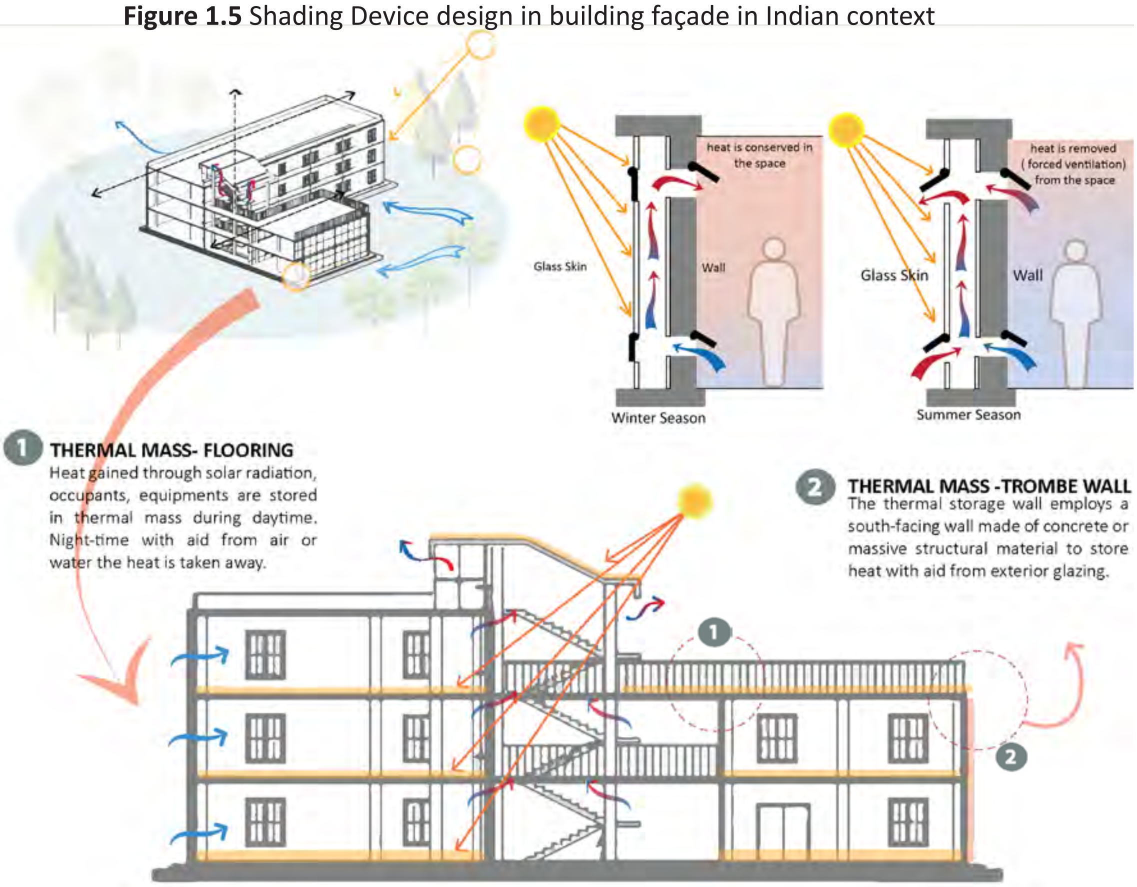


Figure 1.6 Trombe walls application in building walls to regulate indoor temperature

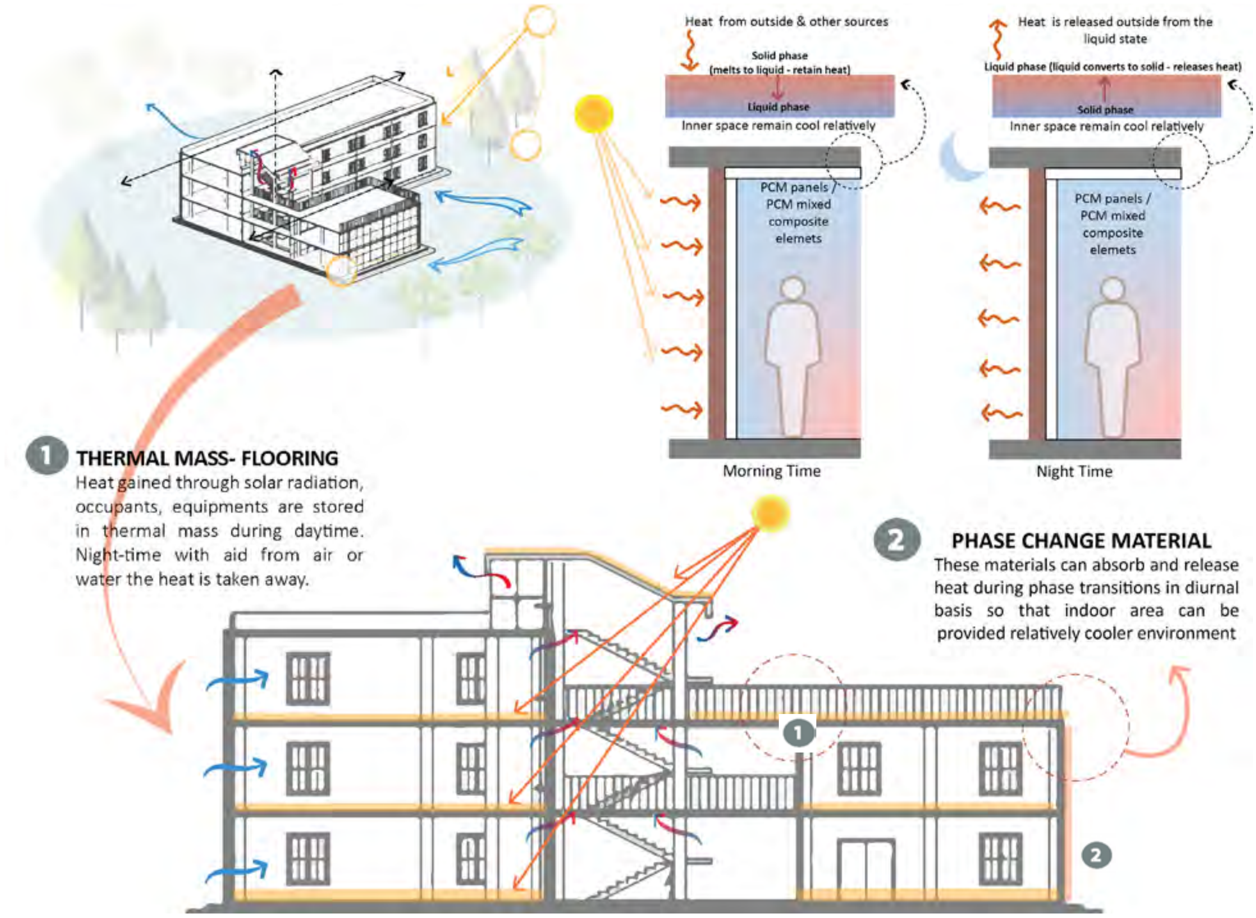


Figure 1.7 Phase change material (PCM) application in building envelope to regulate indoor temperature

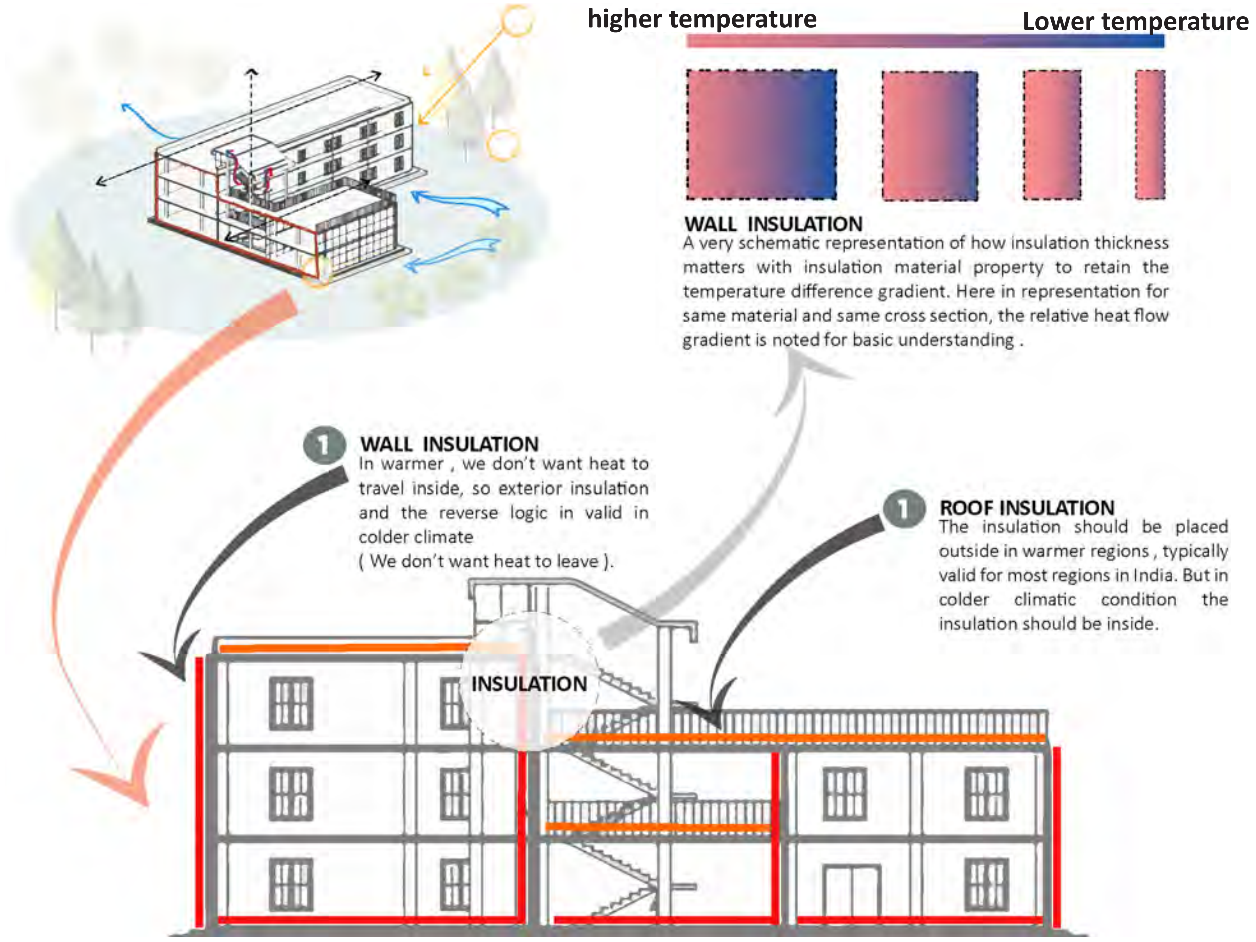


Figure 1.8 Application of building insulation

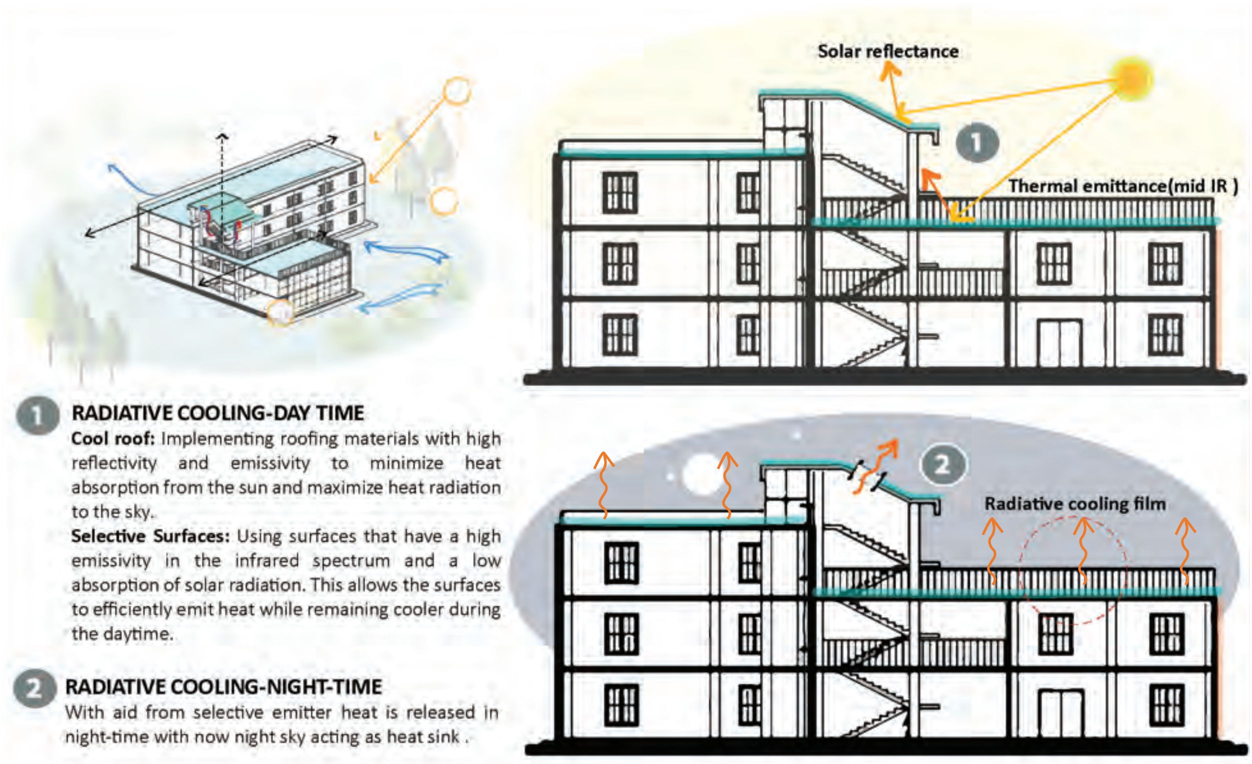


Figure 1.9 Schematic diagram of the radiative cooling

1.2.3 Heat Dissipation

Heat that builds up inside a building needs to be released. Here are some effective ways to do this:

- **Natural Ventilation:** Designing windows and openings to allow fresh air to flow through the building helps cool it down naturally. This is a simple and cost-effective way to keep homes comfortable. (**Fig 1.10, Fig 1.11**).
- **Water Features:** Adding fountains, ponds, or wet walls near buildings cools the surrounding air through evaporation, providing relief from the heat (**Fig 1.12**).

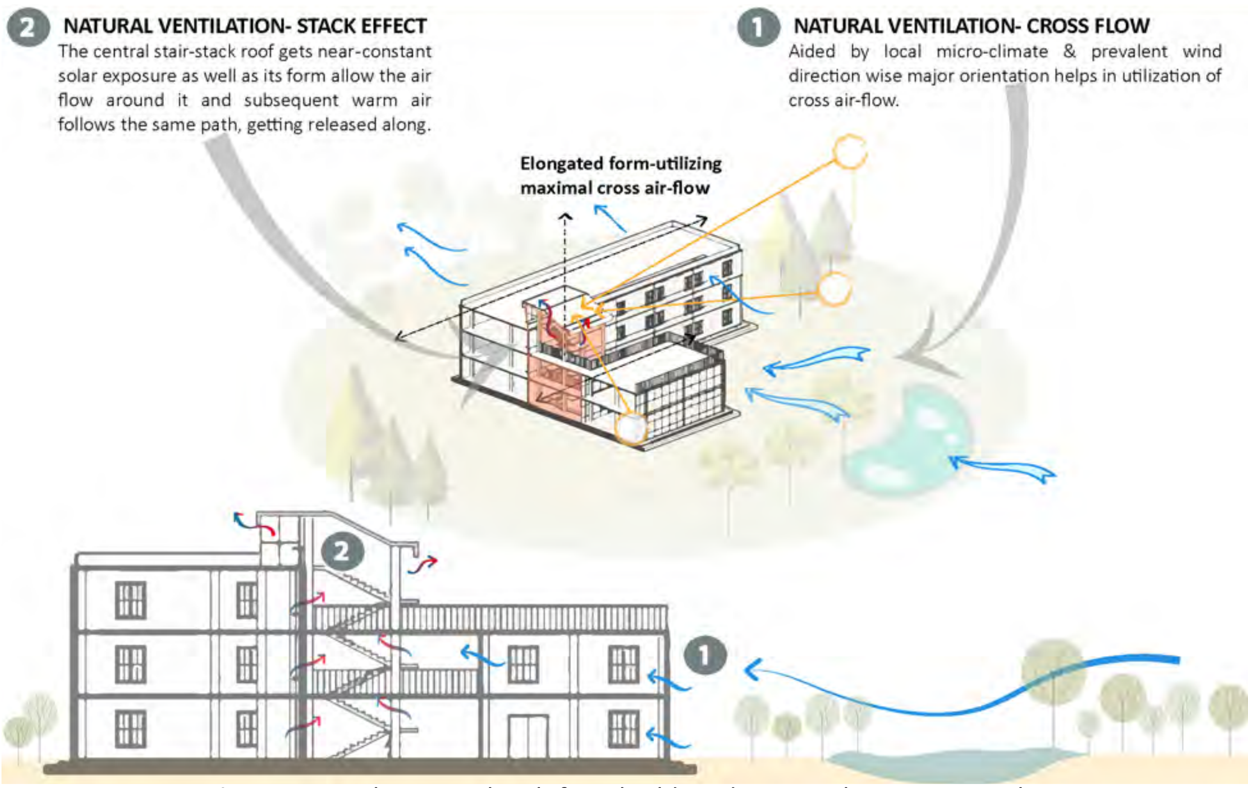


Figure 1.10 Schematic sketch for a building design with passive ventilation

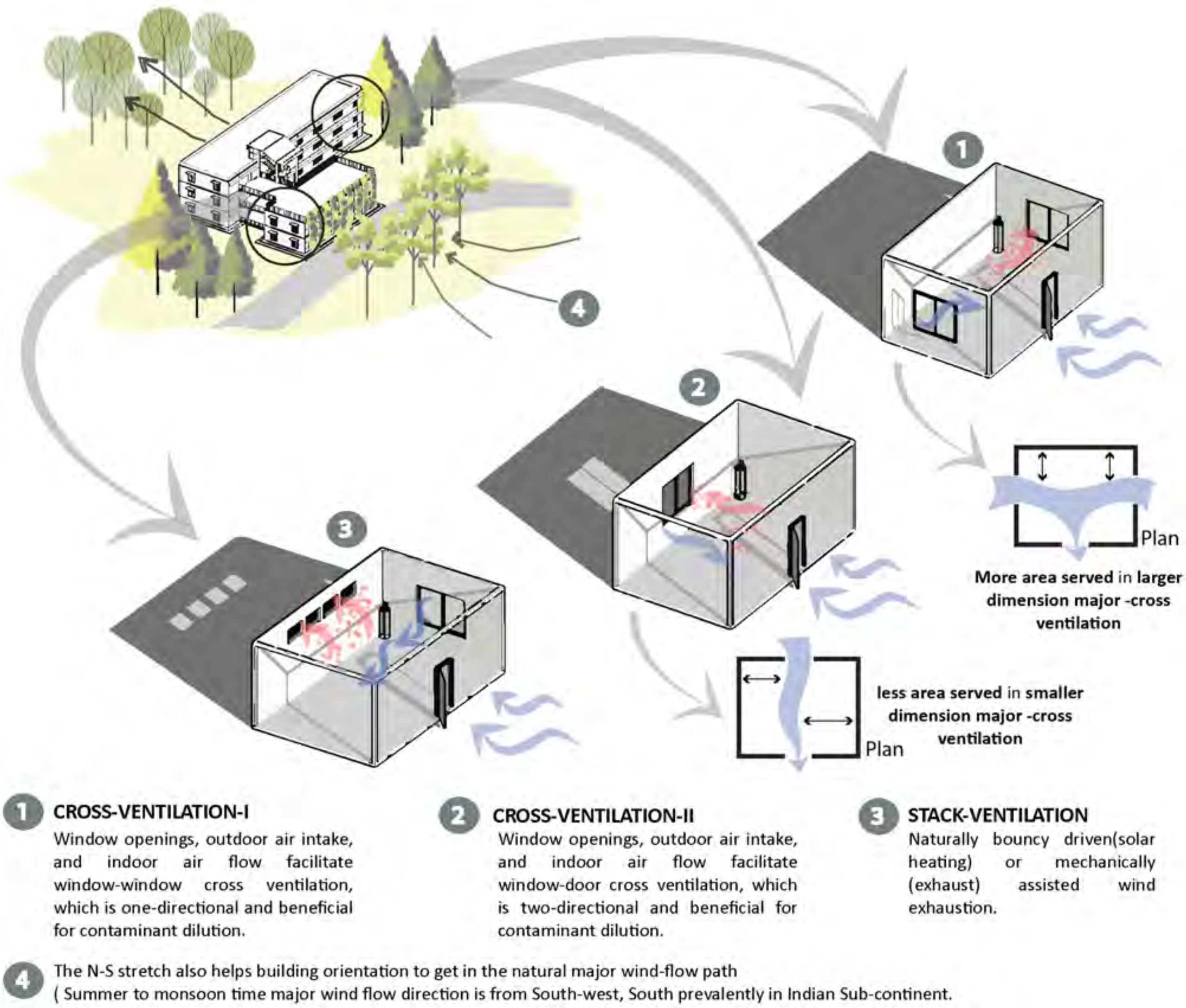


Figure 1.11 Natural ventilation strategies for room layout design

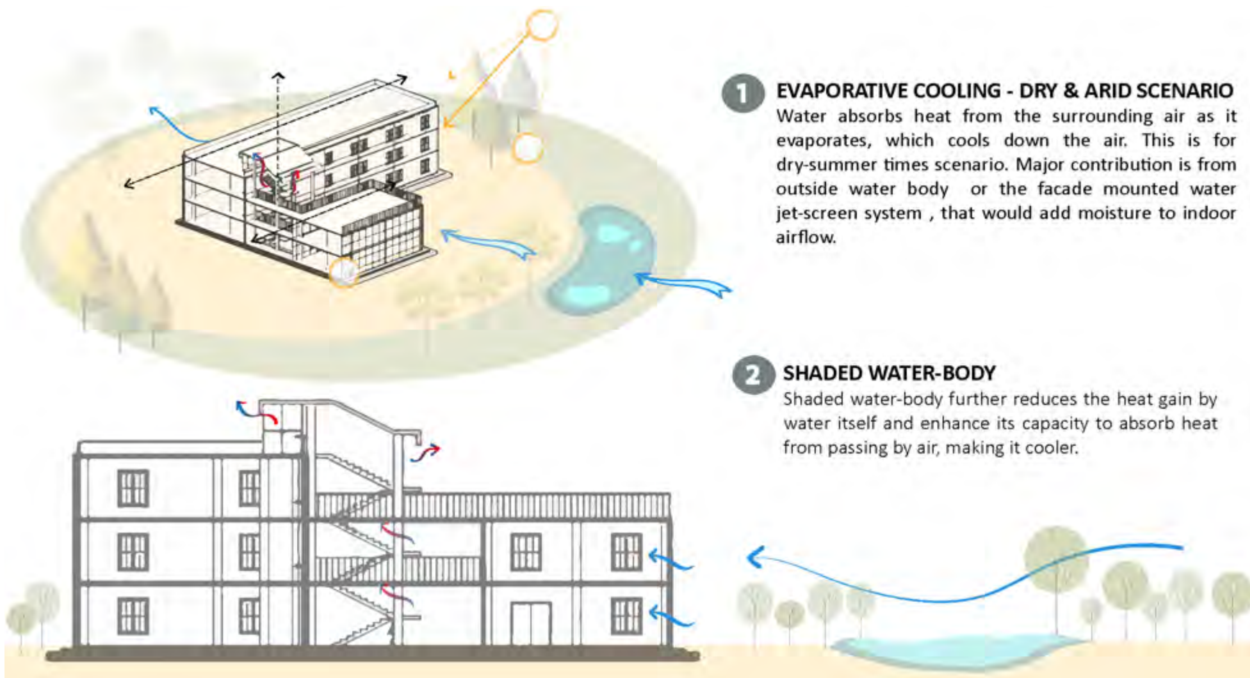


Figure 1.12 Schematic diagram of the evaporative cooling process aided by local micro-climate regulation

1.3 Why Passive Cooling is Important for India?

In regions with hot climates, such as many parts of India, passive cooling strategies are crucial for reducing energy consumption and improving indoor comfort. These techniques, can lower electricity bills, create healthier living spaces, and reduce the strain on power grids. Convective cooling methods, like wind-driven and buoyancy-driven ventilation, are effective in both hot and humid as well as temperate climates. On the other hand, techniques like the Trombe wall are better suited to hot and dry, as well as hot and humid conditions. For heat dissipation, evaporative and radiative cooling techniques are most effective in hot and dry climates.

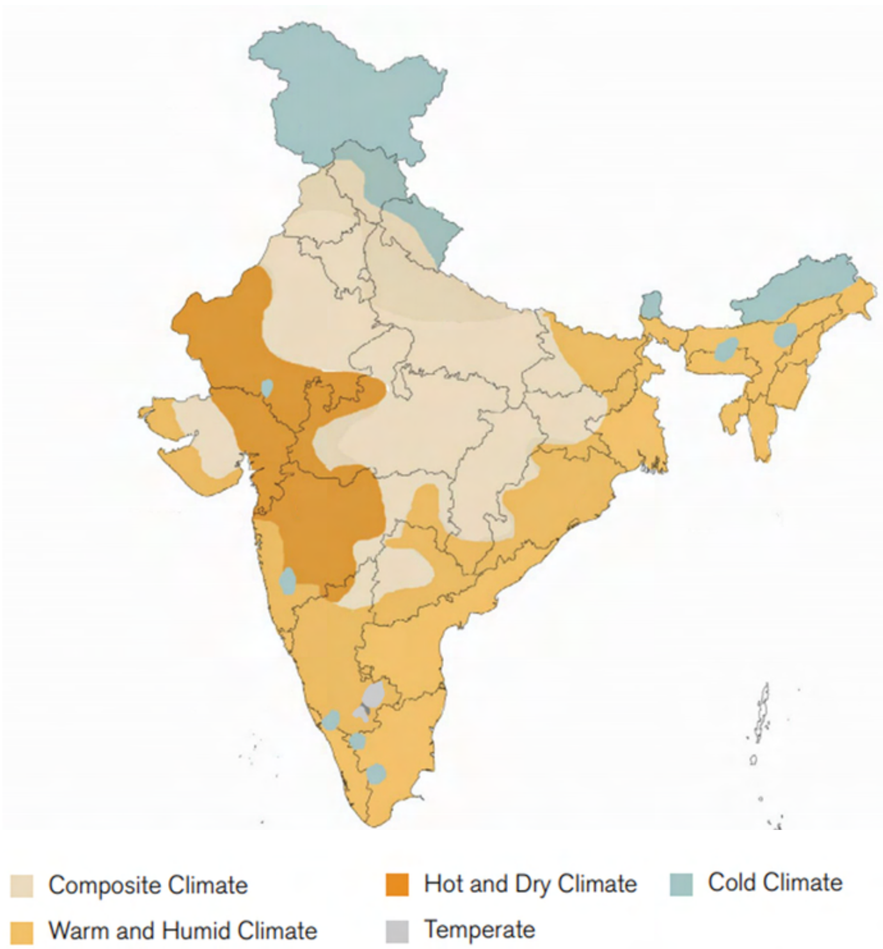


Figure 1.13 climate regions in India

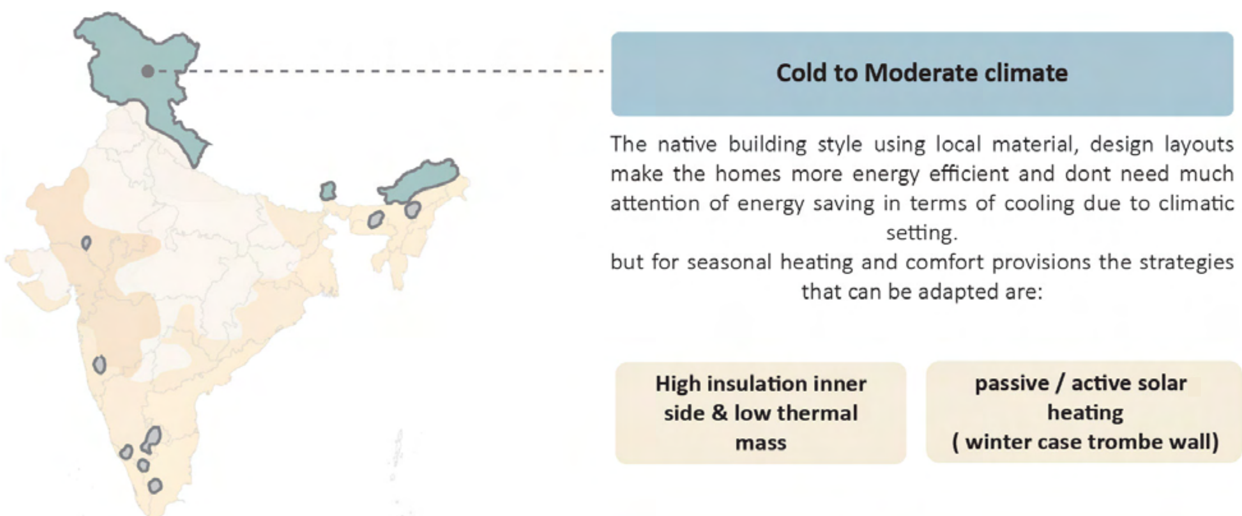


Figure 1.14 Passive Cooling Techniques adapted around the climate regions in India

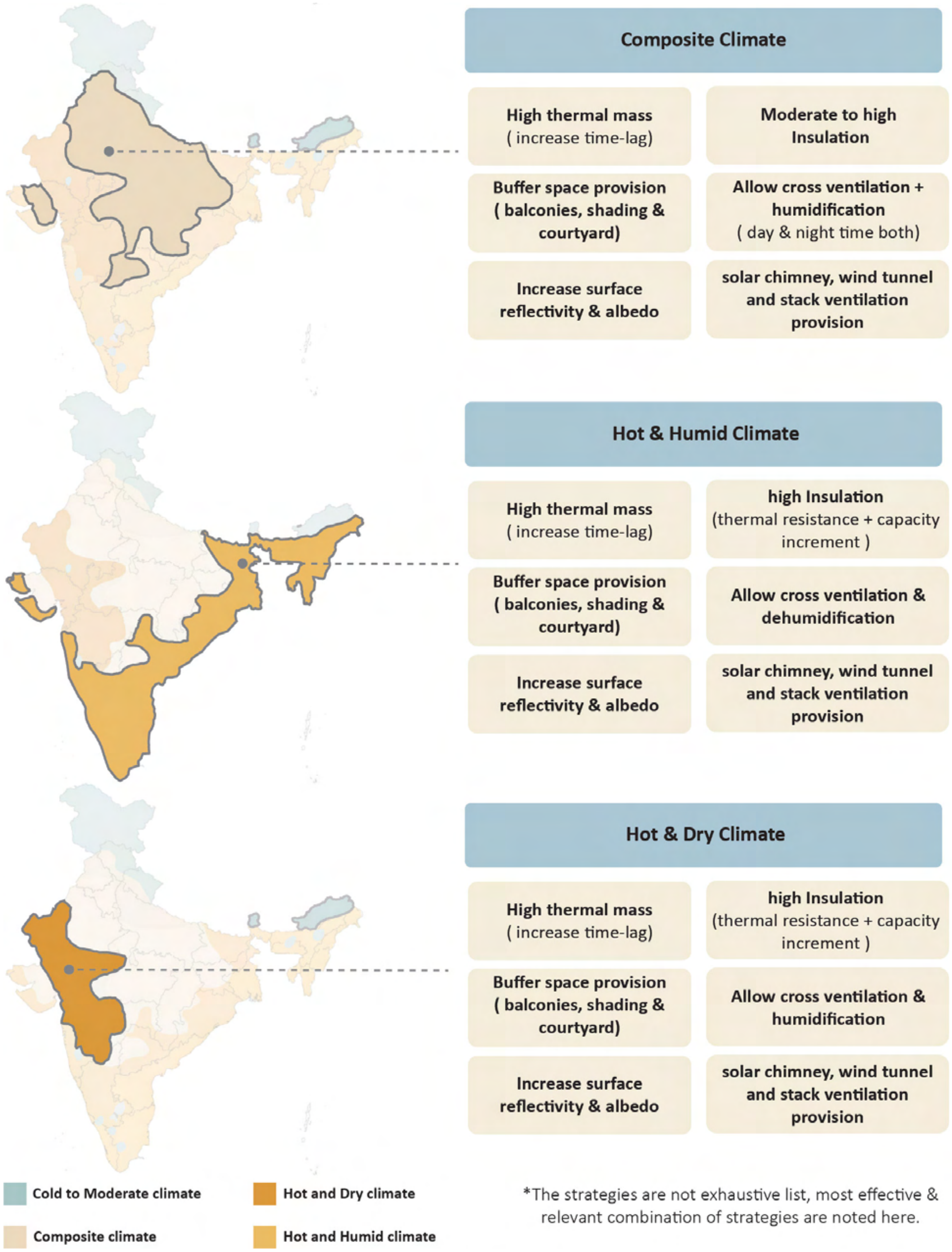


Figure 1.13 Passive Cooling Techniques adopted around the climate regions in India

The key takeaway from this chapter is that passive cooling techniques can be tailored to specific climate conditions, building designs, and local resources, resulting in energy-efficient cooling solutions.

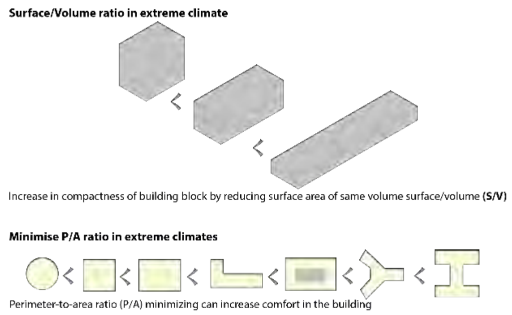
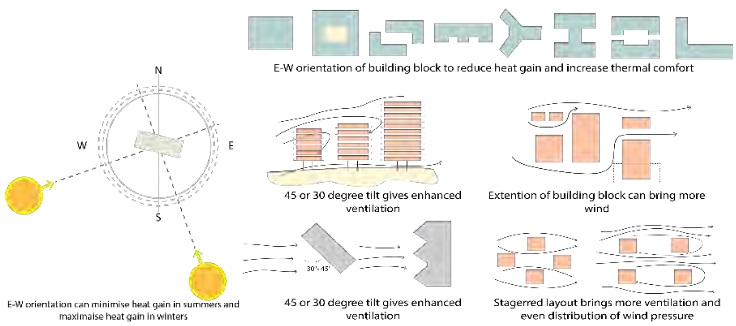
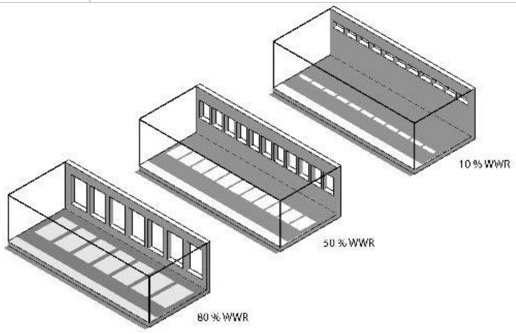
This chapter provides practical guidance on how passive cooling can be applied to both new buildings and older ones that need retrofitting. These strategies help homeowners and communities create cooler, more energy-efficient spaces without relying on costly and energy-hungry air conditioning systems.

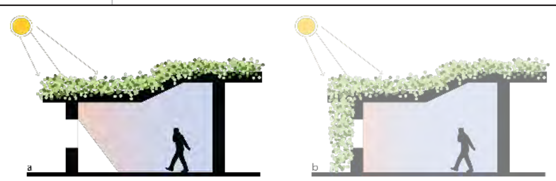
Reported Benefits Through Best Practices of Passive Cooling

(Performance metrics are based on referenced sources. These figures are indicative and may vary depending on specific conditions like climate, building design, and operations. Users should consult professionals to tailor strategies to their unique situations.)

<table>
<tr><th>Passive Strategy</th><th>Sub category of strategy</th><th>Scenario</th><th>Reported benefits</th></tr>
<tr><td rowspan="6">Building massing and Orientation

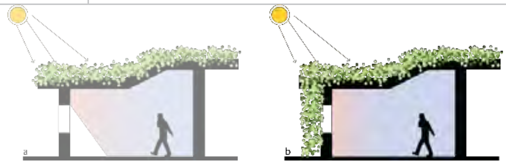
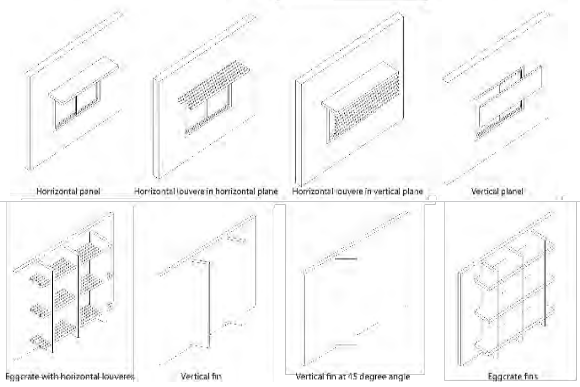
(Abanda and Byers 2016; Bhamare, Rathod, and Banerjee 2019; Ciardiello et al. 2020; Feng et al. 2021; Kheiri 2018; Mirrahimi et al. 2016; Ndiaye 2018; Savvides et al. 2019; Yilmaz 2007)</td><td>Building Design</td><td>Compact building shape

(Lower Surface Area / volume ratio)</td><td rowspan="6">Thermal comfort hours are increased by 1.5%</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Building Orientation</td><td>North-South elongated orientation</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Window Design (WWR)</td><td>Lower WWR on south-facing walls (Indian scenario) (e.g., 20%) % overall <=30%</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td rowspan="2">Building Micro-climate & Landscape

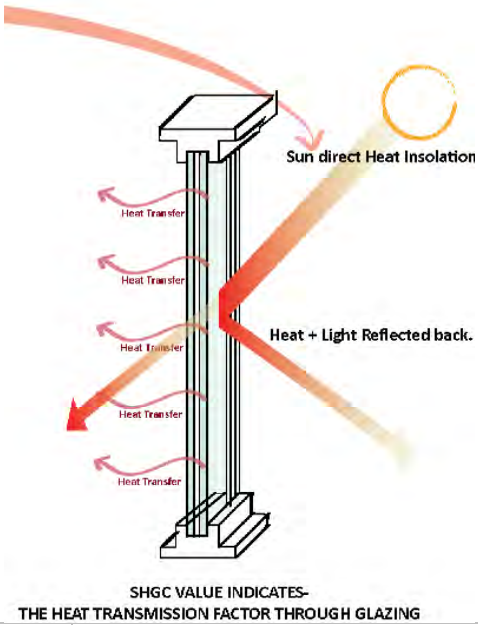
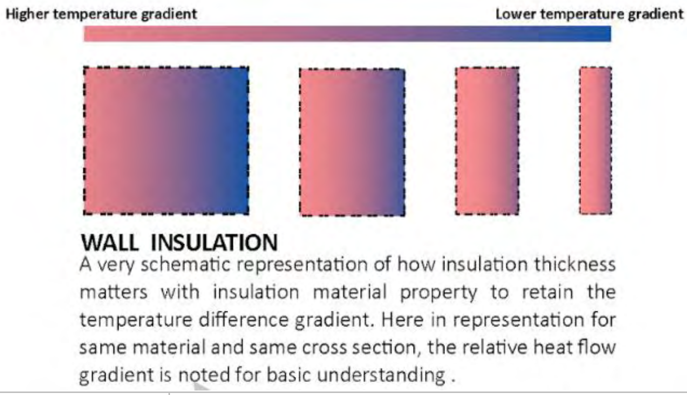
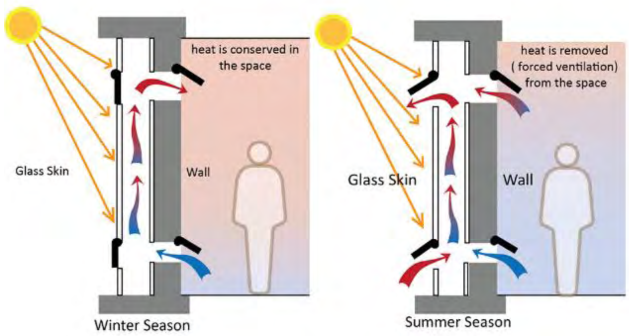
(Berardi 2016; Besir and Cuce 2018; Borràs et al. 2022; Dahanayake and Chow 2018; Manso et al. 2021; Wang, Yang, and Xiang 2023)</td><td>Green Roofs</td><td>Green roof with vegetation for insulation, evapotranspiration cooling</td><td rowspan="2">Thermal comfort hours are increased by 0.5-2%</td></tr>
<tr><td colspan="2">

Flexible shading devices for shading building as per the seasons. (a) Winter sun bringing light in the building</td></tr>
</table>

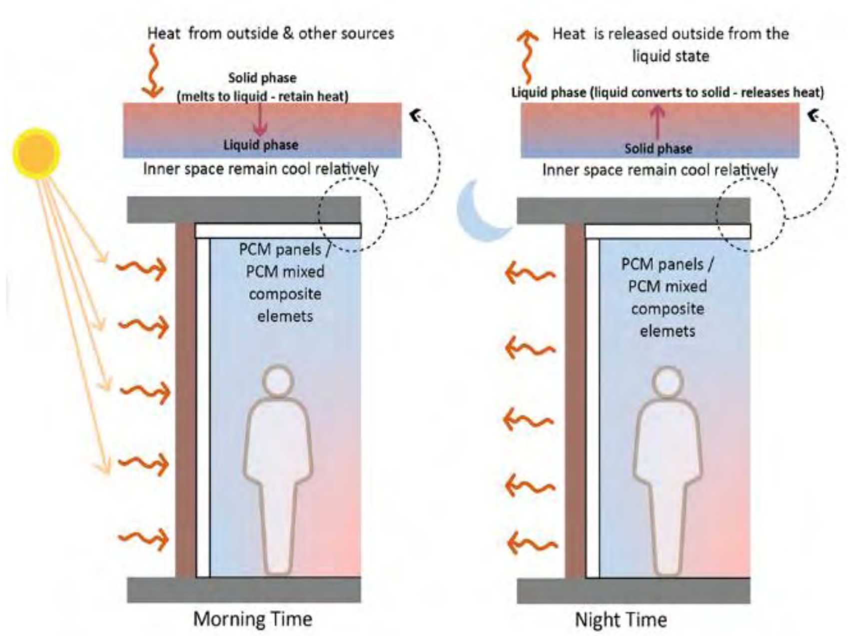
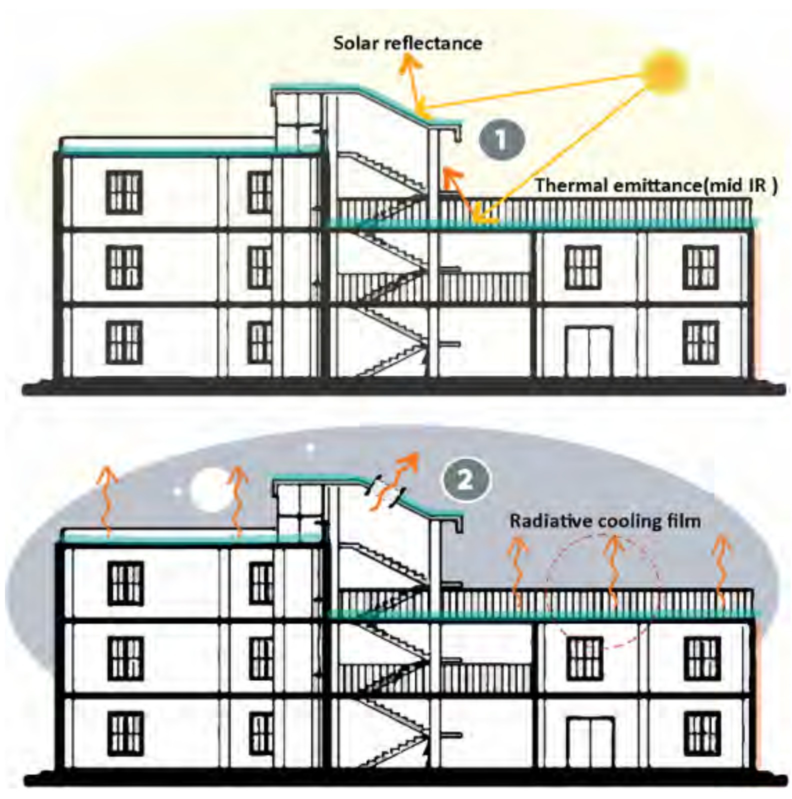
Reported Benefits Through Best Practices of Passive Cooling

Passive Strategy	Sub category of strategy	Scenario	Reported benefits
Building Micro-climate & Landscape (Berardi 2016; Besir and Cuce 2018; Borràs et al. 2022; Dahanayake and Chow 2018; Manso et al. 2021; Wang, Yang, and Xiang 2023)	**Green Roofs**	**Green roof with vegetation for insulation, evapotranspiration cooling**	**Thermal comfort hours are increased by 0.5-2%**
	 Flexible shading devices for shading building as per the seasons (b) Summer covering the facade to avoid heat gain through facade.		
	Site overall Landscaping	**Strategic landscaping with trees, shrubs, and groundcover for shade, wind channelling, and heat mitigation**	
	 		
	Shading Devices	**Overhangs and deep eaves for shading (e.g., shading 50% of south-facing windows)**	
Building Solar Control - Shading (Cho, Yoo, and Kim 2014; Dabbagh and Krarti 2021, 2022; Dutta and Samanta 2018; Lau et al. 2016; Liu et al. 2019)	 		**Thermal comfort hours are increased between 0.5% and 2%.**

Reported Benefits Through Best Practices of Passive Cooling

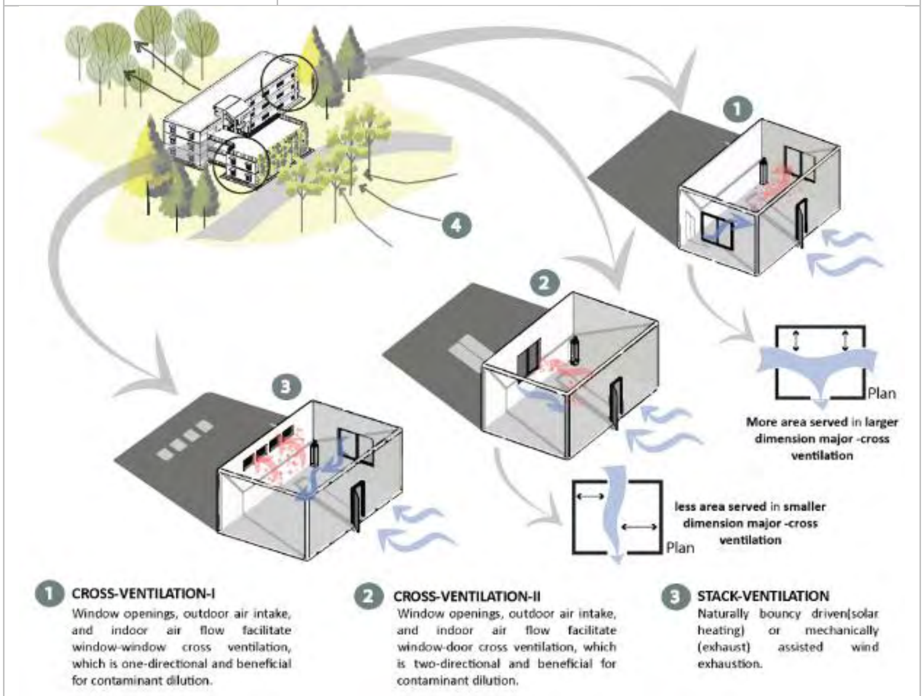
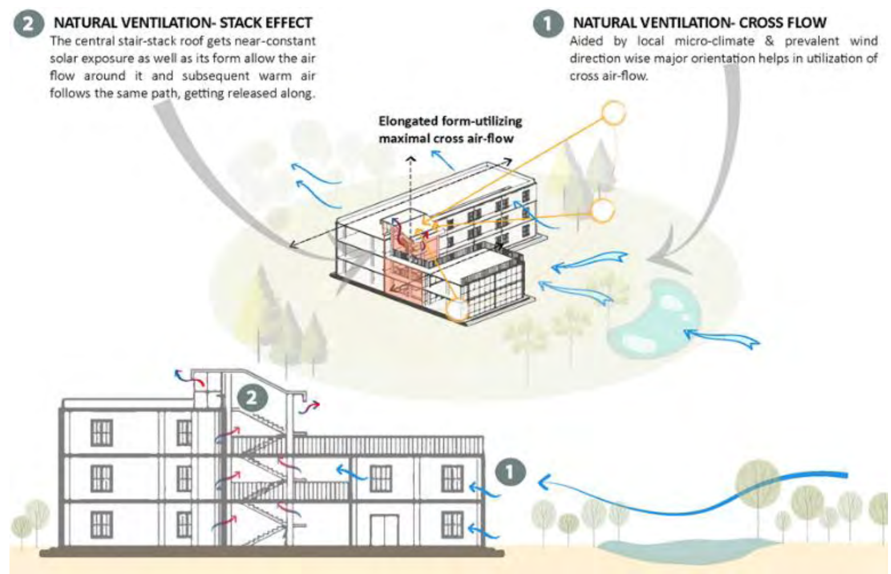
Passive Strategy	Sub category of strategy	Scenario	Reported benefits
Building Solar Control – Fenestration (Dutta and Samanta 2018; G et al. 2018; Kim, Yoon, and Lee 2017)	**Glazing Properties**	Judicious window location, sizing, and glazing can reduce cooling loads and enable smaller cooling systems. Also, usage of low SHGC, low E glasses, spectrally selective glasses help in heat gain reduction	**~21-33% annual energy savings**
			
Thermal Mass (Al-Sanea, Zedan, and Al-Hussain 2013; Albayyaa, Hagare, and Saha 2019; Ashtari, Yeganeh, and Daneshjoo n.d.; Le Dréau and Heiselberg 2016; Karlsson 2012; Kuczyński and Staszczuk 2020; Li et al. 2023; Reilly and Kinnane 2017; Sánchez Ramos et al. 2019; Zilberberg et al. 2021)	**Thermal Mass and Insulation**	Thermal mass helps to store heat within the building structure and moderate fluctuations in the indoor temperature.	
			**The intensity of thermal discomfort decreases with a potential reduction of indoor temperature by 4.8-6 °C**
	Trombe Wall	Seasonal working pattern to note, more efficient with PCM, insulation/air gap	
			

Reported Benefits Through Best Practices of Passive Cooling

Passive Strategy	Sub category of strategy	Scenario	Reported benefits
Thermal Mass (Al-Sanea, Zedan, and Al-Hussain 2013; Albayyaa, Hagare, and Saha 2019; Ashtari, Yeganeh, and Daneshjoo 2020.; Le Dréau and Heiselberg 2016; Karlsson 2012; Kuczyński and Staszczuk 2020; Li et al. 2023; Reilly and Kinnane 2017; Sánchez Ramos et al. 2019; Zilberberg et al. 2021)	**Phase change Material application**	Integrating PCM in walls, floors, and ceilings and also as nano format helps 	**The intensity of thermal discomfort decreases with a potential reduction of indoor temperature by 4.8-6 °C**
Radiative Cooling (Bijarniya, Sarkar, and Maiti 2020; Hanif et al. 2014; Vall, Castell, and Medrano 2018; Wijesuriya et al. 2022; Zhang et al. 2018)	**Daytime and night-time cooling**	Application on the exterior surface (roof majorly) with high albedo value >0.5 	**Indoor temp. reduction is up to 1.6°C**

Reported Benefits Through Best Practices of Passive Cooling

<table>
<tr><th>Passive Strategy</th><th>Sub category of strategy</th><th>Scenario</th><th>Reported benefits</th></tr>
<tr><td rowspan="2">Ventilation and Airflow

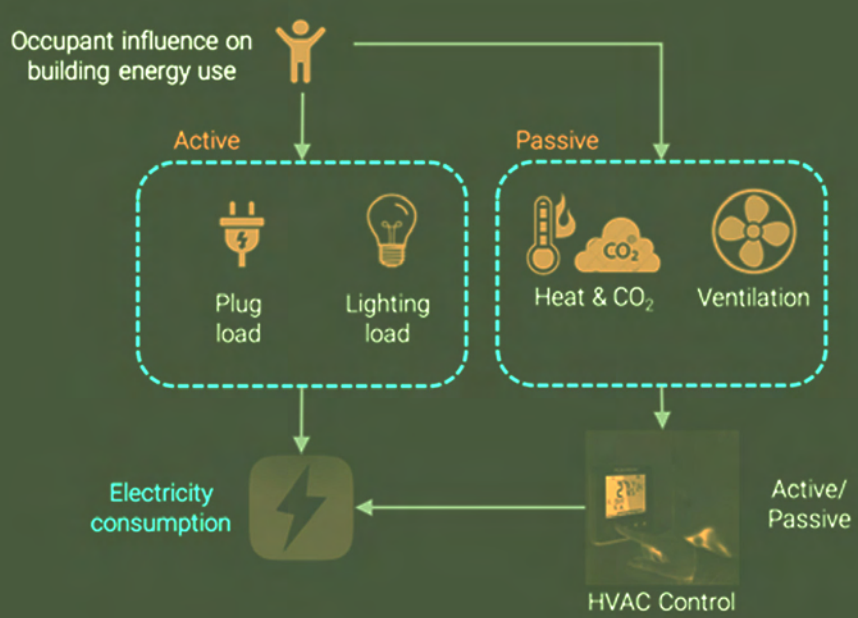
(Ben-David and Waring 2016; Chenari, Dias Carrilho, and Gameiro Da Silva 2016; Oropeza-Perez and Ostergaard 2014; Schulze and Eicker 2013)</td><td>Cross Ventilation and Stack ventilation</td><td>a mixed-mode building operated based on the adaptive comfort criteria can have a large reduction of energy use</td><td rowspan="2">Indoor temp. reduction is up to 5 °C</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td rowspan="2">Evaporative Cooling
(Cuce and Riffat 2016; Naticchia et al. 2010; Ryan Savero et al. 2020)</td><td>Site major evaporative cooling</td><td>Placement of water source in natural ventilation pathway
Effective for hot and dry climate zones</td><td rowspan="2">Indoor temp. reduction is up to 2.5 °C Relative humidity increased up to 70-80%</td></tr>
<tr><td colspan="2">
</td></tr>
</table>


@created with help of AI

2

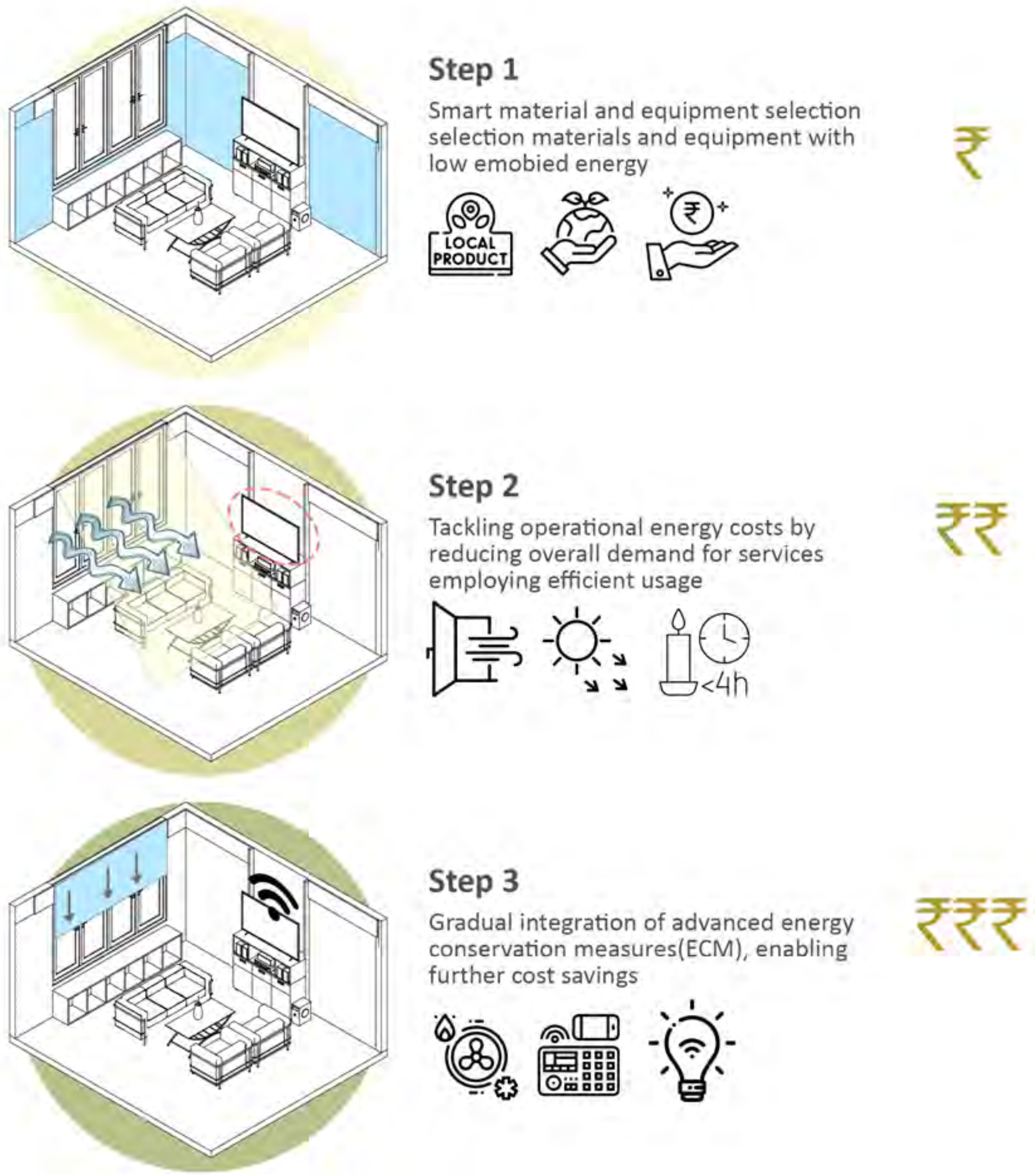
BUILDING RETROFITTING STRATEGIES

This chapter discusses key considerations for the design of new buildings and retrofitting of existing buildings. While there is a focus on energy efficiency in new buildings, retrofitting existing structures is crucial for improving urban sustainability. Buildings depend on various electrical and mechanical systems to maintain comfort and efficiency of indoor occupants. Effective retrofitting can enhance thermal, acoustic, and visual comfort while addressing energy use, occupant health and well-being, and urban heat challenges.



2.1 Why Retrofitting Matters

Retrofitting existing buildings in India is essential for creating more liveable and sustainable urban environments. By addressing urban heat and improving energy efficiency, retrofitting can serve as a model for new building designs and city planning, better preparing them to handle the challenges of a warming world. The potential for energy savings through retrofitting is evident, as shown in **Fig. 2.1**, which illustrates the cost versus energy conservation measures. However, careful evaluation and accurate estimation of these savings are crucial for effective implementation. For example, post-COVID, proper ventilation in building design has become even more critical for maintaining healthy indoor environments, but it must be balanced with energy efficiency. Integrating strategies that enhance ventilation while optimizing energy use ensures that indoor spaces are not only energy-efficient but also comfortable and conducive to the well-being of occupants. Furthermore, before retrofitting, it is vital to assess a building's energy-saving potential through a thorough investigation or audit of its current performance. Conducting a building energy and Indoor Environmental Quality (IEQ) audit provides the foundation for enhancing existing structures and guiding future urban development toward greater sustainability and resilience. The following sections discuss key areas of building retrofitting, supported by research and field experiment findings.



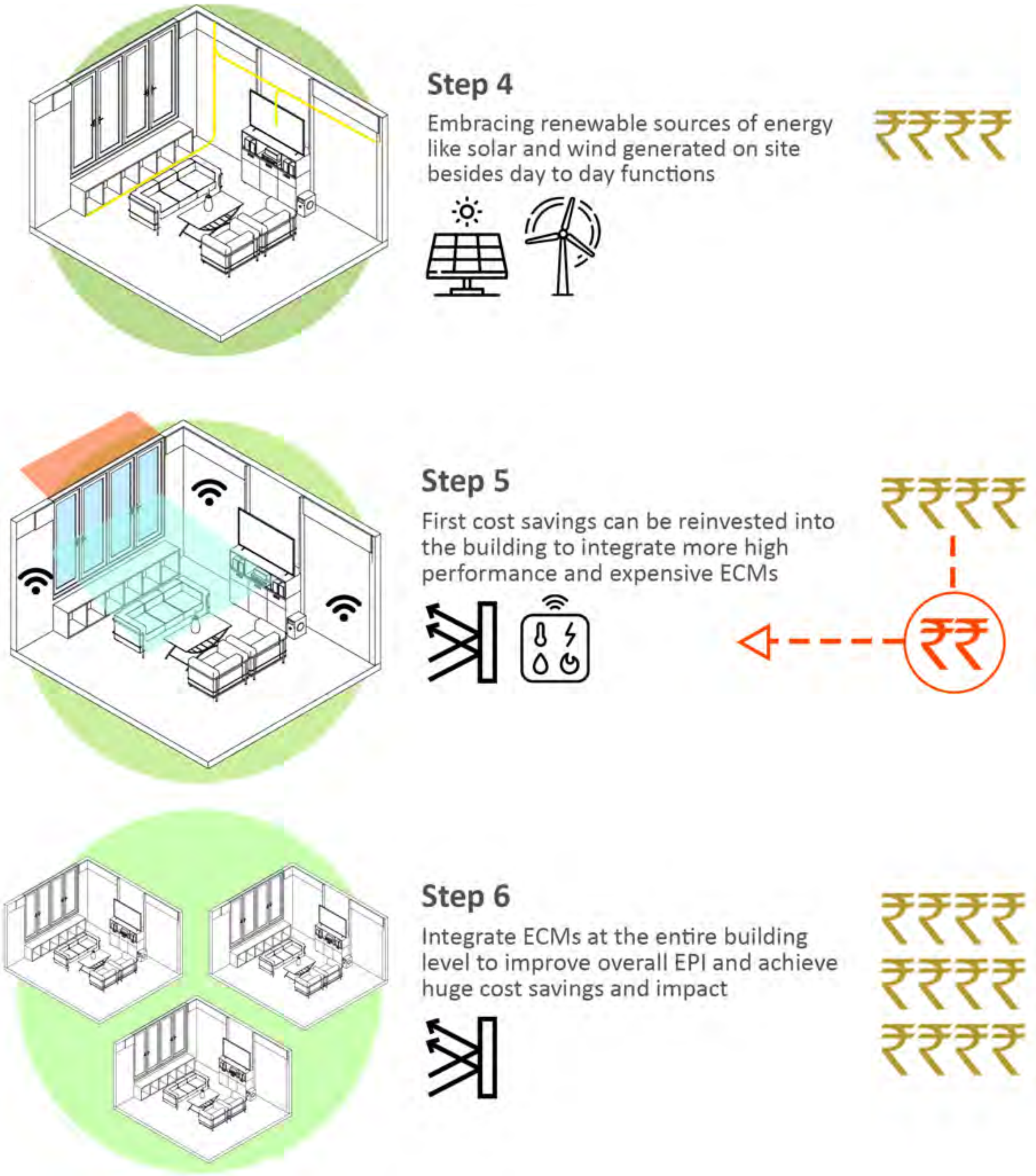


Figure 2.1 Energy Conservation Measures (ECMs)

2.2 Building Envelope Design and Retrofitting

2.2.1 Shading

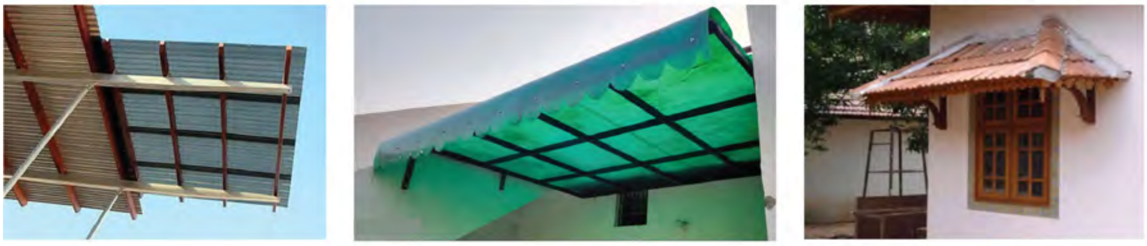
In India, traditional methods for controlling incoming solar radiation in buildings often involve external shading devices like overhangs, pergolas, and jaali screens, which block or filter sunlight to reduce heat gain and glare (see **Fig. 2.2, Fig 2.3**). To retrofit these systems passively, upgrading to more efficient designs or materials is recommended. For example, adjusting overhang dimensions based on local sun angles or replacing conventional blinds and jaali screens to match the sun path can significantly improve their effectiveness. Additionally, installing manually adjustable external shades allows for optimized shading throughout the day, further enhancing energy efficiency and indoor comfort.

Shades / Chajjas under construction

Decorative concrete chajja with tile finish

Simple Concrete slab-chajja

FRP (fiberglass reinforced polymer) Shed



Tin shading

Shading using polythene/polycarbonate sheet

Tiles + tin combined shading with drop

Figure 2.2 Shading options

source: https://healthyhomes.co.in/know-more-about-chajja/, https://shop.sourcefromindia.net/product/frp-chajja/, https://www.indiamart.com/proddetail/tin-shade-colored-roofing-shade-22415959855.html, https://www.indiamart.com/proddetail/fiberglass-roof-sheet-22988257897.html

Figure 2.3 Local recyclable and low-cost overhang options for shading

2.2.2 Insulation

Improving the insulation of building envelopes with advanced materials, such as phase change materials and high-performance thermal insulators, can significantly boost energy efficiency and reduce heat gain. However, selecting the right materials is complex, requiring a balance between thermal performance and embodied energy. Here embodied energy represents the carbon footprint (CO_2 emissions) of a building material from extraction to manufacturing. A lower carbon emission is always preferred and therefore a careful consideration of the same is essential for making informed choices towards sustainability. Additionally, optimizing the balance between performance and cost is crucial for effective insulation solutions (see **Fig. 2.4**).

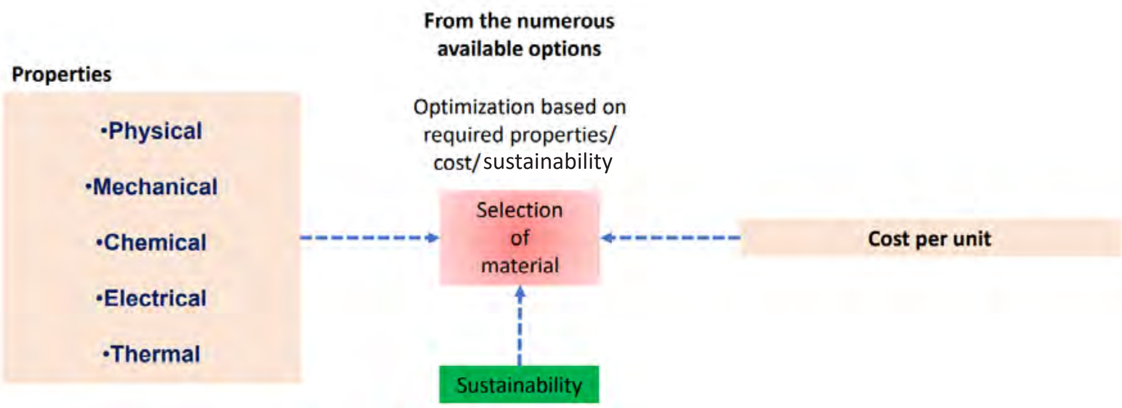


Figure 2.4 Selection criterion of sustainable building material

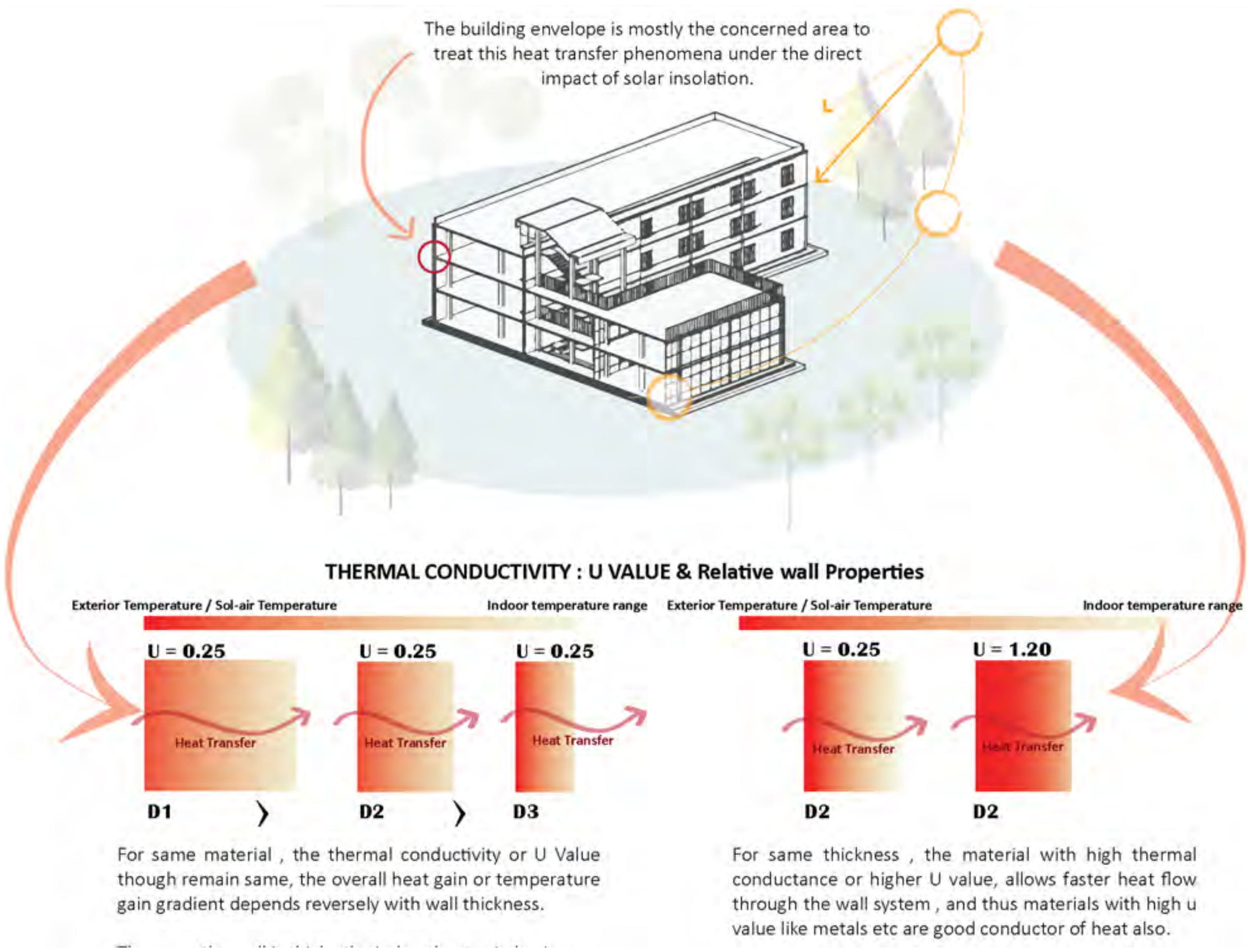


Figure 2.5 Variations in the U-value of building materials with respect to width and thermal conductivity

One of the key indicators for heat gain through a building envelope is the U-value and the Solar Heat Gain Coefficient (SHGC) of the materials used (e.g., walls, windows, roofs). Careful consideration of these values during retrofitting is important to minimize heat gain, with lower values generally preferred. **Figure 2.5,2.6a, 2.6b and 2.7, 2.8** discuss the implications of these values.

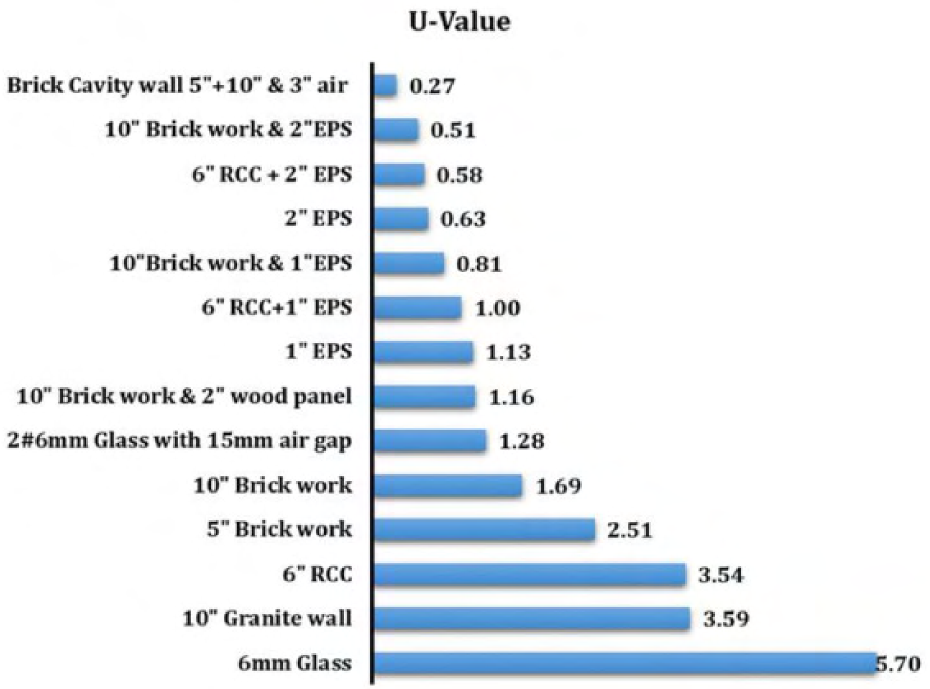


Figure 2.6a Comparative list of U-values for building envelope

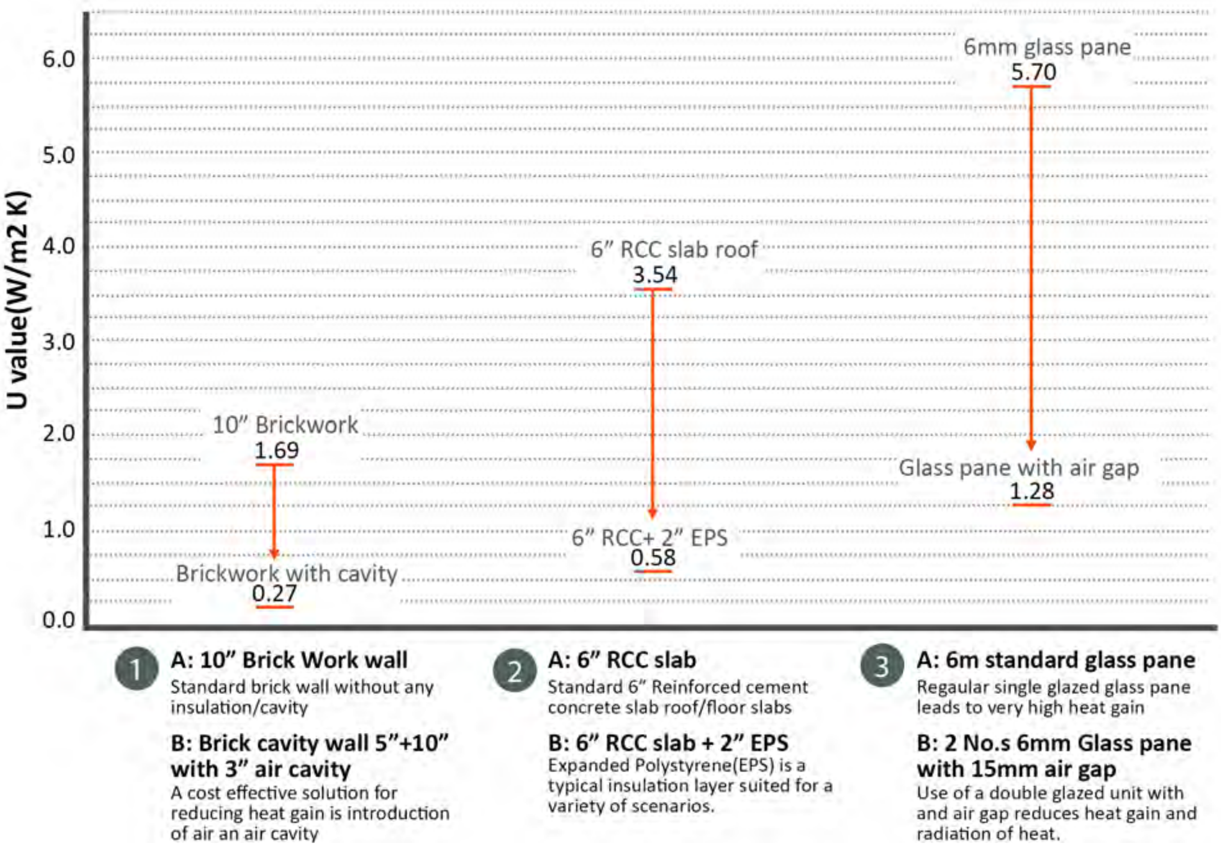


Figure 2.6b Reduction of U-value with an enhanced building envelope (high insulation, low SHGC)

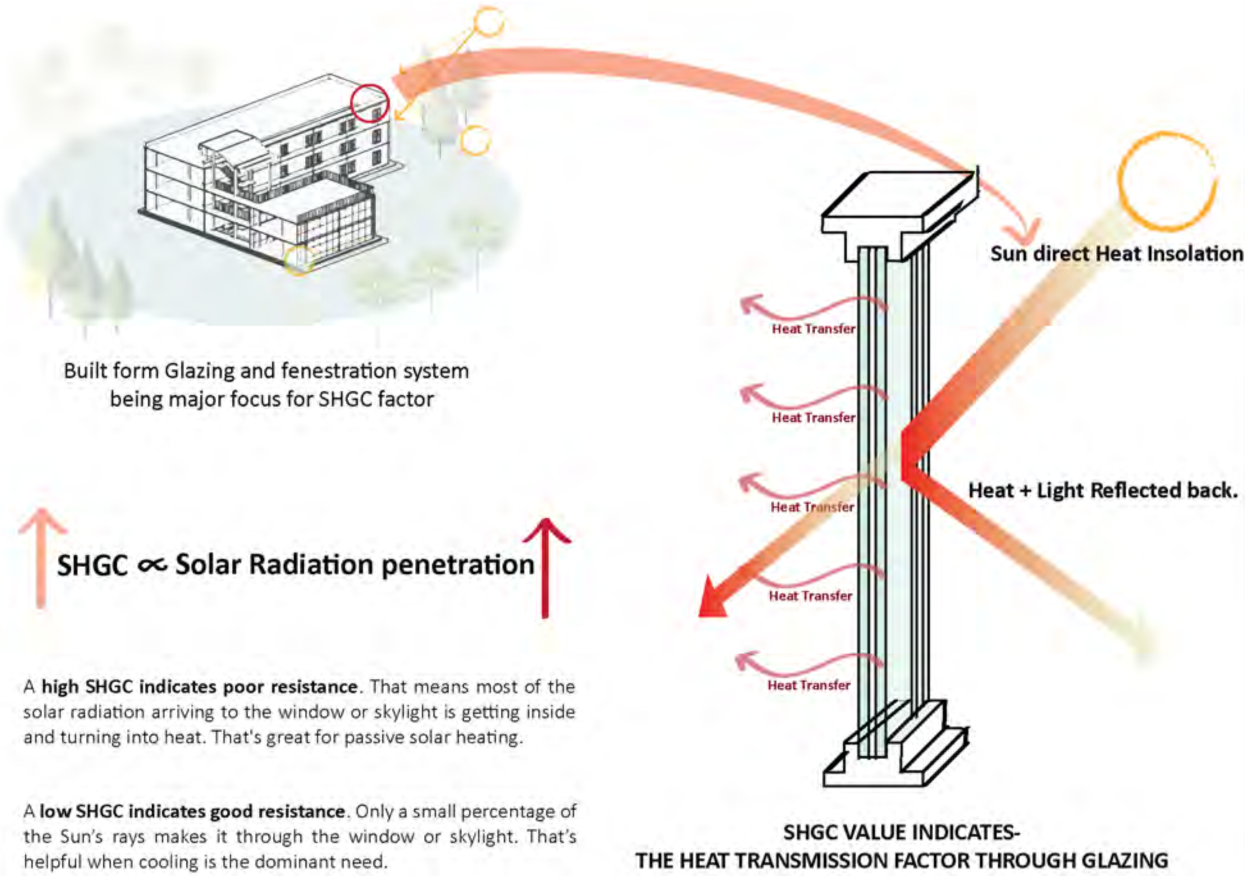


Figure 2.7 Significance of SHGC value in reducing indoor heat gain

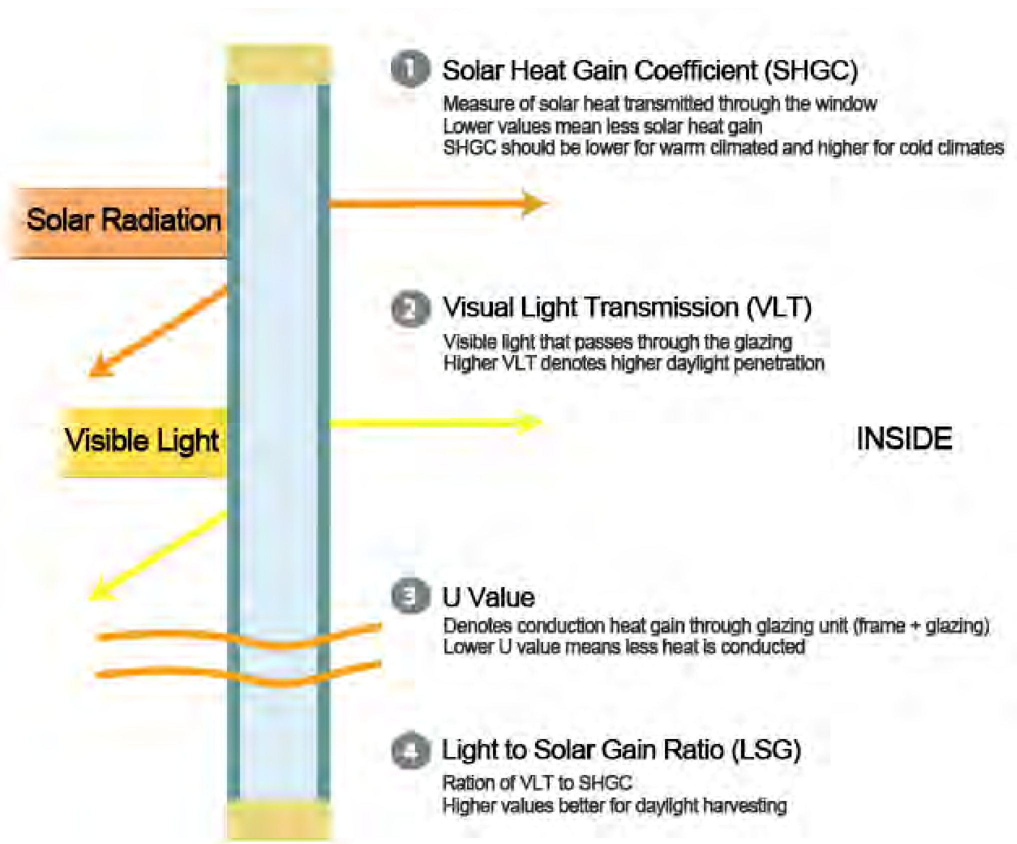


Figure 2.8 Significance of SHGC and VLT value in reducing indoor heat gain

2.2.3 Cool Coatings

Using high-performance materials, such as high reflectivity coatings and broadband super-cool layers on roofs, can effectively lower cooling energy demand and help to mitigate urban overheating. For instance, a cool roof features high solar reflectance and thermal emittance. Solar reflectance measures how much sunlight is reflected versus absorbed, while thermal emittance indicates how efficiently heat is radiated away. Cool roofs, with high reflectance (close to 1) and high emittance (around 0.90), stay cooler in the sun compared to materials with low reflectance (like black paint) and lower emittance (see **Fig 2.9** and **2.10**) (Mattheos Santamouris et al. 2022). Super-cool broadband materials efficiently absorb wavelengths ranging between 8 and 13 µm and subsequently release them into space. However, the performance of super-cool materials can vary based on climatic conditions. For example, in hot desert areas like Riyadh, optimal cooling occurs in dry conditions with clear skies. Conversely, in tropical wet and dry climates like Kolkata, cooling is hindered by water vapor that tends to trap infrared radiation in humid conditions (Khatun et al. 2024; Haddad, Shamila et al. 2024) (**Fig 2.11**). According to a study, cool roofs can lower surface temperatures by up to 6.1 °C. They also make outdoor spaces more comfortable by reducing heat-related discomfort by up to 1.8 °C during the hottest times of the day (Khorat et al. 2024). Some recent application of cool roof coating or painting in India is shown in **Fig 2.12**

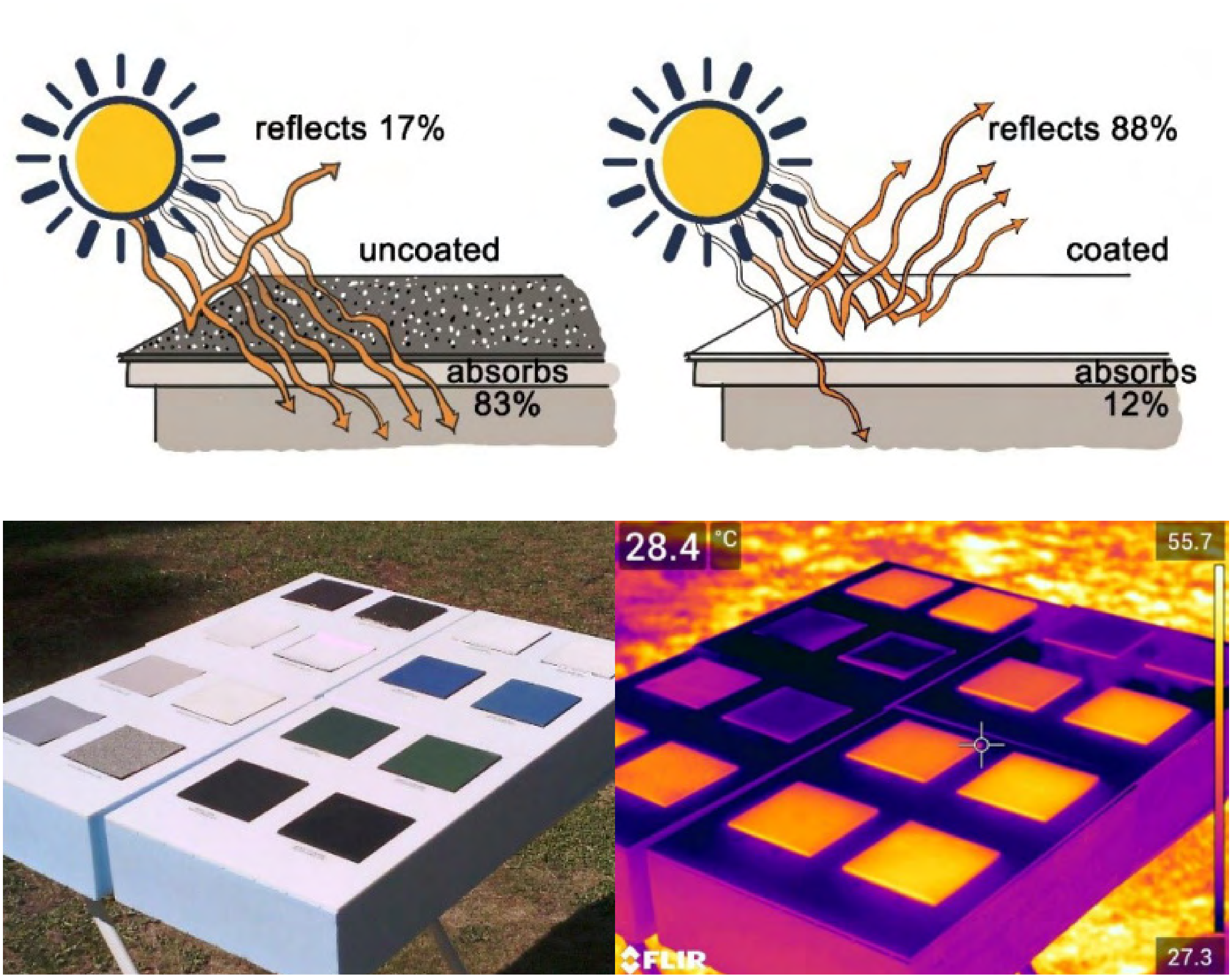


Figure 2.9 Reflection and absorption of sunlight by a conventional dark roof compared with a cool roof (solar reflective) (Mattheos Santamouris et al. 2022)

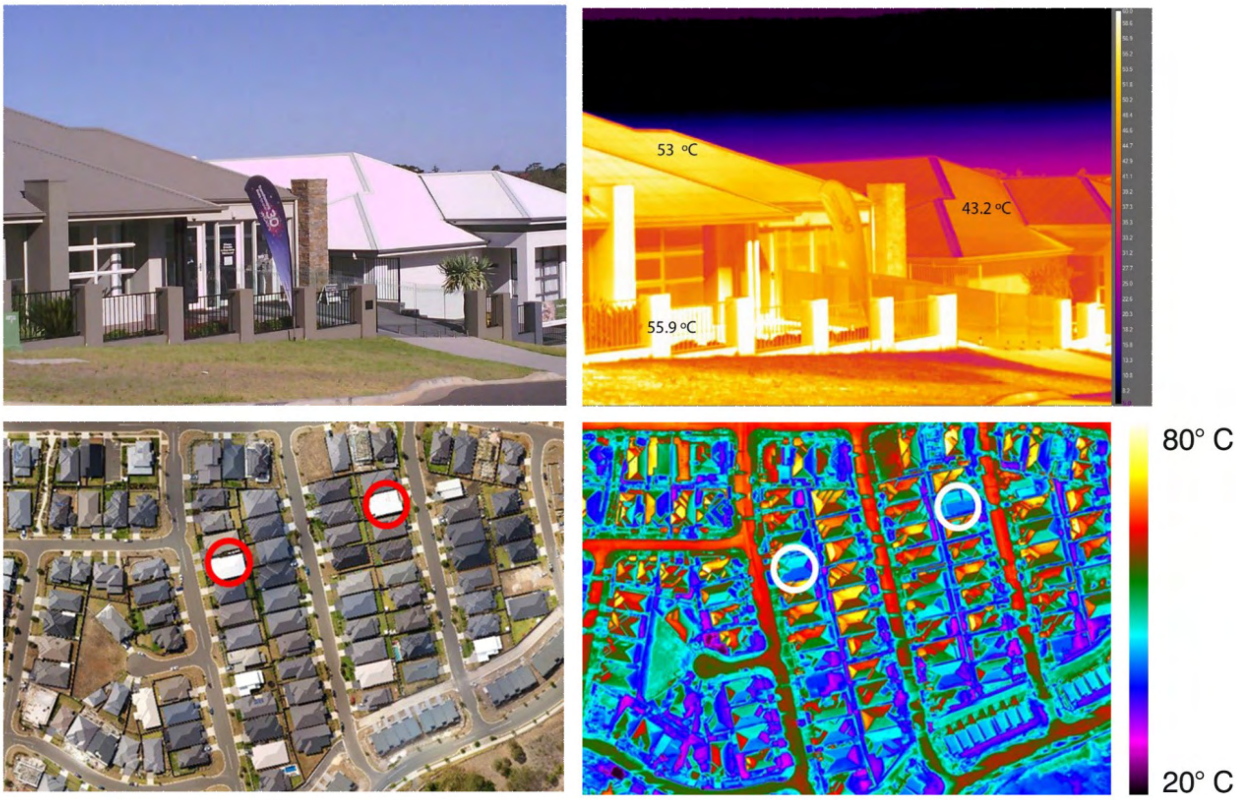


Figure 2.10 Comparison between a dark (surface reflectance = 0.15) and a white cool roof (surface reflectance = 0.75). Measurements were taken in the Campbelltown area (NSW) in February 2018, in the late afternoon, with air temperature ~ 37.1 °C, relative humidity = 10%, and wind speed = 5.2 m/s (Mattheos Santamouris et al. 2022)

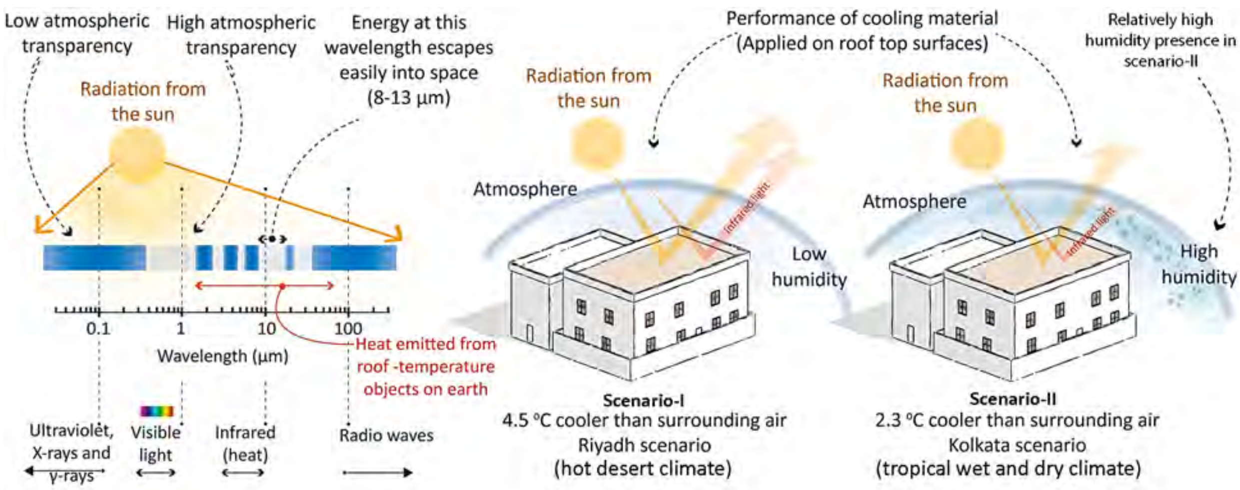


Figure 2.11 performance of super cool materials (Khatun, Khan, Anand et.al. 2024; Haddad, Shamila et al. 2024)

Cool roofs are receiving increasing attention from India's policymakers as essential components of a comprehensive national cooling strategy. Specifically, the ICAP recommends cool roof programs to provide thermal comfort for Economically Weaker Sections (EWS) and Low-Income Groups (LIG) through local Heat Wave Action Plans. Similarly, under India's National Mission on Sustainable Habitat, part of the National Action Plan on Climate Change, cool roof techniques are recommended for all new constructions exceeding 20,000 sq. m in peri-urban areas.(Ministry of Housing and Urban Affairs Government of India 2021).

Cool roof coating/painting/ paneling in India

Figure 2.12 Application of Cool roof coating or painting in India

source: https://epic.uchicago.in/project/cool-roofs/, https://www.bbc.com/future/article/20230628-the-white-roofs-cooling-womens-homes-in-indian-slums https://thebetterindia.com/97105/mahila-housing-trust-cooling-roofs-slums/ https://www.indiamart.com/proddetail/cool-roof-coating-on-metal

2.2.4 Green Roofs

Green roofs offer numerous benefits for building efficiency and urban environments. By covering roofs with vegetation, they reduce heat absorption, leading to cooler indoor temperatures and less reliance on air conditioning (**fig 2.13**). This natural cooling solution not only mitigates peak daytime temperatures but also helps lower night-time temperatures, potentially saving up to 35% in energy costs (Mat Santamouris et al. 2018). Additionally, urban greenery enhances comfort, improves air quality, and provides significant social, health, and economic advantages, including a reduction in heat-related mortality and other health benefits.

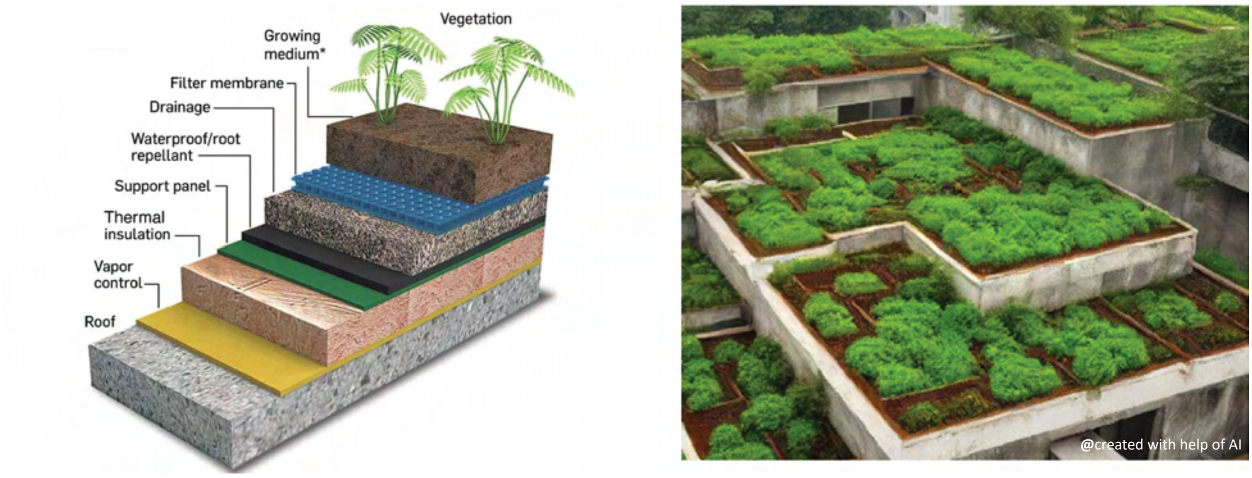


Figure 2.13 Idea of green roof in Indian context
Source: https://blog.denbow.com/greenroof-layers

2.3 Integrating Renewable Energy Sources (Solar Panels)

Integrating renewable energy sources, such as solar panels, in low-rise residential buildings through grid-connected rooftop and facade Building Integrated Photo-voltaics (BIPV) can significantly enhance energy production, potentially making the building nearly zero in overall energy demand (Panicker, Anand, and George 2023) (**Fig 2.14**). Additionally, implementing combined heat mitigation strategies, like green roofs paired with super cool materials on a city scale, can substantially reduce cooling demand and lower peak ambient temperatures, contributing to a more sustainable urban environment.

Further, although roofs shaded by reflective photovoltaic shading panels (RPVSPs) will generally have lower temperatures due to reduced direct solar radiation compared to fully exposed surfaces, it's important to recognize the complexity of the energy balance in urban environments. Implementing solar PV on a city scale can alter the urban microclimate, potentially causing daytime warming and night-time cooling effects (Khan et al. 2024; Sailor, Anand, and King 2021).

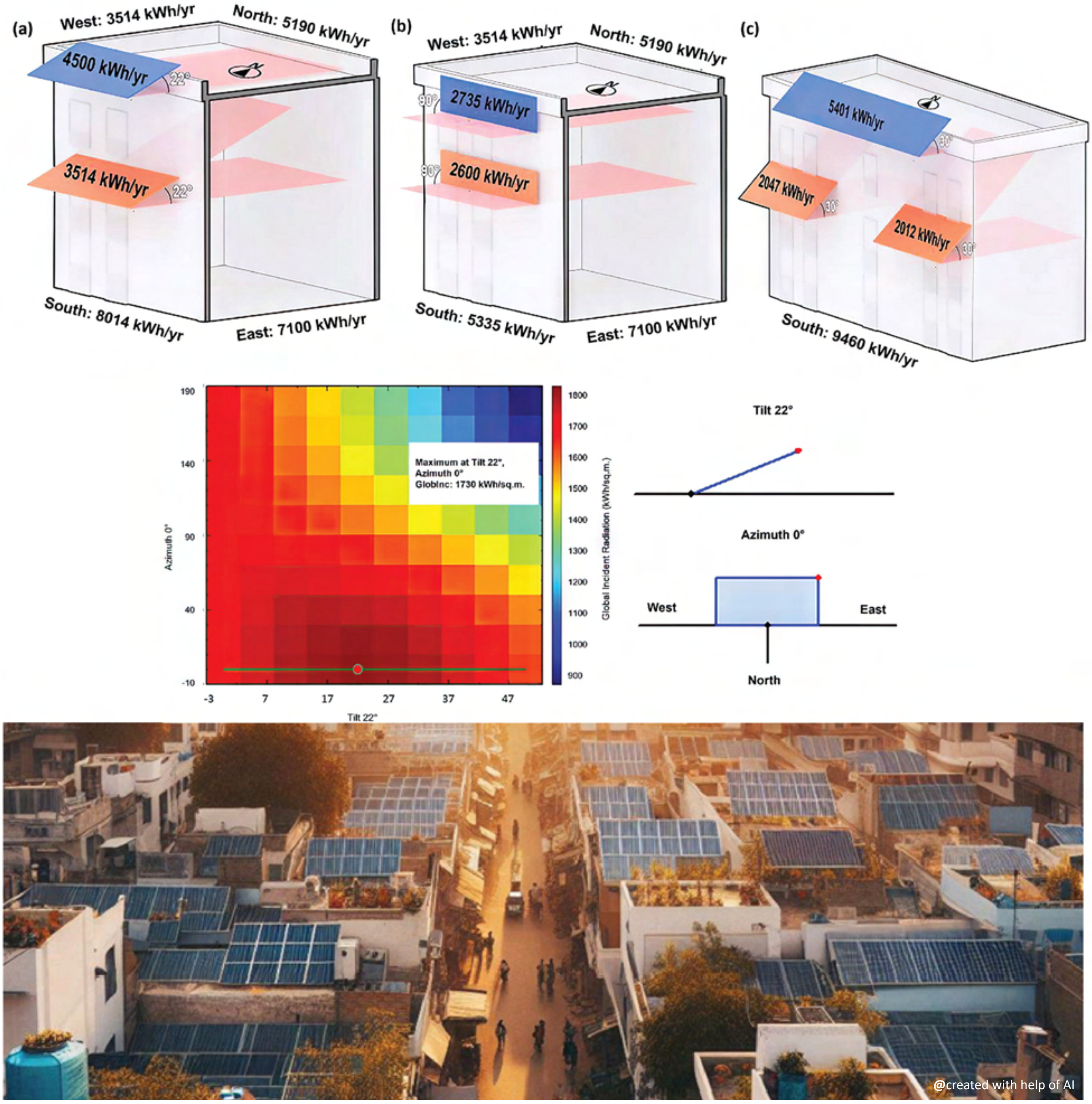


Figure 2.14 Energy retrofitting strategies for the three different typologies of low rise-housing identified based on built-up area and energy consumption patterns

2.4 Building Energy Use System Retrofit

Updating old equipment to modern, energy-efficient models can significantly cut energy use in residential and office buildings. For example, replacing outdated cooling coils with adaptable ones can solve issues like overcooling and high humidity, which impact comfort and efficiency. These new coils adjust their operation based on cooling needs, improving dehumidification and reducing energy waste. This results in better indoor air quality and enhanced overall performance, especially in systems that are oversized and need fine-tuning (Ning et al. 2023; Sekhar et al. 2018).

2.4.1 Occupancy-Based Controls

Upgrading HVAC systems and plug loads with occupant-centric controls can significantly improve energy efficiency and indoor air quality. For instance, occupancy-based controls in HVAC systems can reduce air-conditioning energy use by 19% to 38%, while optimizing energy for plug loads and lighting can save up to 8.9% and 65.1%, respectively. Post-COVID, adding personalized ventilation and high-efficiency air filters (MERV 13 or HEPA) further enhances indoor air quality. While minimum ventilation based on occupancy can save energy, it may not fully address virus transmission (**fig 2.15**). Personalized ventilation and high-temperature cooling combined with increased air movement can improve indoor air quality and reduce energy costs (Anand, Sekhar, et al. 2019; Anand, Cheong, and Sekhar 2022).

Further, in case of the bedrooms of residential buildings and personal office spaces where split AC is preferred, retrofitting these spaces to improve Indoor Air Quality (IAQ) and energy efficiency involves integrating advanced ventilation and air-conditioning systems (**fig 2.16**). The challenge in these spaces often lies in the lack of continuous fresh air supply, leading to poor IAQ and increased energy consumption when occupant's open windows and doors to improve ventilation. Effective retrofitting should focus on integrating ventilation systems with air-conditioning to ensure a steady supply of fresh air, thus reducing manual ventilation needs (Anand, Cheong, and Sekhar 2022; Mondal et al. 2023)

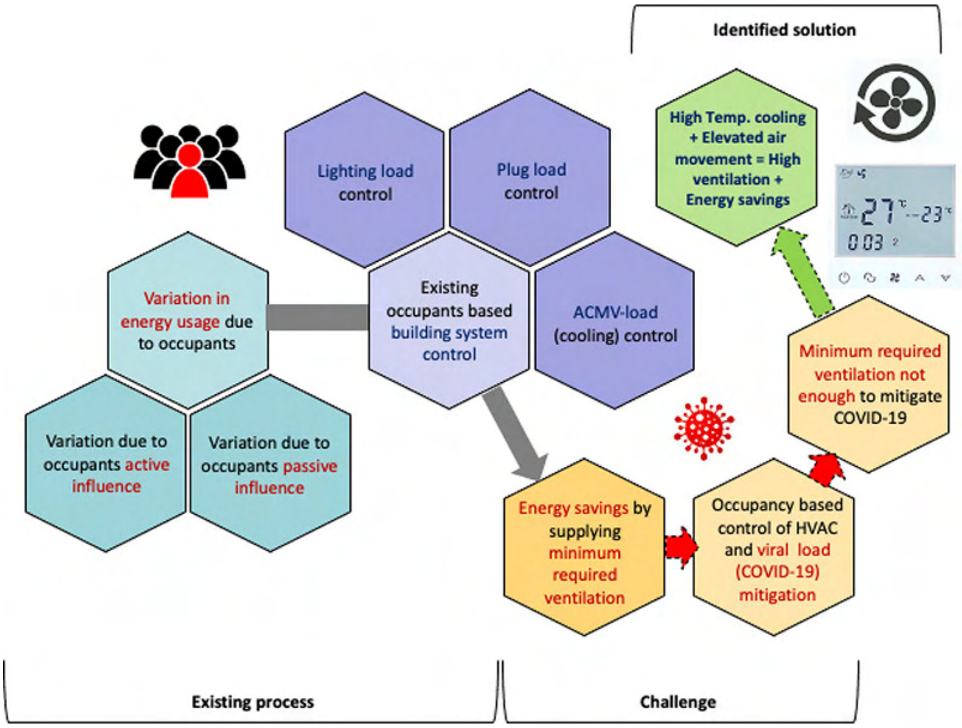


Figure 2.15 Occupancy-based control methodology (Anand, Sekhar, et al. 2019; Anand, Cheong, and Sekhar 2022)

Furthermore, in the management of operations for large spaces, there is growing research around the world that involves taking real-time preference input from actual occupants and continuously updating building energy management controls (**Fig 2.17**).

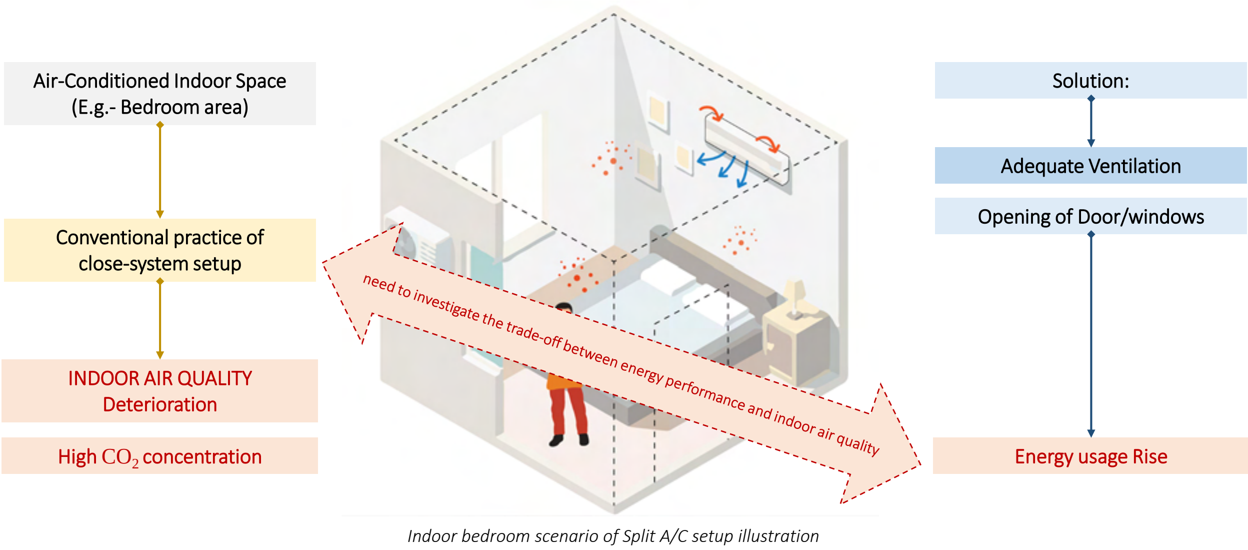


Figure 2.16 Maintaining Indoor Air Quality (IAQ) in split air-conditioned spaces (Anand, Cheong, and Sekhar 2022; Mondal et al. 2023)

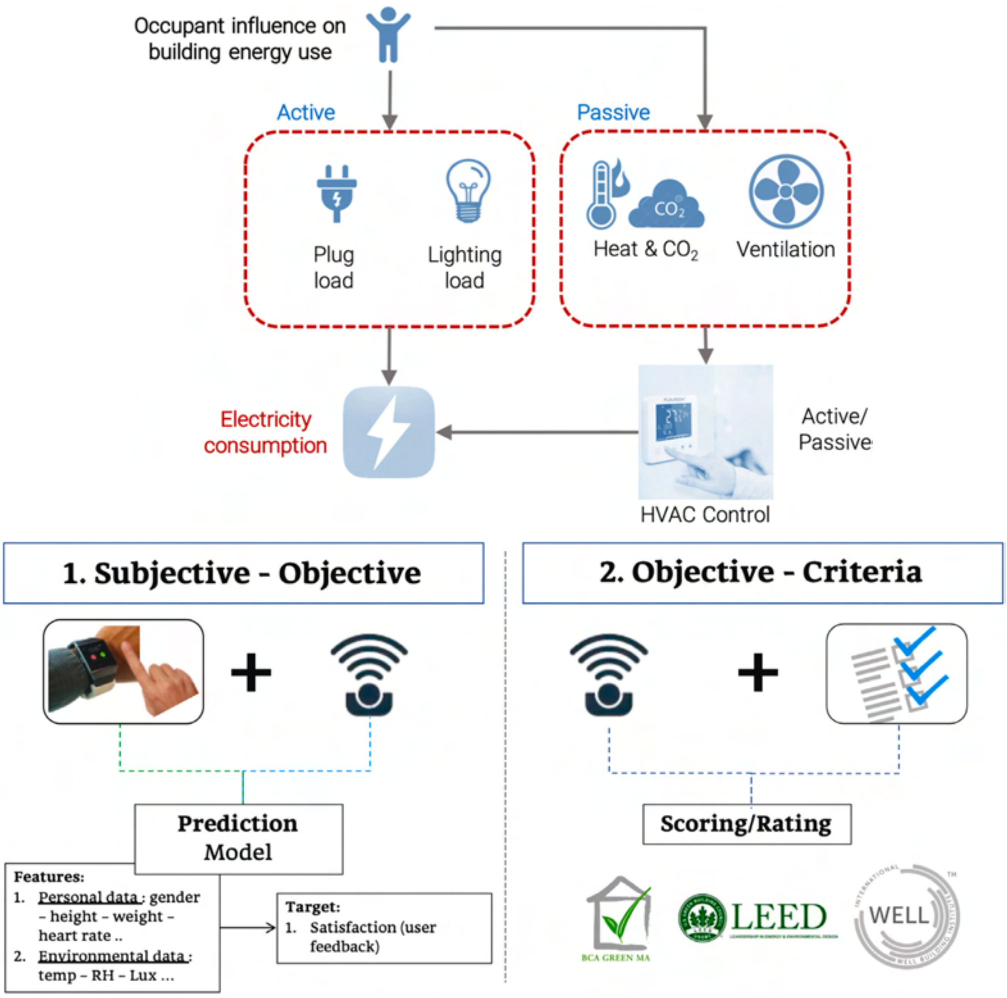


Figure 2.17 Overview of Personal Thermal Comfort Models using Digital Twins and smart building energy management system based on occupant preferences (Anand, Cheong, and Sekhar 2022 ; Abdelrahman, Chong, and Miller 2022)

2.5 City Scale Implication of Retrofitting, Mitigation Strategies

At the building scale, retrofitting to enhance energy performance is widely regarded as preferable in the current urban setting, rather than opting for new construction. However, the impact of retrofitting or mitigation strategies on the surrounding microclimate is often not well addressed (**fig 2.18**). Limiting the energy analysis scope for retrofitting to just the building scale overlooks the combined impact of the surrounding microclimate and built morphology, which can increase the overall energy load of a building in dense urban settings by 15-200% (Mondal, et al. 2024; Joshi et al. 2024).

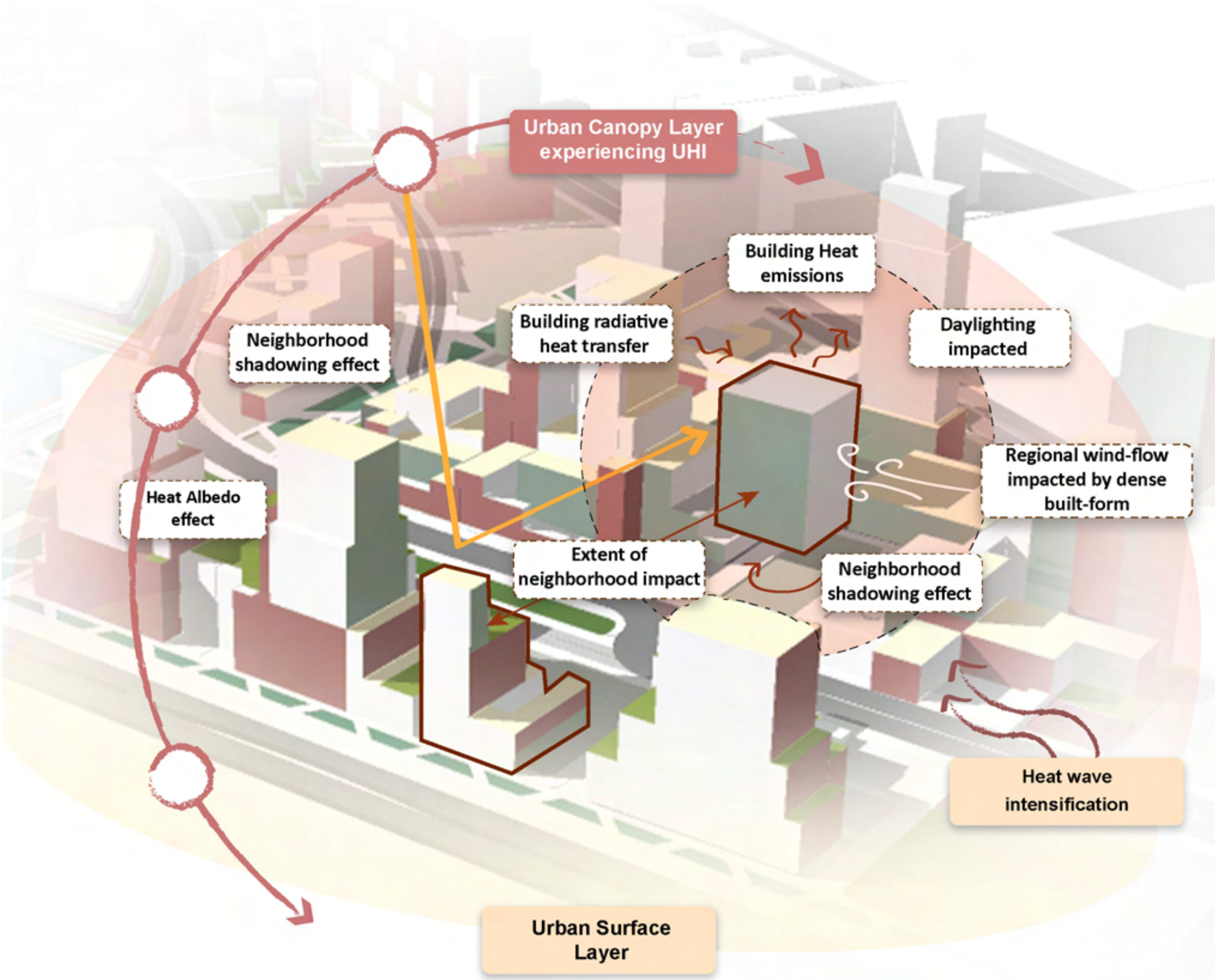


Figure 2.18 Impact of Urban Micro-climate and Neighbourhood on Building Energy Demand (Mondal, Anand et al. 2024).

In summary, while energy-efficient designs for new buildings are important, retrofitting existing structures is vital for urban sustainability. Retrofitting improves comfort and energy efficiency but often overlooks the impact on the surrounding microclimate. Focusing solely on the building level can miss how urban density affects energy demands, highlighting the need for a more comprehensive approach that considers both the building and its environment.

Reported Benefits Through Retrofitting

(Performance metrics are based on referenced sources. These figures are indicative and may vary depending on specific conditions like climate, building design, and operations. Users should consult professionals to tailor strategies to their unique situations.)

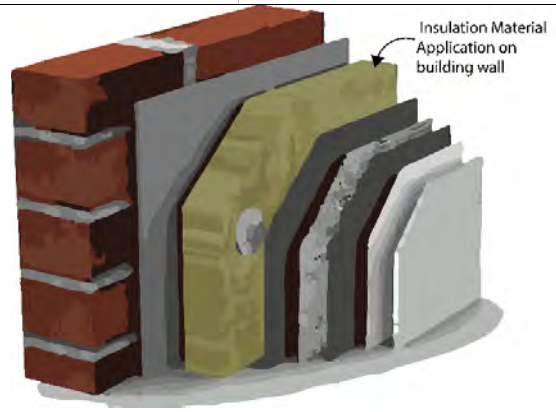
<table>
<tr><th rowspan="2">Component of Building retrofitting strategy</th><th rowspan="2">Sub category of strategy</th><th rowspan="2">Scenario</th><th colspan="2">Reported benefits</th></tr>
<tr><th>Energy saving</th><th>Indoor Comfort Improvement / Environmental Impact Reduction</th></tr>
<tr><td rowspan="3">Improving Insulation of building envelope through thermal mass

(El-Darwish and Gomaa 2017; Saikia et al. 2020; Sharma et al. 2024)</td><td>Residential Building envelope</td><td>multi-retrofit envelope (carrying phase change material and thermal insulator)

intervention points:

external walls, windows glazing type, air tightness (infiltration) and solar shading enhancement</td><td rowspan="3">up to 9.2 kWh/day of electricity saving

or

33% of annual energy savings</td><td rowspan="3">33.5% of heat gain reduction</td></tr>
<tr><td colspan="2">
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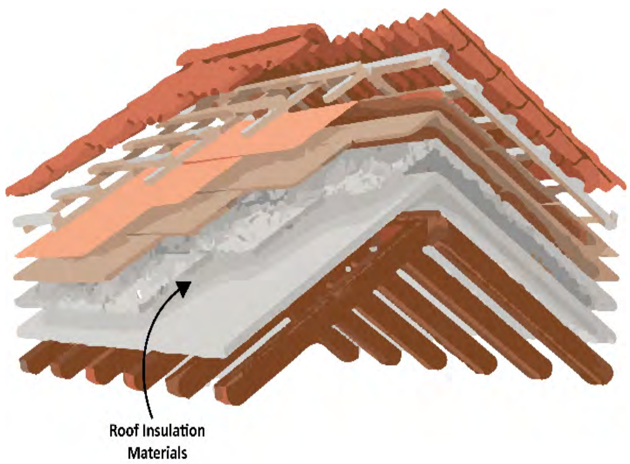
<tr><td colspan="2">
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Reported Benefits Through Retrofitting

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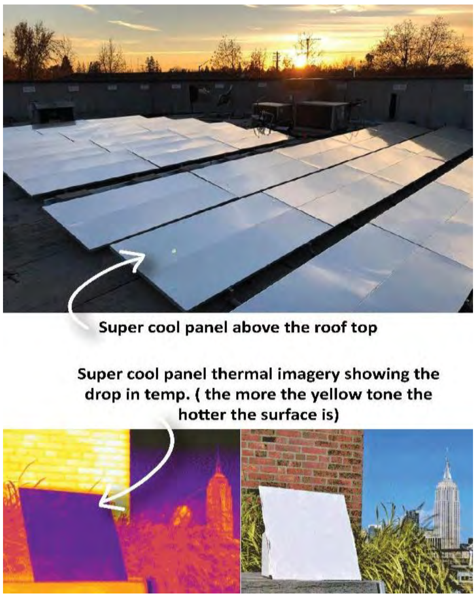
<tr><th rowspan="2">Component of Building retrofitting strategy</th><th rowspan="2">Sub category of strategy</th><th rowspan="2">Scenario</th><th colspan="2">Reported benefits</th></tr>
<tr><th>Energy saving</th><th>Indoor Comfort Improvement / Environmental Impact Reduction</th></tr>
<tr><td rowspan="3">Reducing heat gain of building envelope through high performance materials

(de Azevedo Correia, Amorim, and Santamouris 2024; Khatun et al. 2024; Mohammed, Khan, Khan, et al. 2024; Mohammed, Khan, Saeed Khan, et al. 2024, 2024, Lim 2020)</td><td>Residential Building envelope</td><td>Addition of high reflectivity (value > 0.8) / high albedo material and broadband super cool coating layer application on building roofs</td><td rowspan="3">7.2%- 36.4% reduction in cooling energy demand for uninsulated building and up to 24.3% for insulated buildings.</td><td rowspan="3">City wide application yield reduction of urban overheating or urban heat island effect</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Residential and office Building fixtures, equipment</td><td>Application of low energy consuming fixtures, workstations and shared used of high energy consuming equipment like printers.

Efficient artificial lighting system installation</td></tr>
<tr><td>Replacing old equipment with modern energy-efficient models

(Lobato et al. 2011; Mata, Sasic Kalagasidis, and Johnsson 2013) (Johnson 2019; NREL 2019)</td><td colspan="2">Energy efficient lighting + Equipment setup in Building interiors (Example : NREL , Colorado office interior)

</td><td>up to 53% of annual operational energy savings</td><td>up to 63% reduction in CO_2 emissions</td></tr>
</table>

Reported Benefits Through Retrofitting

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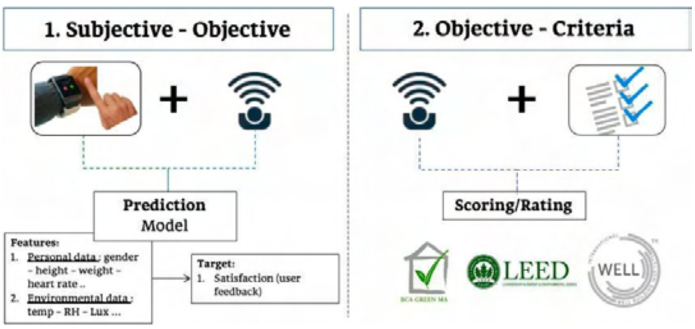
<tr><th rowspan="2">Component of Building retrofitting strategy</th><th rowspan="2">Sub category of strategy</th><th rowspan="2">Scenario</th><th colspan="2">Reported benefits</th></tr>
<tr><th>Energy saving</th><th>Indoor Comfort Improvement / Environmental Impact Reduction</th></tr>
<tr><td rowspan="2">adding controls to optimize system performance

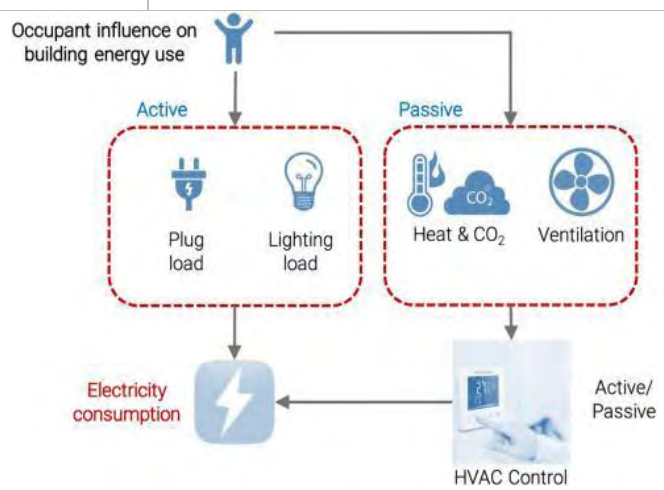
(Lee and Cheng 2016) (Abdelrahman, Chong, and Miller 2022)</td><td>Residential, commercial, office Building-energy management system (BEMS)</td><td>Smart energy management systems installation (energy control inputs undated by regular real time user preference inputs like set point temperature control)</td><td rowspan="2">For HVAC savings is up to 14.07%

For other equipment energy saving is up to 16.66%</td><td rowspan="2">11.39% - 16.22% yearly financial benefit

Thermal comfort provision can be uplifted from baseline by 14-28%</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td rowspan="3">Occupant centric controls in HVAC systems and plug loads

(Anand, Cheong, et al. 2019; Anand, Sekhar, et al. 2019)</td><td rowspan="2">Building HVAC system as well as workstation fixtures retrofitting</td><td>Occupancy-based zone-level VAV system control</td><td rowspan="3">Plug load Energy saving potential ~ 1.3-8.9%

And

Lighting load Energy saving potential ~ 38.4-65.1%</td><td rowspan="3">Enhanced Indoor Environment quality</td></tr>
<tr><td>rule-based energy-use behaviour application into BEMS based on machine learning based analysed occupancy data</td></tr>
<tr><td colspan="2">
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Reported Benefits Through Retrofitting

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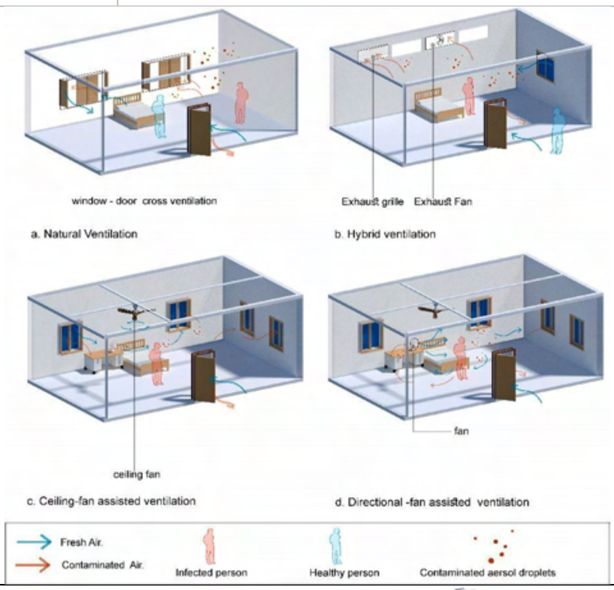
<tr><th>Energy saving</th><th>Indoor Comfort Improvement / Environmental Impact Reduction</th></tr>
<tr><td rowspan="3">Post COVID Building Indoor systems retrofitting

(Nair et al. 2022)</td><td>Building HVAC system retrofitting</td><td>Air filtration through the application of air filters such as MERV 13, HEPA
+
It is recommended to set the zone temperature at the higher end of the comfort zone post A/C retrofitting
+
In case of demand-controlled HVAC systems, the CO_2 setpoint should be significantly lowered to maintain significantly higher ventilation</td><td rowspan="3">Potential energy saving scope in displacement ventilation</td><td rowspan="3">Enhanced Indoor Environment quality and Indoor air quality</td></tr>
<tr><td colspan="2">


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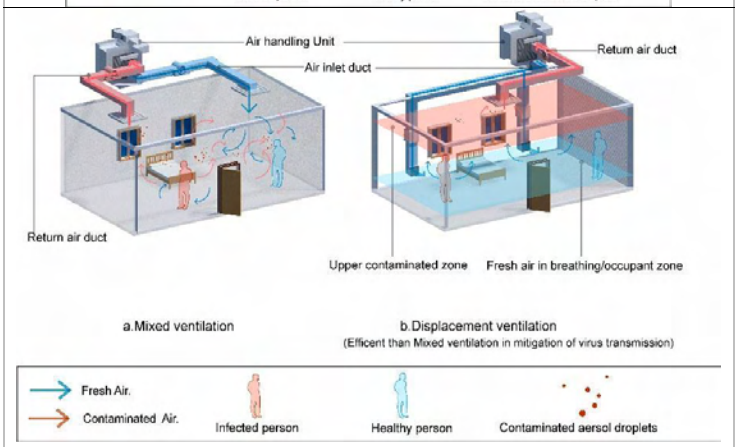
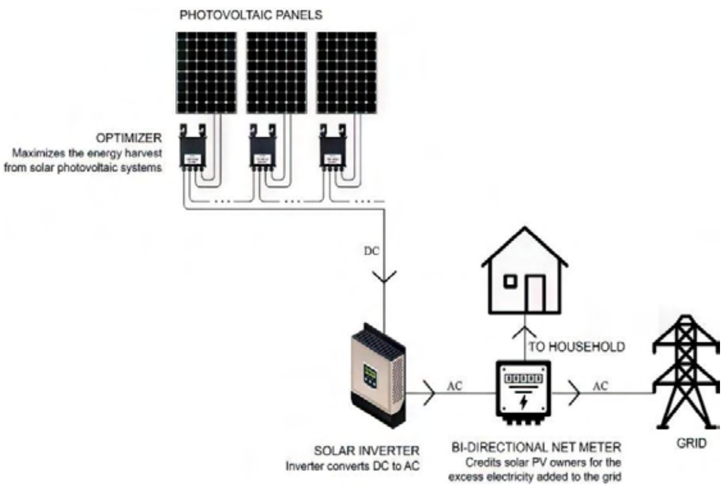


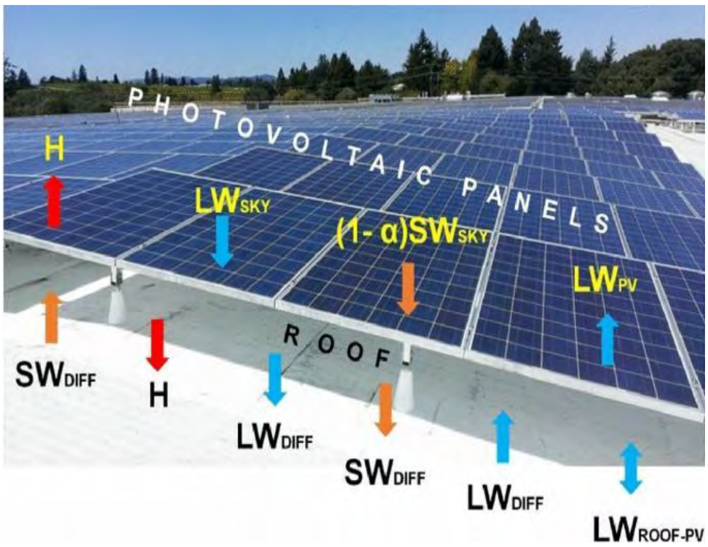
Mixed and Displacement ventilation strategies among which second one is more preferred for post covid scenarios, so can also be adapted for whole building HVAC retrofitting.
</td></tr>
</table>

Reported Benefits Through Retrofitting

<table>
<tr><th rowspan="2">Component of Building retrofitting strategy</th><th rowspan="2">Sub category of strategy</th><th rowspan="2">Scenario</th><th colspan="2">Reported benefits</th></tr>
<tr><th>Energy saving</th><th>Indoor Comfort Improvement / Environmental Impact Reduction</th></tr>
<tr><td rowspan="2">Integrating renewable energy sources like solar panels

(Noh, Jafarinejad, and Anand 2024; Panicker, Anand, and George 2023)</td><td>Implementation in low rise residential buildings</td><td>grid-connected rooftop and façade BIPV for low-rise residential buildings</td><td rowspan="2">Integration of Façade BIPV with Rooftop BIPV increases the system production to up-to 62.5%</td><td rowspan="2">Helps in making the overall building near zero in terms of overall energy demand</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td rowspan="2">Integrating renewable energy sources like solar panels in city scale

(Adilkhanova, Santamouris, and Yun 2024; Haddad et al. 2024; Khorat et al. 2024; Mohammed, Khan, Saeed Khan, et al. 2024; Vasilakopoulou et al. 2023)

(Khan and Santamouris 2023)</td><td>city scale Existing building rooftops</td><td>Roof top PV implementation in city scale</td><td rowspan="2">decreases the cooling demand by up to 35%</td><td rowspan="2">According to the study, when 25–100% of roof areas are covered by PVs, the ambient air temperature may rise by 0.6–2.3 °C.</td></tr>
<tr><td colspan="2">
</td></tr>
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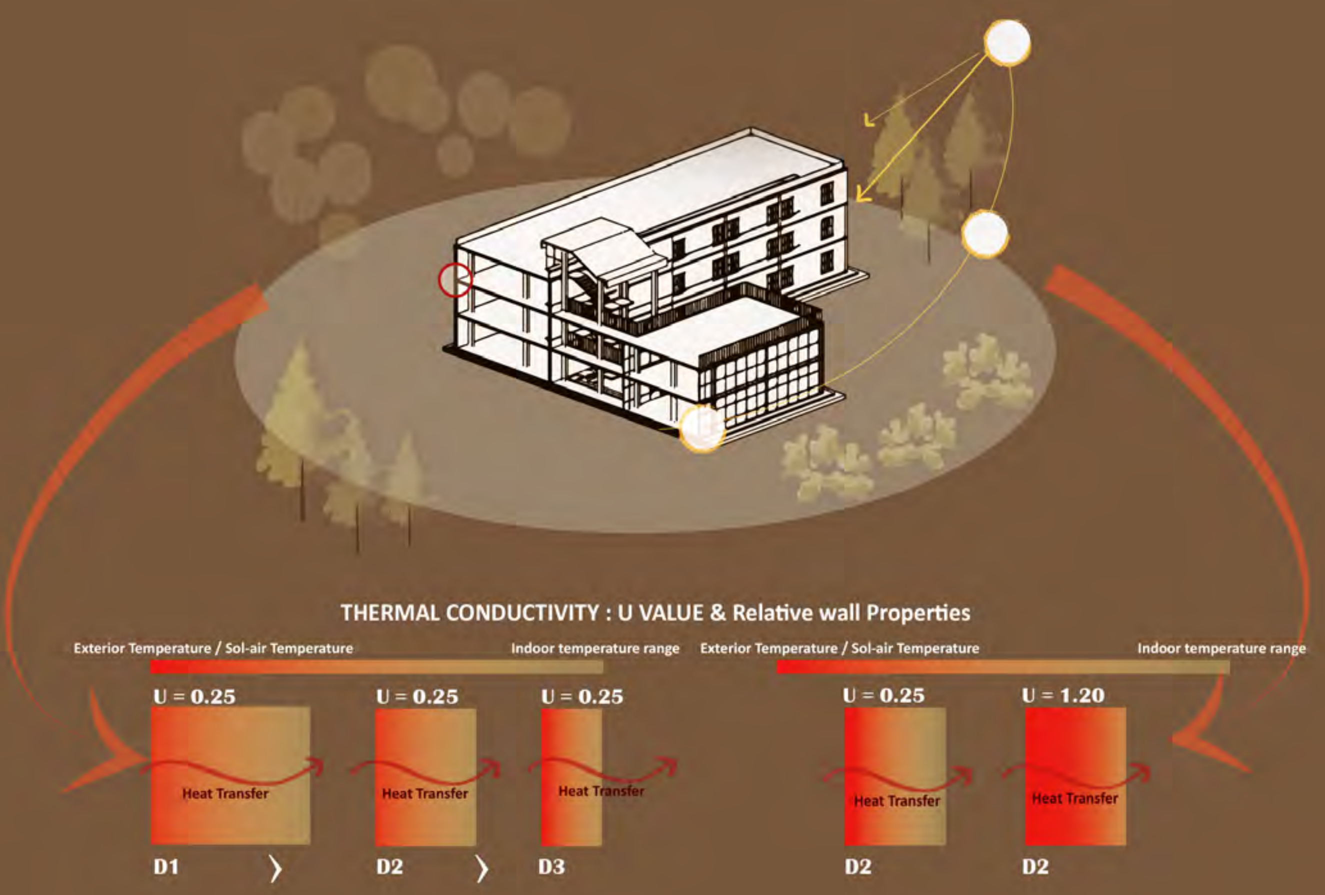
3

BUILDING MATERIAL

This chapter builds on the previous discussions by focusing on the importance of selecting appropriate materials for both new constructions and retrofitting. The thoughtful choice of building envelope materials plays a critical role in passive cooling and energy efficiency. By selecting materials that improve thermal performance, buildings can reduce their reliance on mechanical systems, enhance occupant comfort, and contribute to urban sustainability. Both passive cooling strategies and retrofitting efforts are heavily dependent on the use of high-performance materials that support long-term energy savings and resilience.



3.1 Choice of Materials for Walls and Roofs to Reduce Heat Gain

3.1.1 Wall Materials

Various wall materials, from conventional burnt clay bricks to eco-friendly options like Autoclave Aerated Concrete (AAC) blocks, can be used for construction (**Fig 3.1**). Traditional brick and concrete walls allow more heat transfer, while eco-friendly alternatives like AAC, Porotherm blocks with glass fibre, and Cellular Lightweight Concrete (CLC) offer better insulation, reducing heat gain. In contrast, reinforced concrete walls perform poorly in thermal insulation (IGBC 2022).

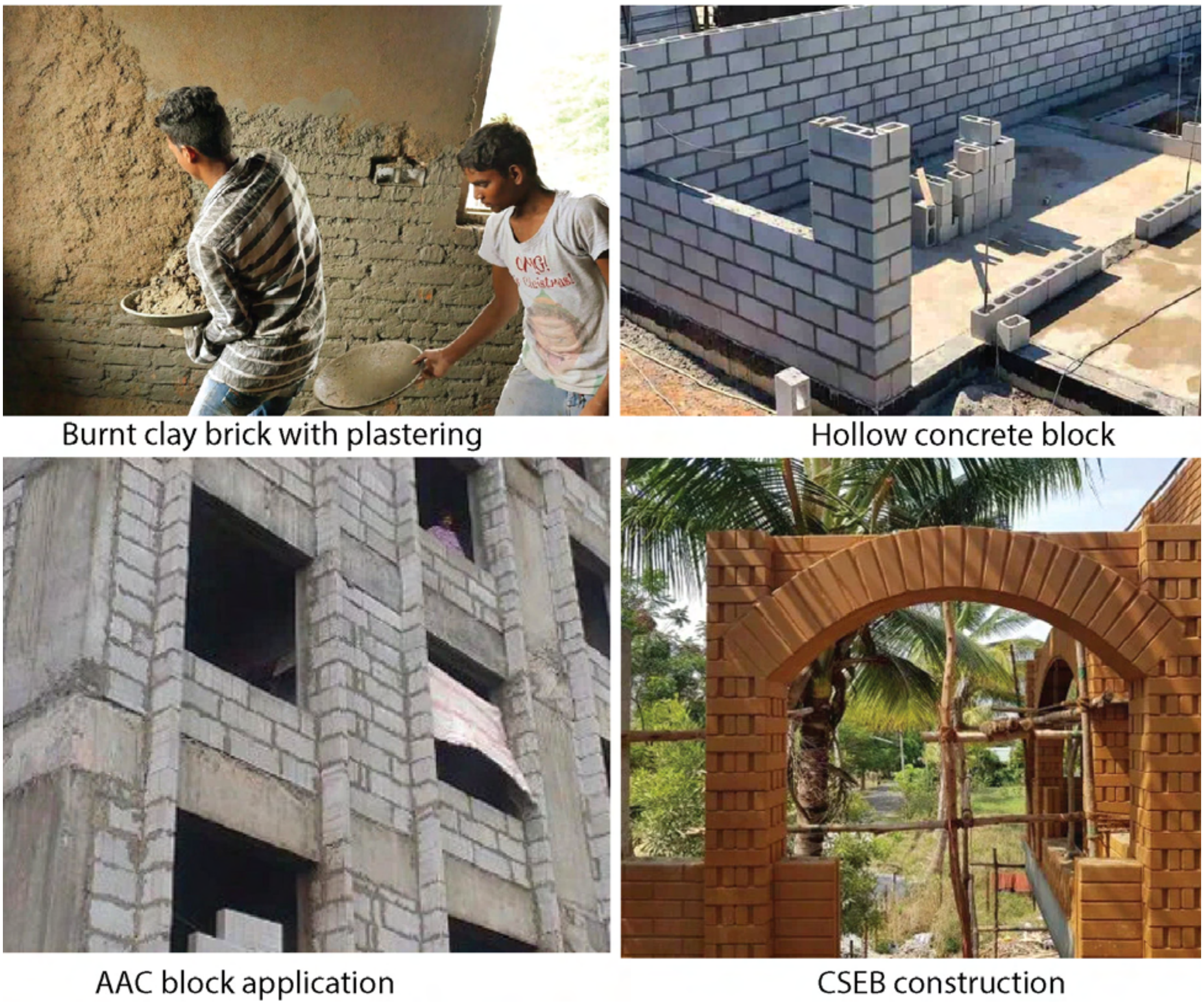


Figure 3.1 Wall Construction with Different Blocks and Bricks

source: https://www.pinterest.com/pin/31-photos-of-hollow-concrete-block-work--668714244690965078/, https://www.indiamart.com/proddetail/aac-blocks, https://www.indiamart.com/proddetail/compressed-stabilised-earth-block-cseb

3.1.2 Sustainable Roof Construction

Sustainable roofing options for residential buildings include filler slabs (**Fig 3.2**), which reduce concrete use and weight, as well as recycled materials like rubber, metal, or plastic that minimize waste and are cost-effective. Clay tiles provide durability and strong thermal performance, while corrugated metal sheets are durable, reflective, and easy to install. Traditional thatched roofing, made from locally sourced grasses or reeds, offers good insulation and aesthetic appeal. Bamboo roofing, being strong, flexible, and made from a rapidly renewable resource, is another sustainable option.

Figure 3.2 Roof Construction with Different filler materials
source: https://www.studiodcode.com/filler-sab.html, https://doi.org/10.1016/j.enbuild.2013.09.051, https://housing.com/news/filler-slab/

3.1.3 Insulation Materials (External and Internal)

Insulation acts as a barrier to heat transfer, preventing external heat from entering or indoor cool air from escaping. In the Indian context, using insulation in walls and roofs can keep homes cooler, especially in peak summer, reducing electricity consumption for cooling(**Fig. 3.3**). **Fig. 3.4** compares different insulating materials based on their thermal properties and embodied energy those can be used for insulation of internal surfaces (for example: auditorium or a residential building in cold climates) mainly but can be also used in external surfaces for special cases as outdoor material (example: infill of external wall as a insulator) as these material cannot be directly exposed to external moist weather.

Figure 3.3 Insulation material application

INSULATION MATERIALS	Thermal Conductivity (W/mk)	Embodied energy (MJ/g)	Carbon Emission (CO2 eq/g)
 Fiberglass (~100–320 mm)	0.049–0.05	26	0.8–0.9
 Mineral Wool (~100–220 mm)	0.035–0.065	26	0.8–0.9
 Cellulose (~100-200 mm)	0.040	3-7	0.3–1.2
 Polyurethane/ Polystyrene (~80-300 mm)	0.049–0.05	70–130	5–8

Ways of applying insulation materials
(for both exterior and interior applications)

Figure 3.4: Application of Insulation materials in building retrofitting. Environmental impact of widely applied materials is also mentioned (Ijjada and Nayaka 2022; Insulation | YourHome 2020).

3.1.4 Reflective Paints/Tiles for Walls and Roofs

Reflective paints, also known as cool or high Solar Reflective Index (SRI) paints, reduce heat absorption by reflecting sunlight, lowering surface temperatures (**Fig 3.5**). Applied to walls and roofs, they can significantly cool homes in India's hot regions. Cool roofs, typically white, use reflective coatings to repel heat, reducing the heat island effect and minimizing thermal impact on the local environment. Modern options include thermoplastic materials with high reflectivity.

Figure 3.5: Application of reflective paints, cool roofing tiles on building roofs in India

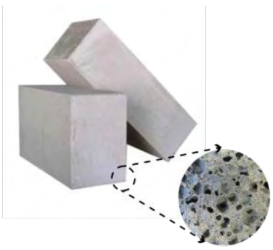
source: https://www.youtube.com/watch?v=VeZDrFqJcj8, https://odishabytes.com/cool-roofing-keep-summer-heat-at-bay-by-painting-rooftop-white-check-the-options-available/, https://www.indiamart.com/proddetail/cool-roof-tiles

3.2 Choosing Materials for Windows and Openings

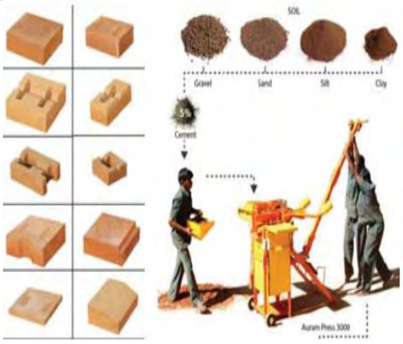
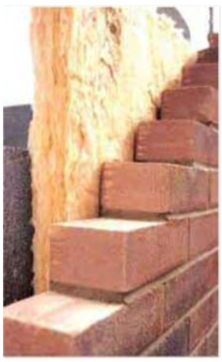
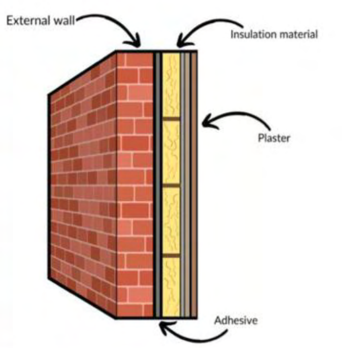
High-performance glass, such as double-glazed or low-emissivity (low-E) glass, reduces the amount of heat entering a building while allowing natural light to pass through. This is particularly beneficial in India's tropical regions, where controlling indoor heat while maintaining daylight is important.

Applications of Building Materials

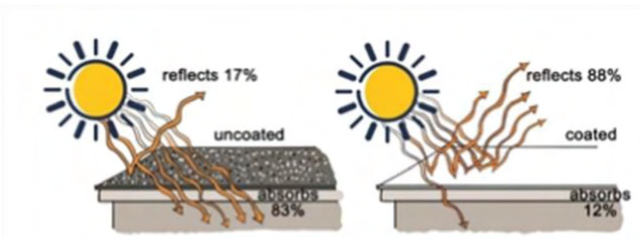
Suggested materials are based on referenced sources. These figures are indicative and may vary depending on specific conditions like climate, building design requirements, and local availability. Users should consult professionals to tailor strategies to their unique situations.

Building materials		U value (W/m²K)	Suggestion of use / Environmental impact Reduction
	Wall Materials		
Conventional brick walls with plaster (IGBC 2022)	 	**1.91** (230mm Brick wall with 15mm external & 12mm internal plaster)	The **less the U** value, the **more is heat-gain reduction in indoors**
concrete block (IGBC 2022)	 	**3.09** (200mm concrete block with 15mm external & 12mm internal plaster)	
AAC blocks (IGBC 2022)	 	**0.56** (200mm AAC block with 15mm external & 12mm internal plaster)	
Fly ash brick (Sameer Maithel, Rajan Rawal 2023)	 	**~ 0.67**	

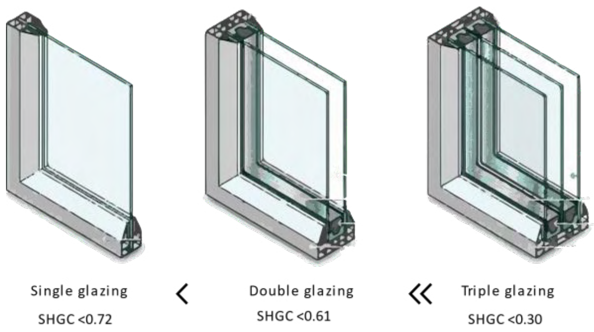
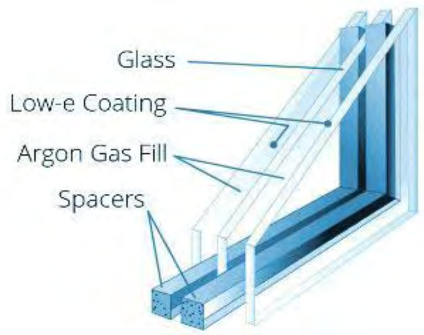
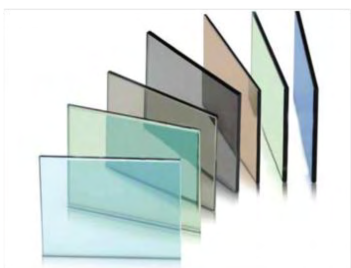
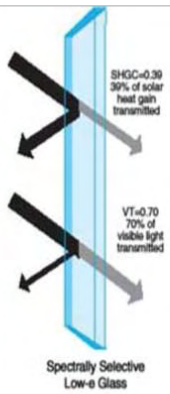
Applications of Building Materials

Building materials		U value (W/m²K)	Suggestion of use / Environmental impact Reduction
Wall Materials			
Porotherm block with glass fibre (IGBC 2022)	 	**<0.27** 140mm Porotherm block with 100mm glass fibre	
CLC block (IGBC 2022)	 	**0.80** (150mm CLC block with 15mm external & 12mm internal plaster)	The **less the U** value, the **more is heat-gain reduction in indoors**
Compressed stabilized earth blocks (GHTC 2021) (BEE 2017)	 	**0.84-1.3**	
Insulation Materials application on walls (BEE 2017)	 	**0.25-0.56**	eco-friendly insulation (i.e. cellulose based) with high durability is preferred

Applications of Building Materials

Building materials		U value (W/m²K)	Suggestion of use / Environmental impact Reduction
Roof Materials			
Filler slab or pots application as a Substitute to Customary Roofing Mechanism (Madhumathi, Radhakrishnan, and Shanthi Priya 2014)	 	**2.33-3.35**	Cost effective roofing systems Reduce concrete usage in comparative to conventional roofing systems
Temporary shading of local recyclable materials on flat roof systems		**NA**	
Wall and Roof paints / tiles			
Wall and Roof paints with high surface reflectivity paints (de Azevedo Correia, Amorim, and Santamouris 2024; Khatun et al. 2024; Mohammed, Khan, Khan, et al. 2024; Mohammed, Khan, Saeed Khan, et al. 2024, 2024)	 	**Solar Reflective Index (SRI)** SRI > 82, Preferred is SRI >95 Reflectance or albedo value >0.8	**7.2%- 36.4%** reduction in cooling energy demand for uninsulated building and up to **24.3%** for insulated buildings.

Applications of Building Materials

Building materials		SHGC values (the less the SHGC the less the gain it allow)	VLT values (indicating how much daylight it allows)	Environmental impact
High Performance glasses as window/fenestration material				
Double or Triple Glazing with or without low E coating (Singh and Garg 2009)		~0.52-0.68 with low E coating for double glazing	>60%	More glazing layers improve thermal performance, reduce noise, and boost energy efficiency (30-45% in comparison to conventional single glazing systems). Low-e coatings increase solar reflectivity, minimize heat gain, and enhance insulation.
Double or Triple Glazing with gas filled (Gueymard and duPont 2009; Singh and Garg 2009)		~ 0.2-0.3	>70%	
Heat absorption tint, spectrally selective glasses (Gueymard and duPont 2009)	 	~0.162-0.45	<70%	Tinted glass absorbs large fraction of solar radiation. Spectrally selective glasses block long wave radiation

Reference

The performance metrics, including energy and cost savings potentials, for various energy conservation measures discussed in this guide—covering both passive and active strategies—are derived from multiple sources listed herein. These figures are indicative and may vary based on specific case conditions. Actual performance and savings can differ based on factors such as local climate, building design, and operational practices. Users are advised to consult with professionals to assess and tailor strategies to their unique circumstances.

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