

How can Building Materials and Urban Design Strategies Contribute to Temperature Reduction at the Campus Level

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Abstract In today's world, rising temperatures and rapid urban development are creating serious environmental problems in cities. One of the biggest challenges is the Urban Heat Island (UHI) effect, where cities become much hotter compare to their surrounding rural areas due to the loss of green spaces, the use of heat-absorbing materials, and poor urban planning. This heat makes cities thermally uncomfortable, increase heat energy use for air conditioning, and affects people's health. This research paper explain how building materials and urban design strategies can help reduce high temperatures at a campus level. Campuses are often large spaces with many buildings and open areas, so they are ideal locations to apply smart design ideas that reduce heat and improve comfort. The study looks at different types of materials like high albedo surfaces, insulation panels, phase change materials (PCMs), and eco-friendly bricks and how they help in keeping buildings cooler. There is also some studies of urban design strategies like planting trees, using green roofs, creating water bodies, and designing open spaces that allow airflow and shade. These techniques not only lower the surface and air temperature but also reduce the need for artificial cooling systems, and saving energy and also making the campus more sustainable.

Keywords- Urban Heat Island (UHI), Climate-responsive design, Green development strategies, Passive cooling, Building envelope, Thermal insulation, High albedo surfaces, Phase Change Materials (PCM), Vegetation cover, Evapotranspiration, Urban cooling island (UCI)

I. INTRODUCTION

From studies of present scenario, rapid urbanization and the effects of climate change, the urban thermal environment has become a critical concern for planners, and designers. Urban areas are losing their green cover due to unplanned development and the use of environmental impact materials, which contribute to the Urban Heat Island (UHI) effect. This phenomenon is particularly in subtropical and tropical regions where intense solar radiation and a lack of natural shading is increasing air temperatures and reduced outdoor thermal

comfort, and that is increase energy demands for cooling.

In this context, green development strategies such as tree planting, green roofs, and landscaping are the solutions for mitigating heat stress, this mitigation strategies improving air quality, and enhancing the overall sustainability of urban environments.

Studies from institutional campuses, which functioning like micro-cities, are rarely optimized for climate-responsive design. Campuses have huge potential to integrate green infrastructure, not only

to improve thermal comfort but also to reduce energy consumption. At the same time, modern buildings especially in rapidly developing countries like India.

Indigenous architectural practices, which is advanced on low-energy materials, local resources, and climate-sensitive design, are now being replaced by unsustainable construction patterns that further stress the urban climate. As temperatures rise across India with a 1°C increase in India's maximum temperature over the past century, it becomes essential to rethink our building strategies. The rising heat not only burdens energy systems and step up climate change, but also impacts the learning environment in educational institutions, creating a productivity, and well-being. This study therefore aims to explore the role of green development strategies and environmentally responsive architecture in mitigating the urban heat problem, particularly within institutional campuses. The goal is to design approaches that can be implemented at local scales to achieve long-term sustainability and climate resilience.

marble, gravel concrete, and asphalt, must be used with precaution in warm climates. materials such as wood and glasses that reduce the transfer of heat.

Cork insulation has been used as a rigid insulation material for decades in Europe. Cork granules are compressed at high temperature and pressure to provide low thermal conductivity and are widely used for construction applications, flooring, interior or exterior wall buildings and ceilings, to provide thermal and acoustic insulation in North American and European buildings. Depending on the cost and the local availability, expanded cork may find its application in tropical settings for providing insulation, especially in the roof.



Fig. 01 Cork Insulation

II. METHODOLOGY

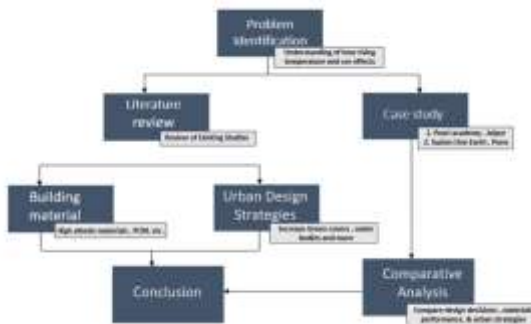


Fig. 02 Rock insulation

III. LITERATURE REVIEW

Building Materials

Heat enters buildings in the form of conduction, convection, and radiation through the building envelope. which is covered of the walls, windows, and roof. Materials that conduct heat well, such as

Rockwool insulation, constructed out of real rocks and minerals, can be used to make a broad collection of goods due to its outstanding capability to obstruct sound and heat and finds wide spread application in building assembly. Rock wool is a superior conductor of warmth, but rolls and sheets of this insulation are extremely proficient at stopping heat movement and also

meet the principle of sustainability, power protection and recyclability with added advantages of being environmental friendly and non-ozone-depleting properties

Clay brick has a high thermal conductivity of 0.82 (W/m K) and provides high thermal mass performance



Fig.03 Clay Brick



Fig.04 Fly Ash Brick

Fiber reinforced mud brick keeps the indoor temperature cooler during summer. Use of Fly Ash Bricks (FAB) is also gaining momentum and finds major use as building materials in Green Buildings.

Tuff stones and act as good heat insulators owing to their porosity. Walls made with tuff stone are biodegradable and have been found to be more durable compared with other contemporary building materials with high embodied energy



Fig.05 Tuff Stones



Fig.06 Stone Rocks

Stone rocks especially granite and marble can be used for flooring, providing cooler indoor temperature and is very popular in tropical settings.

Autoclaved concrete/Autoclaved Cellular concrete (AAC) are considered highly sustainable building material requiring low energy and raw material consumption, are non-toxic and are durable, that have good thermal performance. AAC has high thermal capacity and absorbs large quantities of radiant heat and does not transmit it through the structure rapidly and using coal Bottom AAC began in the US in 1990 for residential and commercial complexes and now is being used in structure, envelope and cladding applications in residences, hotels and in high-rise buildings of Mexico.



Fig.07 Autoclaved concrete/Autoclaved Cellular concrete (AAC)

Phase change materials (PCM) have emerged as key role players as thermal comfort materials and trap heat by storing the thermal energy better when impregnated in the building materials. PCMs can be encapsulated in concrete, gypsum wallboard, ceiling and floor to capture solar energy directly and increase human comfort by decreasing the amplitude of internal air temperature swings and maintaining the temperature closer to the desired

temperature for a longer period of time and may minimize the need for air conditioning



Fig.08 Phase Change Material (PCM)

placed green zones can significantly influence the city's microclimate, making vegetation an essential element in sustainable urban planning.

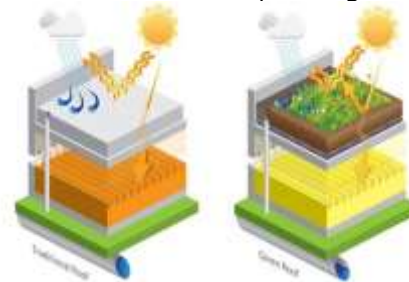


Fig.09 Vegetation Covers

M. No.	Thermal properties and performance	Building materials
1.	Low thermal conductivity	Wood, cork, straw bale, vermiculite concrete, vacuum insulated panel, hollow chip fibre
2.	High heat capacity	Wood & timber, brick, phase change material
3.	High thermal mass	Stone, concrete, autoclaved cellular concrete, phase change materials
4.	High thermal resistance	Insulation, straw, vermiculite concrete, polymer slabs, aerogel, shaped memory polymers
5.	High solar reflectivity	Structures coated with white elastomeric coatings, grey cool paint with titanium dioxide, red-brown roof tiles
6.	High thermal emissivity	Low-E coating glass, high-absorbance paints

M. No.	Building	Material features	Proposed climate region
1.	Mod Block (MB)	1. Thick roof walls with high thermal mass reduce indoor temperature fluctuations. 2. Air curtain in the roof (Rafter rafters) 3. Air curtain in the roof (Rafter rafters) 4. Roof system with solar heat gain control	Hot and semi-arid regions
2.	Insulated Mod Block (IMB)	1. Cooling by mass effect 2. No window covering below the roof reduces the radiative heat transfer from the roof 3. Red spray foam to walls and floor (insulation) (Mingosha film) with air curtain reduce heat transfer and control solar	Regions with extreme dry/semi-arid climate
3.	Anti-Arch (AA)	1. Self-shading by arches reduces solar heat gain 2. Roof made of brick (low thermal conductivity than concrete) also reduces solar heat gain	Tropical regions
4.	Stone Wall (SW)	1. Thick stone walls reduce the indoor temperature fluctuations 2. Double glazed for adequate daylighting	Hot regions
5.	Block House (BH)	1. The dense shape of the roof provides self-shading 2. Red spray foam to walls and floor (insulation) (Mingosha film) with air curtain reduce heat transfer and control solar	Tropical regions
6.	Stone Concrete Channel (SC)	1. SCC structures are eco-friendly, energy efficient and cheap compared to concrete and steel	Regions with moderate climate
7.	Stone Wall (SW)	1. Air flow effect through central area at the bottom portion of roof reduces heat gain	Tropical regions

Evapotranspiration

The combined process of evaporation and plant transpiration, is a key mechanism through which trees help reduce urban temperatures. Trees cool the environment by shading surfaces and using solar energy for transpiration rather than heating the air. This process, especially effective in dense urban areas, significantly lowers summer temperatures without intensifying winter cold. Studies show that increasing tree cover around residential buildings not only enhances thermal comfort but also reduces cooling and heating costs, offering both environmental and economic benefits. Mature trees also contribute to higher property values, especially near parks and green spaces. Urban green areas create a "park cool island" effect, providing localized cooling even in high-density settings. The presence and strategic placement of vegetation can influence microclimatic conditions, reduce radiant temperatures, and enhance overall thermal comfort. Additionally, trees improve air quality, reduce carbon emissions, and help with rainwater absorption, making them crucial elements in sustainable urban development and climate resilience.

Urban Design Strategies

Vegetation covers

Vegetation plays a vital role in reducing the Urban Heat Island (UHI) effect by cooling the air through shading and evapotranspiration, which converts solar energy into latent heat rather than raising air temperature. Trees and green spaces help lower surface and air temperatures, reduce long-wave radiation from the ground, and improve the urban microclimate by absorbing solar radiation, offering low thermal conductivity, and cooling the air. They also reduce infrared radiation, trap dust and pollutants, insulate against noise, and improve air quality. Strategically placed vegetation around buildings and roofs reduces energy demand by providing shade in summer and allowing sunlight in winter, contributing to thermal comfort. Green areas not only aid in mitigating climate extremes and lowering pollution levels but also enhance human health and urban livability. Even small, well-

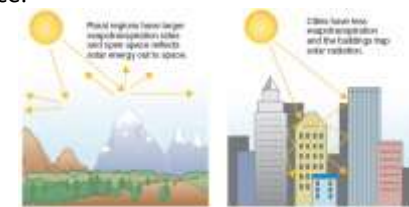


Fig.10 Evapotranspiration

Water bodies

Because the water body has a high thermal capacity and inertia, it has a lower LST and a strong UCI. It acts as an extra cold source in the green space buffer, changing the GCI efficiency. GCI effects will be strengthened by increasing vegetation and water body fractions or decreasing impermeable surfaces. Conversely, rapid evaporation creates "oasis effects" in water bodies and helps cool the surrounding surface air. In the summer, water bodies serve as urban cooling islands (UCI) due to the temperature differential.

Note -

LST – Land Surface Temperature

UCI – Urban Cooling Island

GCI – Green Cooling Island

UCL– Urban Canopy Layer

High albedo surfaces

which reflect more solar radiation and emit infrared energy efficiently, help reduce heat absorption and surface temperatures, especially in summer. These surfaces, when used in pavements, can mitigate Urban Heat Island (UHI) effects and aid in stormwater management. Permeable interlocking concrete pavers, in particular, show high permeability and cooler surface temperatures when wet, as they allow moisture retention and evaporation. The cooling effectiveness depends on surface moisture and evaporation rates. Studies, including those by UCPRC, indicate that well-designed full-depth permeable pavements can support both light and heavy traffic while managing stormwater runoff effectively. Combining reflective and permeable pavement systems can thus address both thermal and water-related challenges in urban areas.

Other strategies

- Planting trees
- Roof and create roof gardens or rooftop gardens

Case Studies

Pearl Academy Jaipur – Architectural + Urban Hybrid The Pearl Academy of Fashion, JAIPUR has a design that fosters an environmentally conscious atmosphere.

It offers innovative spaces for creative students, blending indoor and outdoor areas harmoniously. The institute's unique architecture combines traditional building techniques with modern design concepts.

Location – Jaipur Rajasthan, India

Climate – Hot And Dry

Architect – Morphogenius

Plot Area – 12250 Sq M [3 Acres]

Architecture Style – Traditional / Contemporary Fusion

Typology – Fashion Institute With An Aim Of Optimising The Building As A Device For Environmental Control

Designed – 2006

Completed – 2008

Passive Cooling With Traditional Rajasthani Elements

Incorporates passive climate control using traditional Indo-Islamic architecture and modern cooling strategies

Example - like open courtyards, water bodies, step-well (baoli), jaalis (perforated stone screens), and a Rajasthani jaali double skin façade.

Computational analysis guides the perforation density based on orientation, and drip channels in the jaali aid evaporative cooling.

The combination of traditional and modern techniques creates an environmentally sustainable solution for reducing heat loads and cooling the interior spaces naturally.



Fig.11 Pearl Academy Jaipur air flow movement

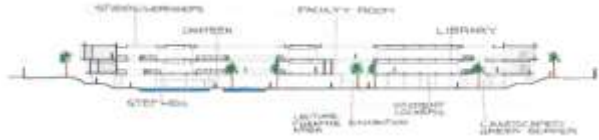


Fig.12 Pearl Academy Jaipur spaces use for reduce temperature

Suzlon One Earth – Global Corporate Headquarters.

Suzlon believes in creating and maintaining a positive environment, both outside its office walls as well as on the inside. Suzlon One Earth is the embodiment of this belief. Situated in Pune, India, it is the eco-friendly, self-sufficient headquarters of the company. The campus is spread across 10 acres and is completely powered by renewable energy, including hybrid wind turbines, solar panels and photovoltaic cells.

Location – Hadapsar Pune, India

Climate – Hot And Dry C climate

Architect – Christopher Charles Benninger Architects

Plot Area – 45,392 Sq M [Acres]

Architecture Style – Climate – Responsive Design & Sustainable Architecture

Typology – Suzlon One Earth serves as a corporate office building, designed to accommodate employees and facilitate work processes.

Designed – 2005

Completed – 2009

Since the site is located in a hot and dry climate, Christopher Charles Benninger aimed to utilize natural sources of daylight and ventilation wherever possible. Daylight is let in through Aluminium louvers which also act as a protective skin. The openable fenestrations which are provided in most areas allow for natural cross ventilation.

Concept of Suzlon One Earth Corporate Headquarters

- Integration of inside and outside.
- A green building.

- The southwest side of the structure put with an overload water tank and with minimum openings/windows.
- The center of the building is open to the sky to get enough light.
- The direction of the building is North-South direction.
- The water feature should be on the east side of the plot

Sustainability regulations have right from site selection and design to engineering, construction, materials, and operations. This includes usage of native flora, minimizing both environmental impact and decreasing the need for landscaping water, low-energy/green materials, proper orientation of the building facades that ensures adequate daylighting and minimizes glare.

A big water body in the central court helps in enhancing the air quality and evaporative cooling. All the exterior landscape areas brought into the indoors along the perimeter of the structure bringing fresh air, nature, and natural light into the work areas so as to improve the productivity of occupants.

Materials used in Suzlon One Earth

The use of PPC cement for non structural places with fly ash, use of Rerolled reinforcement steel, Fly Ash Bricks, High recycled content carpets, and modular ceilings are also a part of the Green design features.

To support the regional economy and reduce the environmental impact resulting from transportation. However, around 80% of regional materials (within a radius of 800 km) used in this project. Out of this around 20% of regional materials have extracted and manufactured regionally.

Rapidly renewable materials like Tarkett Bamboo flooring, Asis Board, Archidply, Interface Carpets, Cotton/ Jute carpets were and amounted to 5.89% of the building material cost.



Fig.13 Suzlon One Earth water bodies

Comparative Analysis

(Pearl Academy, Jaipur vs. Suzlon One Earth, Pune)

To better understand how temperature can be reduced on educational and institutional campuses, this research compares two important examples: Pearl Academy in Jaipur and Suzlon One Earth in Pune. Both are well-known buildings that use different types of materials and design strategies to keep the indoor and outdoor spaces cool, especially in India's hot climate. Although both aim to reduce heat and create comfortable environments, they follow different paths based on their location, climate type, and design philosophy.

Climate Context

- Pearl Academy, Jaipur is located in a hot and dry desert-like climate. This means temperatures are extremely high during the day, but can drop at night. Managing heat gain during the daytime is the biggest challenge here.
- Suzlon One Earth, Pune is situated in a hot and semi-humid climate. The city receives a fair amount of rainfall and stays warm throughout the year. Here, the focus is on balancing heat reduction with moisture control and ventilation.

Urban Design and Landscaping

Pearl Academy is designed around a central courtyard with water features. This traditional layout helps create a cool microclimate. The buildings are placed to allow cross ventilation, and large overhangs and shaded corridors help block sunlight.

The water court in the center further cools the air as water evaporates, a technique traditionally used in desert architecture. Dense tree plantation around

the courtyard provides additional shade and temperature regulation.

Suzlon One Earth has a modern and open campus layout. The buildings are placed to allow maximum airflow, and pathways are shaded by trees and pergolas. There are green roofs and terrace gardens that help lower the temperature on the upper floors and provide insulation to the building.

It also has small water bodies near buildings and sun-path based orientation to reduce direct solar exposure. The entire design follows a LEED Platinum-rated green building concept.

Use of Materials

Feature	Pearl Academy, Jaipur	Suzlon One Earth, Pune
Wall & Roof Material	High thermal mass + cavity walls	Double-glazed façades + insulation
Reflective/Albedo Surfaces	Light-colored lime plaster	White roofs + paved courtyards
Use Of Traditional Materials	Yes – jaali screens, lime plaster	No – uses modern materials
Phase Change Materials (PCM)	No	Yes (in selected zones)

Urban Design Strategies

Feature	Pearl Academy	Suzlon One Earth
Green Roofs/Terraces	No	Yes
Tree Plantation	High – courtyard surrounded by vegetation	Extensive – shaded pathways
Water Bodies	Yes – central water court cools surroundings	Yes – water features for microclimate
Orientation & Wind Movement	Buildings oriented for cross-ventilation	Open layout to allow wind flow
Shading Devices	Jaali screens, overhangs	Horizontal louvers, pergolas

Energy & Environmental Impact

Feature	Pearl Academy	Suzlon One Earth
Reduction In Indoor Temperature	4–5°C lower than outside	Up to 8°C cooler

Use Of Air Conditioning	Minimal, only in some areas	Highly reduced due to passive cooling
Overall Comfort Level	High, especially in central courtyard	Very high due to combined strategies

Both Pearl Academy and Suzlon One Earth show us that temperature reduction on a campus can be achieved in different ways. Pearl Academy follows a more traditional and passive approach, using materials and techniques that have worked in Rajasthan’s hot climate for centuries. Suzlon One Earth, on the other hand, shows how modern technology like reflective surfaces, PCMs, and advanced insulation can also lead to effective results.

Each has its own strengths:

- Pearl Academy is cost-effective, culturally rooted, and suitable for hot-dry areas.
- Suzlon One Earth is high-performing, eco-certified, and ideal for hot-humid or mixed climates.

This comparison helps us understand that there is no single solution for all campuses. The right combination of materials, design strategies, and climate understanding is the key to creating cooler and more sustainable learning or working environments.

IV. CONCLUSION

As urban areas grapple with rising temperatures and climate-induced challenges, campuses like Pearl Academy Jaipur & Suzlon one Earth exemplify how thoughtful integration of building materials and urban design strategies can significantly mitigate heat stress and enhance thermal comfort. The selection of climate-responsive materials—such as AAC blocks, fiber-reinforced mud bricks, and phase-change materials—not only reduces heat transmission but also promotes sustainability and energy efficiency. Simultaneously, urban strategies such as the use of shaded courtyards, dense vegetation, water bodies,

and high-albedo surfaces demonstrate how passive design can transform campuses into self-regulating, cooler microclimates. These approaches not only reduce dependence on mechanical cooling but also foster healthier, more productive environments.

The evidence from case studies suggests that a hybrid approach, combining traditional wisdom with modern technology, is key to designing thermally comfortable and environmentally responsible campuses. As continue to expand, they hold immense potential to lead by example showcasing how architecture and planning can actively respond to climate challenges at the local scale

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