COMPENDIUM FOR PASSIVE COOLING STRATEGIES IN CAMBODIA

November 2024

Purpose

The purpose of this compendium is to provide a resource on integrating passive cooling strategies (PCS) in the building sector in Cambodia. Cambodia experiences a tropical climate with substantial space cooling requirements for attaining thermal comfort. The compendium offers a collection of information and techniques aimed at reducing space cooling demand and addressing unmet thermal comfort periods. Architects, engineers, building owners, and professionals involved in building design, construction, operation, and maintenance can refer to this compendium as a guide to adopting PCS.

The compendium categorizes PCS into three groups: site-oriented measures, design-oriented measures, and material/technology-oriented measures. Each category is elaborated with technical descriptions, application processes, and analysis tools. This information enables informed decision-making and the selection of suitable PCS measures for projects.

The compendium complements other project resources such as the PCS material directory and international case studies compilation fostering the implementation of PCS in buildings.

Technical and financial support was provided by:

ESCAP Economic and Social Commission for Asia and the Pacific
UN environment programme
Cool Coalition
climateworks FOUNDATION

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Definition

Terminology	Definition	Unit
Density	Density is a physical property that measures the amount of mass per unit volume of a substance.	kg/m^3
Emissivity	Emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a perfect emitter, known as a blackbody, at the same temperature and wavelength and under the same viewing conditions. It is a dimensionless number between 0 (for a perfect reflector) and 1 (for a perfect emitter).	NA
Specific heat	Specific heat is a physical property of a substance that describes the amount of heat energy required to raise the temperature of a unit mass of the substance by one degree Kelvin.	J/kg.K
SHGC (Solar Heat Gain Coefficient)	The ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convection into the space	%
Thermal mass	Thermal mass is a physical property of a material that describes its ability to absorb and store heat energy	NA
Thermal conductivity	Thermal conductivity can be defined as the rate at which heat is transferred by conduction through a unit length of a material when a temperature gradient exits perpendicular to the cross-sectional area.	W/m.K
U-Value	Heat transmission in unit time through the unit area of a material or construction and the boundary air films, induced by a unit temperature difference between the environments on each side	$W/m^2.K$
Visible Light Transmittance	Visual Light Transmittance (VLT) is a measure of the amount of visible light that passes through a fenestration product such as windows, skylights, and doors. VLT is expressed as a percentage of the total visible light that strikes the surface of the glass, and it ranges from 0% (completely opaque) to 100% (completely transparent).	%

Abbreviations

AAC	Autoclaved Aerated Concrete
BIM	Building Information Modelling
EPS	Expanded Polystyrene
MEPS	Moulded Expanded Polystyrene
MJ	Mega Joule
MRT	Mean Radiant Temperature
MS	Mild Steel
PCS	Passive Cooling Strategies
PMV	Predicted Mean Vote
PPD	Predicted Percentage dissatisfied
PUF	Polyurethane Foam
QGIS	Quantum Geographic Information System
RCC	Reinforced Cement Concrete
SHGC	Solar Heat Gain Coefficient
SRI	Solar Reflective Index
UHI	Urban Heat Island
UPVC	Unplasticized Poly Vinyl Chloride
UWG	Urban Weather Generator
VI	Vegetation Index
VLT	Visible Light Transmission
WWR	Window-To-Wall Ratio
XPS	Extruded Polystyrene Insulation

Acknowledgement

The Ministry of Environment express its gratitude to the relevant ministries, development partners, academia, private sectors and all stakeholders for their contribution to the development of the Compendium for Passive Cooling Strategies in Cambodia.

This *Compendium for Passive Cooling Strategies in Cambodia* was developed as a collaboration between the General Directorate of Environmental Protection and General Directorate of Policy and Strategy, the Ministry of Environment with technical and financial support from the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) and United Nations Environment Programme (UNEP) within the framework of the Cool Coalition and Climateworks Foundation.

The Compendium for Passive Cooling Strategies in Cambodia is designed to provide building sector stakeholders a practical tool to identify and implement passive cooling strategies appropriate to Cambodia's climatic and architectural context based on locally and regionally available materials and building components.

I would like to congratulate Ministry of Environment including H.E Pak Sokharavuth, Under Secretary of State, the Ministry of Environment, H.E Danh Serey, Director General of General Directorate of Environmental Protection, the Ministry of Environment, H.E Sum Thy, Director General of General Directorate of Policy and Strategy, Dr. Hak Mao, Director of the Department of Climate Change of the General Directorate of Policy and Strategy, and Mr. Chea Nara, Director of the Department of Air Quality, Noise and Vibration Management, the General Directorate of Environmental Protection for their leadership and coordination in developing the Compendium for Passive Cooling Strategies in Cambodia. I would like to congratulate the project team supporting the development of the Compendium including Lun Lido, Lily Riahi (UNEP), Kimberly Rosebery (ESCAP), Marco Duran, Manjeet Singh (UNEP), and the technical experts Raj Kumar Balasubramaniyan, Kanagaraj Ganesan, Andeol Cadin, and Philip Tepyuthyea. The development of this Compendium has benefitted from the review and inputs of a range of national and international experts from the government, academia (ITC), architects and building developers, including Dr. Sarin Chan (ITC), Dr. Zhuolun Chen (UNEP CCC), Aarti Nain (UNEP Cool Coalition), Gennai Kamata (UNEP Cool Coalition), David Ferrari (ESCAP), Butchaiah Gadde (UNDP Cambodia), Mark Low (UrbanLand), and Martin Aerne.

I sincerely hope that the *Compendium for Passive Cooling Strategies in Cambodia* will be an important source and a key building block for Cambodia's building sector policies on PCS.

Minister

EANG SOPHALLETH

Purpose

The purpose of this compendium is to provide a resource on integrating passive cooling strategies (PCS) in the building sector in Cambodia. Cambodia experiences a tropical climate with substantial space cooling requirements for attaining thermal comfort. The compendium offers a collection of information and techniques aimed at improving access to thermal comfort in buildings and reducing space cooling loads. Architects, engineers, building owners, and professionals involved in building design, construction, operation, and maintenance can refer to this compendium as a guide to adopting PCS.

The compendium categorizes PCS into three groups: site-oriented measures, design-oriented measures, and material/technology-oriented measures. Each category is elaborated with technical descriptions, application processes, and analysis tools. This information enables informed decision-making and the selection of suitable PCS measures for projects.

The compendium complements other project resources such as the PCS material directory and international case studies compilation fostering the implementation of PCS in buildings.

1 Building Physics

The building is an open system which exchanges heat and mass with the surroundings and internal activities. The purpose of the building is to provide a conducive environment for the occupants so that they can perform their tasks comfortably. Hence the building must provide thermal comfort, visual comfort, acoustic comfort, and requisite indoor air-quality to the occupants. The building designers and occupants need to understand the basics of building physics for attaining thermal comfort.

Cambodia exhibits a tropical climate with significant requirements of space cooling for attaining occupant thermal comfort.

1.1 Thermal Comfort

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment. It is the state in which individuals feel neither too hot nor too cold, but rather experience a sense of thermal well-being.[1]Achieving thermal comfort is essential for maintaining occupant satisfaction, productivity, and overall well-being in various indoor spaces, including homes, offices, schools, and public buildings. Thermal comfort is dependent on four environmental parameters and two personal parameters as shown in Figure 1.

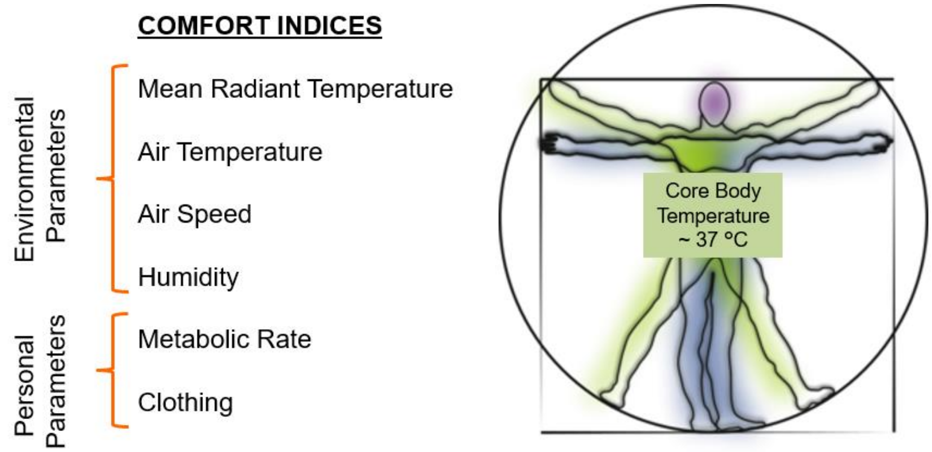


Figure 1 Comfort indices and parameters affecting the thermal comfort (developed by authors)

Environmental Parameters

i. Mean radiant temperature (MRT): The MRT refers to the average temperature of all the surfaces surrounding a person in an indoor or outdoor environment. It includes the temperature of walls, floors, windows, and other objects that radiate heat.

ii. Air temperature: Air temperature is the measure of the average thermal energy present in the air surrounding occupants. It is commonly measured using a thermometer and expressed in Celsius or Fahrenheit.

iii. Humidity: Humidity refers to the amount of moisture present in the air. It is typically measured as relative humidity, expressed as a percentage.

iv. Air speed: Air speed, also known as air velocity, is the measure of the movement or flow of air in each space. It is typically measured in meters per second or feet per minute.

[1] "ANSI/ASHRAE Addendum a to ANSI/ASHRAE Standard 55-2020," 55.

Personal Parameters

v. Metabolic rate: Metabolic rate refers to the rate at which the human body generates heat through metabolic processes. It varies among individuals based on factors such as physical activity, age, gender and overall health. The unit of metabolic rate is MET.

vi. Clothing: Clothing insulation is a measure of the thermal resistance provided by the clothing worn by individuals. It affects the heat exchange between the body and the environment. "Clo" is a unit used to express the thermal insulation provided by clothing.

The personal parameters take into account the gender, age and clothing practices for defining a combination of environmental parameters to attain occupants thermal comfort.

ASHRAE 55-2020 discusses use of two thermal comfort models: the Predicted Mean Vote-Percentage of People Dissatisfied (PMV-PPD) model and the Adaptive Comfort Model.

The PMV-PPD model is based on the principle of energy balance. It predicts the average thermal sensation of a group of people in a given environment. The PMV scale ranges from -3 to +3, where negative values indicate cold sensation, zero represents thermal neutrality, and positive values indicate a warm sensation.

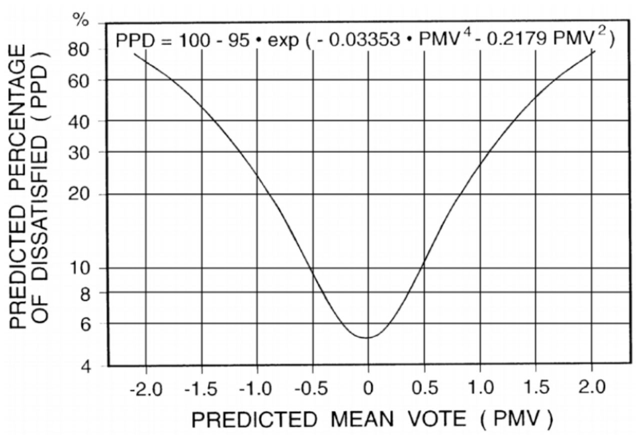


Figure 2 PPD as a function of PMV to define thermal comfort for conditioned spaces[2]

The adaptive comfort model is applicable for occupant-controlled naturally conditioned spaces. It is applicable for naturally conditioned spaces with no mechanical cooling or heating. With metabolic rate between 1.0 to 1.5 MET, occupant are able to adapt their clothing at least as wide as 0.5 to 1.0 clo, and the prevailing mean outdoor temperature is greater than 10 °C and less than 33.5 °C.

[2] "ANSI/ASHRAE Addendum a to ANSI/ASHRAE Standard 55-2020."

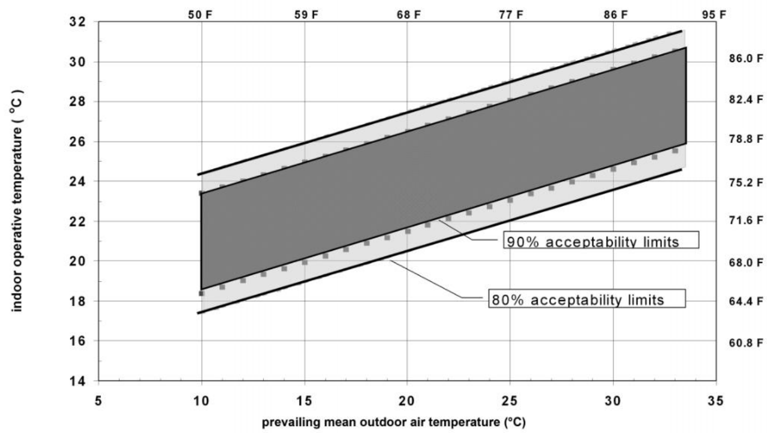


Figure 3 Acceptable indoor operative temperature ranges as per adaptive comfort model

1.2 Mode of Heat Transfer in Buildings

Heat transfer will always take place from a warmer medium to a cooler one. Three modes of heat transfer are:

- **Conduction**: The heat transfer through a solid medium due to the temperature difference. The two things required for conduction to take place are surface contact and temperature difference e.g., an uninsulated wall exposed to high outdoor temperatures can conduct heat into the building, causing increased indoor temperatures and discomfort.
- **Convection**: This form of heat transfer involves energy transfer by fluid movement and molecular conduction e.g., warm outdoor air in tropical climate infiltrates through cracks or gaps in the wall, it can convectively transfer heat into the building, leading to increased indoor temperatures.
- **Radiation:** The heat transfer through electromagnetic radiation. Any surfaces at differing temperatures that facing each other will emit and absorb radiant energy continuously e.g., sunlight passing through a window brings radiative heat into the room, contributing to an increase in indoor temperatures.

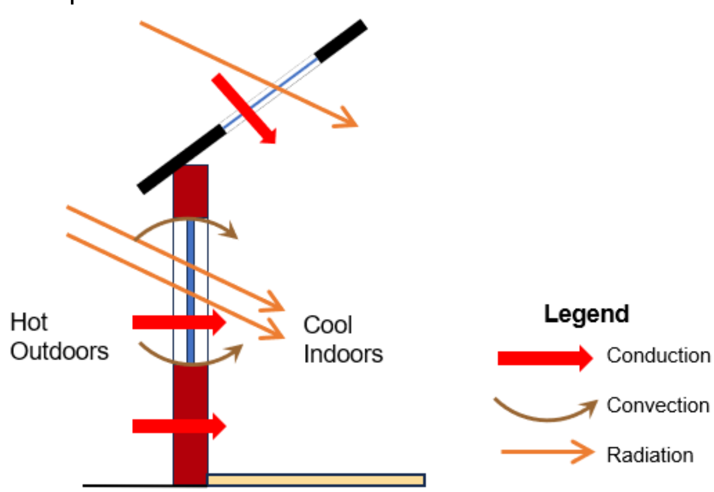


Figure 4 Modes of heat transfer through the building envelope (authors)

1.3 Heat Gain Loss and Storage

The heat gain, heat loss and heat storage to a building can disrupt the thermal comfort. The heat gain and heat loss in a building envelope attributes to the heat storage capacity in the thermal mass elements. Heating and cooling equipment balances this to maintain comfortable conditions for the occupants. In the tropical climate of Cambodia, increases in the cooling load of buildings is of greater concern.

The cooling load of a building refers to the amount of heat energy that needs to be removed to maintain thermal comfort in a space. Cooling loads are classified based on their impact on the temperature and moisture content of the air:

i. Sensible cooling load: This type of heat load is caused by changes in the air temperature and is felt as the warmth of the air. The sensible heat load includes conduction and radiation heat gain through the building envelope and from the internal load of occupancy, lighting, and equipment.
ii. Latent cooling load: This type of heat load is caused by changes in the moisture content of the air without changing the temperature and is related to the amount of water vapour in the air. The main sources of latent load in a building are from building occupancy, infiltration and equipment contributing to the addition of moisture content in the air.

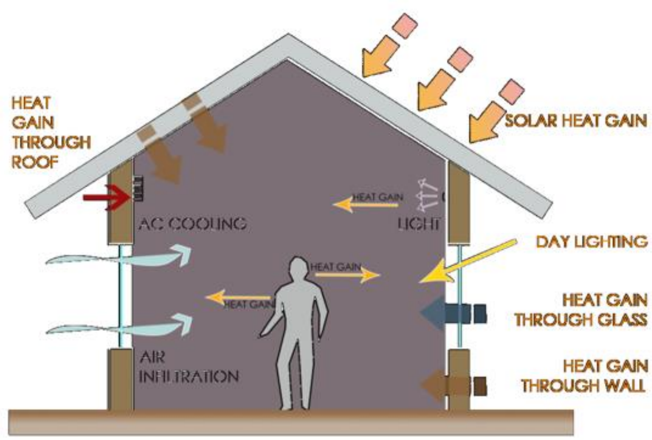


Figure 5 Building cooling mode (authors?)

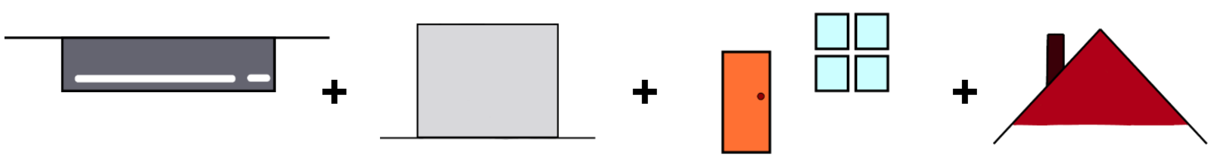
The cooling load can be further classified based on their source

iii. Building Envelope Load relates to heat gain through building envelope components like walls, fenestration, floors, and roofs of a building.
    a. Transmission heat load: This type of heat load is caused by heat transfer through the building envelope, including walls, windows, roofs, and floors.
    b. Infiltration heat load: This type of heat load is caused by air entering or leaving the space through cracks, gaps, and other openings in the building envelope.
    c. Thermal bridge heat load: This type of heat load is caused by the presence of materials or components with higher thermal conductivity within the building envelope. These materials or elements create localized areas of increased heat transfer, leading to higher heat flow than in the surrounding insulated regions.
iv. Internal Load

a. Occupancy Load: The occupancy load represents the heat generated by the occupants within the space. The number of people present, their activity level, and their metabolic rate influence the amount of heat produced.
b. Lighting Load: The lighting load represents the heat generated by artificial lighting sources, such as incandescent, fluorescent, or LED lamps.
c. Equipment Load: The equipment load refers to the heat generated by various electrical and mechanical equipment used within the building. This includes computers, servers, kitchen appliances, refrigeration units, and any other equipment that releases heat during operation.

1.4 Components of Building Envelope

The building envelope refers to the exterior enclosure of a building that separates the interior conditioned spaces from the external environment. Opaque components include walls, roofs, slabs, basement walls and opaque doors.



FLOORING	WALL	FENESTRATION	ROOF
Flooring act as a barrier between the interior and the ground below. To optimize thermal performance of flooring, it is essential to consider the interface between the flooring and the ground to minimize undesired heat transfer.	Wall in a building includes opaque elements which are inclined at an angle of 60 degrees or more from the horizontal. It constitutes of above and below-grade walls.	Fenestration comprises of transparent and translucent elements in the building envelope, including glazing, frames, and shading devices. This encompasses windows, clerestories, skylights, glass block walls, and doors with significant glass areas.	The roof is the uppermost covering of a building, providing protection against weather elements and serving as a barrier between the topmost floor interior space and the external environment.

1.5 Passive Cooling Strategies

Passive cooling strategies (PCS) encompass techniques and design principles that minimize heat gain in buildings without relying on operational energy consumption, thereby reducing, or eliminating the need for mechanical systems like air-conditioning. By leveraging natural processes such as convection, radiation, and conduction, these strategies effectively manage heat transfer from the building envelope.

To classify these PCS for easy understanding and implementation at both site and building levels they are classified into three distinct categories:

i. Site-oriented PCS

Site-oriented PCS encompass a range of techniques and design principles applicable to outdoor spaces aimed at improving the microclimate at the site level. These strategies involve interventions such as incorporating vegetation, water features, permeable surfaces, and cool pavements at the site level.

ii. Building design-oriented PCS

Building design-oriented PCS refer to the techniques and design principles that focus on building design to manage heat gain or loss to attain enhanced indoor thermal comfort. These strategies involve optimizing the building's orientation, massing, spatial configuration etc.

iii. Building materials/technologies-oriented PCS

Building materials/technologies-oriented PCS refer to the use of specific materials and technologies used for the building envelope to manage heat gain. This includes building deploying components such as insulation and shading, or ventilation of building spaces.

Effectively utilizing these PCS will ensure the building spaces are comfortable and thermally appropriate for its occupants with reduced demand for cooling energy. A breakdown of suggested PCS for the tropical climate of Cambodia is presented in Figure 6.

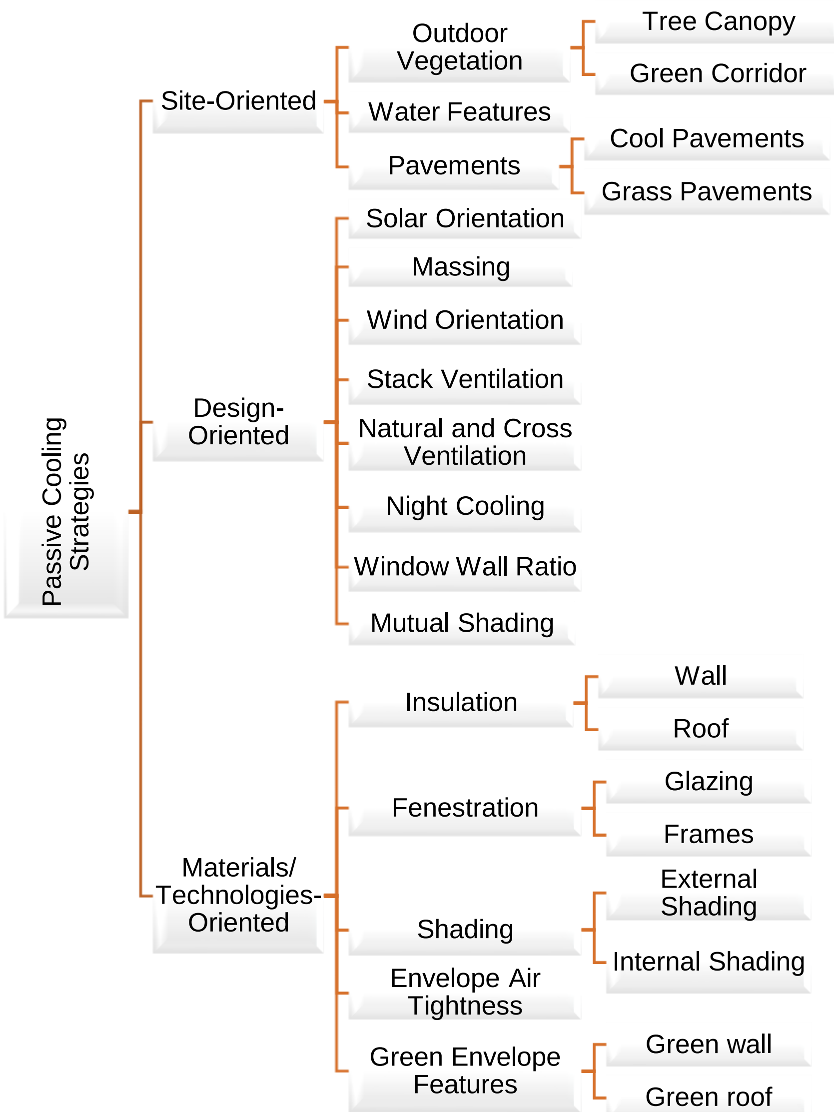


Figure 6 List of PCS

Mainstreaming the implementation of PCS at the large scale in cities in Cambodia through building regulation, incentive programs, improved urban planning, raising awareness among others, will improve micro-climate[3], enhance outdoor thermal comfort and reduce space cooling demand.

Implementing climate-responsive building envelopes, exterior finishes, efficient windows, natural *ventilation, optimal orientation, and incorporating nature-based solutions can significantly reduce*

[3] Microclimate pertains to the climatic conditions experienced in a particular site or location, encompassing any small-scale variations from the overall climate of a broader region or zone. These localized fluctuations in climate can occur at various levels, such as within a settlement (urban or rural), neighborhood, cluster, street, or even in the buffer spaces between buildings or within a building itself..

cooling demand by 30% to 50%. Investing effort into thoughtful design during the initial stages yields cost-effective solutions that result in long-term energy savings and improved sustainability[4].

Adopting PCS will unlock multiple benefits, including:

- Reduce heat stress: Air temperature, operative and radiant temperatures
- Reduce discomfort hours
- Lower electricity consumption associated with active cooling (air conditioners)

Save money in electricity bills for the population and businesses

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[4] PEEB Cooling Building, 2020

2 Site-oriented Passive Cooling Strategies

Ensuring thermal comfort for urban populations is paramount in addressing cooling requirements. Therefore, effective urban planning and design, aimed at mitigating heat, holds immense value at the city or urban district level. Natural elements, such as trees and vegetation, offer cooling advantages through evapotranspiration and shading. Incorporating nature-based solutions like greenery, water bodies, and permeable pavements into the urban landscape can significantly lower local and ambient temperatures, enhancing the overall comfort and well-being of urban residents. The following sub-sections of the chapter discuss site-oriented PCS (PCS) that designers can adopt to enhance thermal comfort in urban environments.

2.1 Outdoor Vegetation: Tree Canopy

2.1.1 Description

Trees help in achieving passive cooling through shading and evapotranspiration. Evapotranspiration refers to the natural process by which plants release moisture through their leaves, which then evaporates into the surrounding air producing a cooling effect. The rate of evaporation depends upon water availability, the degree to which that surface is heated, the humidity of the overlying air and air movement.

The presence of tree canopies can effectively modify wind patterns, providing opportunities to enhance outdoor thermal comfort. When considering the cooling effects of trees on buildings and surrounding spaces, it is important to account for various variables such as tree density, surface characteristics, canopy shape, canopy dimensions (length, width, height), orientation, and the presence of building openings. These factors play a crucial role in harnessing the full potential of tree canopies to optimize cooling strategies and create more comfortable environments for building occupants. This Passive cooling strategy has been implemented in the projects like Indira Paryavaran Bhawan, Ministry of Environment and Forest in India, Osaka Urban Central Area in Japan and Urban Oasis Program for Schoolyards in France and the details are added in the Appendix.

2.1.2 Strategy Application

Description for integrating strategies on tree canopy PCS.

- The strategic placement of outdoor vegetation at the site level is a crucial factor in optimizing the microclimate, resulting in reduced building cooling loads, and enhanced outdoor comfort. This targeted approach proves particularly valuable for outdoor spaces that are intended for utilization during the summer season.
- Tree canopies are most helpful on the east, south and west walls, which are exposed mostly to the summer sun. The canopy size and the distance from the building are crucial parameters to be considered for shading from the tree canopy.
- There will be a reduction of up to 50 percent in the cooling load when an envelope-dominated building is effectively shaded by plants.
- Strategically placing the shrubs can deflect hot prevailing summer winds during the summer reducing the envelope heat gain.
- Trees and shrubs can funnel the cool breeze through buildings.

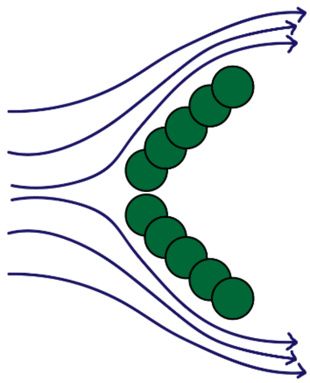


Figure 7 Deflection of undesirable wind by vegetation

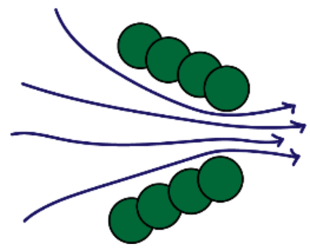


Figure 8 Channelizing of desirable wind by vegetation

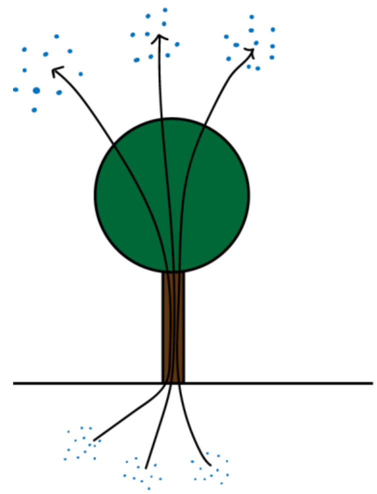


Figure 9 Evapotranspiration

2.1.3 Analysis Tools

To perform thermal comfort analysis at the city level using trees, the designer needs specialized tools that can do 3-D modelling of the urban fabric, solar radiation analysis, wind flow analysis, evapotranspiration modelling, the interaction of ambient environment conditions with the built-form and effective visualization of results.

Citygreen, Envi-met, and Quantum Geographic Information System (QGIS) are examples of tools widely used by designers to analyze outdoor thermal comfort at the urban scale using tree canopy.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the tree canopy PCS.

Building Details	Indira Paryavaran Bhawan
Location	New Delhi, India
Building Typology	Office (Single shift building)
No. of Floors	G+7
Climatic Zone (ASHRAE)	Very Hot and Humid
CDD (Cooling Degree Days)	5629
HDD (Heating Degree Days)	383
Implementation Agency	Central Public Works Department
Occupancy	600
Recognition	LEED India Platinum, GRIHA 5stars

Passive Cooling Strategies	Percentage Reduction in Cooling Demand

Double glazed windows	40%
Façade and envelope	30%
Cool roofs	11 to 27% (depends on the reflectance value)
Rock wool insulation	30 to 70% (depends on the thickness)
Landscape Design	5 to 50%
Other Strategies: Light shelves for diffused sunlight and Bamboo jute composite doors, frames, and flooring.	3 to 8%

Double glazed windows contribute to a significant 40% reduction in cooling demand. The façade and envelope design, along with cool roofs and rock wool insulation, enhance thermal efficiency. Landscape design complements these strategies, providing shading and ventilation.

CaseStudy:
https://drive.google.com/file/d/1tx7JeEKqPmYqtzgk9dX3ckEnN3JLAvTo/view?usp=drive_link

2.2 Outdoor Vegetation: Green Corridor

2.2.1 Description

A green corridor refers to a linear and inter-connected network of vegetation and natural elements designed to enhance thermal comfort and mitigate heat in an urban setting. It involves creating a continuous strip of greenery along pathways, roads, or open spaces to provide shading, evaporative cooling, and improve air quality. By incorporating green corridors as PCS, cities can mitigate the urban heat island effect and enhance the overall comfort and well-being of residents.

2.2.2 Strategy Application

The strategic placement of trees, shrubs, and other vegetation within the corridor helps reduce the ambient temperature, create microclimates, and promote natural airflow.

This can be achieved by planting trees along streets, highways, neighbourhood playgrounds, backyards, community gardens and even along commercial developments.

The regular streets can be upgraded with green corridors. The growth rate of any tree, shrub, or vine can be accelerated by supplying ample nutrients and a steady source of water. A drip-irrigation system is excellent for this purpose.

Figure 10 Green urban corridor

2.2.3 Analysis Tools

To perform thermal comfort analysis at the city level using trees, the designer needs specialized tools that can do 3-D modelling of the urban fabric, solar radiation analysis, wind flow analysis, evapotranspiration modelling, the interaction of ambient environment conditions with the built-form and effective visualization of results.

Citygreen[5], Envi-met, and Quantum Geographic Information System (QGIS) are examples of tools widely used by designers to analyze outdoor thermal comfort at the urban scale using green corridors.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the green corridor PCS.

2.2.4 Implementation Examples

Tree canopy and green corridor plays important role in mitigating heating effect of the building and various projects have implemented outdoor vegetation on site level. These projects emphasize site-level interventions to enhance environmental sustainability. The Austrian Embassy in Jakarta employs landscape design to reduce cooling demand, while Maslid Darul Ibadah in Kuching plants trees for similar benefits. The Urban Oasis Program for Schoolyards utilizes trees and gardens, providing shading and fostering environmental awareness in schools.

Property Details	Austrian Embassy
Location	Jakarta, Indonesia
Building Typology	Office (Single shift building)
No. of Floors	G+1
Climatic Zone	Hot and Humid (ASHRAE) CDD – 62 HDD - 3
Implementation Agency	POS architects

[5] https://citygreen.com/

Passive Cooling Strategies	
Air-tight insulation	Reduction in cooling demand
Timber screen	
Orientation	
Façade and Envelope	
Landscape Design	

Passive cooling strategies for this project encompass air-tight insulation to decrease cooling demands, a timber screen for effective shading, optimized orientation to reduce heat absorption, and a well-designed façade and envelope. The landscape design complements these strategies, enhancing cooling through greenery and natural ventilation.

CaseStudy:https://drive.google.com/file/d/1k6oPH-EWFTWLFY__mQp-DQZFY0lmR5YZ/view?usp=drive_link

2.3 Water Features

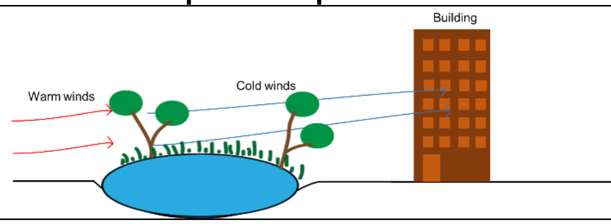
2.3.1 Description

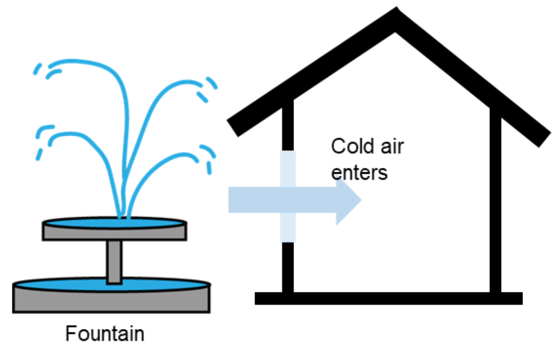
Water bodies in urban areas offer an efficient means of passive cooling, leveraging evaporative cooling to positively influence the microclimate. By mitigating the Urban Heat Island (UHI) effect, where urban temperatures surpass those of neighboring non-urban regions, water bodies such as pools, fountains, indoor canals, and water walls have demonstrated their efficacy in effectively reducing urban temperatures.

2.3.2 Strategy Application

It is important to consider factors such as water availability, maintenance requirements, and sustainability aspects when implementing flowing water features at the building site.

Table 1 Application process for water features strategy

Description	Graphical Representation
Open water bodies can lower air temperature through processes such as evaporation, absorption of heat, and the movement of heat. Designers can consider the use of rainwater catchment areas to develop open water bodies.	
One strategy for incorporating flowing water at a building site is to design and implement water features such as fountains, cascades, or water channels using a recirculation system. A fountain with water spray can provide a greater cooling effect as it increases the surface area of contact between water and air, thus promoting more evaporation. Fountains can also provide a significant cooling effect, with the surrounding air	

temperature being lowered by 3°C and the cooling effect being felt up to 35 meters away from the fountain. Fountains also have a positive social impact as they provide a fun place for children to play and serve as a gathering place for people in parks and squares.[6]	

2.3.3 Analysis Tools

To perform analysis at an urban scale using water bodies, the designer needs specialized tools that can do 3-D modelling of the urban fabric, evaporative cooling assessment of water bodies considering parameters (like water surface area, wind flow pattern, humidity, and temperature differentials) and effective visualization of results. The tool should also facilitate the assessment of the optimal size, shape, and placement of water bodies to maximize their cooling potential.

Envi-met, CitySim, and Urban Weather Generator are examples of tools widely used by designers to analyze outdoor thermal comfort at the urban scale considering water bodies.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the water feature PCS.

2.4 Pavements: Cool Pavements

2.4.1 Description

Cool pavements are widely implemented by many cities globally as effective technologies for mitigating the adverse effects of urban heat islands. A typical pavement has high absorbtivity and low heat emittance, while cool pavement reflects the incident solar radiation during the day and emits heat at night. Cool pavements are based on the use of materials with high reflectance in solar radiation and high emissivity. The surface properties of the cool pavement are measured by the solar reflectance index (SRI). It is a measurement scale ranging from 0 to 100, where higher values indicate a greater ability to reflect solar radiation and emit heat. This Passive cooling strategy has been implemented in the projects Tokyo Cool Pavement Program in Japan and the details are added in the Appendix.

2.4.2 Strategy Application

The application process for cool pavements can vary depending on the type of pavement and the specific project. Choose pavement materials with high solar reflectance (albedo) to increase the amount of solar radiation reflected away from the surface. Light-coloured concrete or porous asphalt can be used as pavement surfaces. Reflective coatings or surface treatments with high

[6] Beating the Heat: A Sustainable Cooling Handbook for Cities

SRI can be spayed or painted on to the pavements to enhance their solar reflectance and thermal emittance.

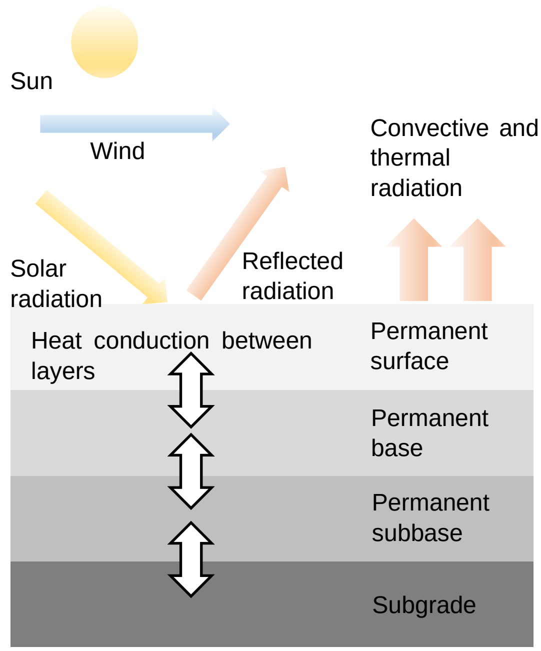


Figure 11 Heat-exchange-related processes in the typical urban pavement

2.4.3 Analysis Tools

To simulate the effect of cool pavements, tools should be capable of modelling the surface reflectance, thermal emittance, and heat transfer properties of the pavement materials. To assess the outside surface temperature difference before and after placement of cool pavements tools such as ENVI-met, Urban Weather Generator (UWG), and EnergyPlus can be used.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the cool pavement PCS.

Building Details	Tokyo Cool Pavement Program
Location	Tokyo, Japan
Climatic Zone	(ASHRAE)Warm and Humid CDD 2418, HDD 1784
Implementation Agency	Tokyo Metropolitan Government

Passive Cooling Strategies	
Reflective coatings	Surface temperatures reduced up to 8°C with reflective coatings.
Permeable coating	Surface temperatures reduced up to 10°C with permeable coating.

Passive cooling techniques, such as reflective coatings and permeable coatings, have proven effective in reducing surface temperatures. Reflective coatings led to an up to 8°C decrease, while permeable coatings achieved an impressive 10°C reduction. These strategies offer promising solutions for tackling heat-related issues and improving overall comfort.

Case Study: https://drive.google.com/file/d/12POWgkq_hDNfywyzB-R5szw44K8NhfKY/view?usp=drive_link

2.5 Pavements: Grass Pavements

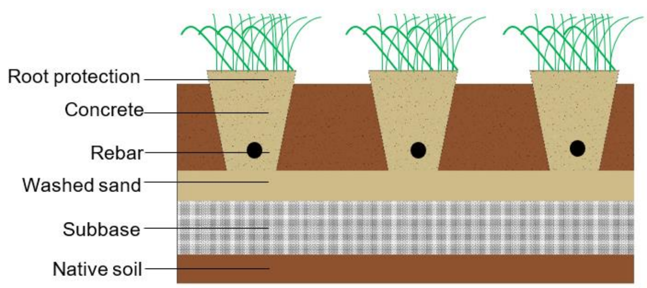
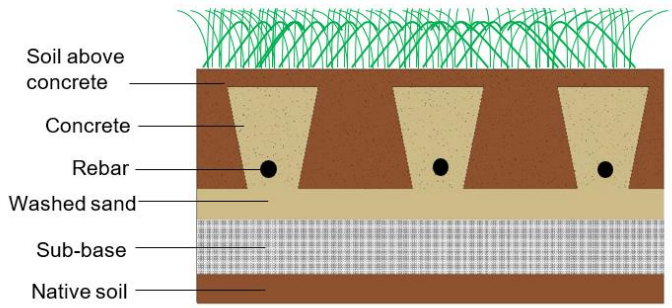
2.5.1 Description

Grass pavements provide an eco-friendly and permeable solution for emergency vehicle access, parking, and water management. They offer benefits such as mitigating the heat island effect, effective stormwater management, long lifespan, and minimal maintenance requirements. Compared to precast concrete and plastic paving systems, grass pavements offer significant advantages in terms of sustainability and environmental impacts. This Passive cooling strategy has been implemented in the projects Tokyo Cool Pavement Program in Japan and the details are added in the Appendix.

2.5.2 Strategy Application

Grass pavements are manufactured by a straightforward process of pouring concrete over styrene void formers. The former is equipment or mould used to create voids in concrete structures. These voids can be subsequently filled with porous materials like soil, gravel, or vegetation. The grass takes a maximum of six months to grow.

Table 2 Types of grass pavements

Types of Grass Pavements	Graphical Representation
Partially concealed grass pavements	
Concealed grass pavements	

2.5.3 Analysis Tools

Simulating the impact of grass pavements requires tools capable of modelling surface reflectance, thermal emittance, and heat transfer properties of the materials. Tools like ENVI-met, Urban Weather Generator (UWG), and EnergyPlus can be utilized to assess temperature differences before and after the installation of grass pavements, providing valuable insights into their thermal performance.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the grass pavement PCS.

2.5.4 Implementation examples

The Urban Oasis Program in Paris focuses on site-level interventions like permeable and high albedo pavement to create cooler and more sustainable schoolyards. Similarly, the Cool Pavement Program in Tokyo utilizes reflective and permeable coatings on over 96km of pavement to achieve surface temperature reductions of up to 8°C and 10°C, respectively, enhancing urban cooling and environmental resilience. Detailed case studies have been mentioned in the annex.

Building Details	The Urban Oasis Program
Location	Paris, France
Climatic Zone	(ASHRAE) Warm Humid CDD 1259, HDD 2736
Implementation Agency	City of Paris' Schools Department, Office of Resiliency, and Architecture Office.

Passive Cooling Strategies	
Permeable and high-albedo pavements	The air temperature is typically 2°C to 4°C cooler than surrounding air temperature
Trees and school gardens	
Cool pathways	

The implementation of passive cooling strategies at this location includes the use of permeable and high-albedo pavements, resulting in air temperatures that are typically 2°C to 4°C cooler than the surrounding environment. Additionally, the integration of trees and school gardens contributes to the creation of cool pathways, further enhancing the cooling effect and promoting a more comfortable outdoor environment.

CaseStudy:https://drive.google.com/file/d/1qaNOh0za2WFuEk29Zl2YjC6N-Lt-In5A/view?usp=drive_link

3 Design-oriented Passive Cooling Strategies

Design-oriented PCS encompass a range of techniques and design principles aimed at effectively managing heat gains to achieve optimal indoor thermal comfort in tropical climates. These strategies involve strategic considerations such as optimizing building orientation, and carefully designing the massing and spatial configuration reflecting climate-responsive design. By incorporating these design elements, buildings can minimize heat transfer, reduce reliance on mechanical cooling systems, and create a comfortable indoor environment.

3.1 Solar Orientation

3.1.1 Description

Solar orientation is the thoughtful and deliberate positioning of a building and building facades to minimize incident solar radiation and heat gain in relation to the sun's annual path. This should be decided together with building massing (discussed in section 3.3) PCS early in the design process to get maximum advantages from other PCS.

3.1.2 Strategy Application

As Cambodia is located between the Tropic of Cancer and the Equator, the summer sun rises from the northeast, travels to the north during at afternoon and sets in the northwest. The preferred orientation for the building in the country would be with a longer building axis aligned to the east-west direction i.e., longer façades should be oriented towards north and south. The designers in this climate should ensure the north-oriented facade windows and facades are shaded well to reduce heat gain.

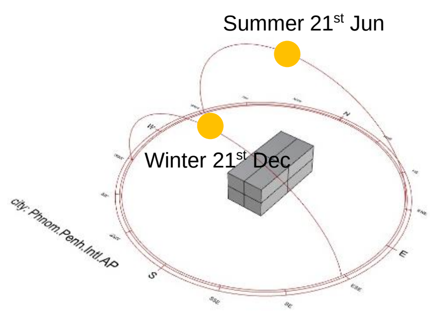


Figure 12 Solar orientation

3.1.3 Analysis Tools

The analysis tools for solar orientation should include sun-path analysis, shadow analysis, solar irradiance tables, solar irradiance calculation, energy performance modelling and effective visualization of results. Some of the tools that can be used for this study of the solar orientation of a project are Autodesk Revit, SketchUp with Solar Analysis Extensions, Rhino Grasshopper with Ladybug plugin, Design Builder etc.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the solar orientation PCS.

3.1.4 Implementation Examples

The Office Room in Tangerang implements solar shading with operable louvers that can be adjusted outside the windows, resulting in a significant 40% reduction in cooling demand. This intelligent design enhances energy efficiency and ensures a comfortable indoor environment. Detailed case study is mentioned in Annexure.

Building Details	The Office Room
Location	Tangerang, Indonesia
Building Typology	Office
No. of Floors	G+2
Climatic Zone	(ASHRAE) Very Hot and Humid, CDD 6240, HDD 3
Implementation Agency	Researchers of School of Architecture, The University of Tokyo, Tokyo, Japan
Occupancy	11
Passive Cooling Strategies	

Solar shading	
Low-E single-pane glass	40% reduction in cooling demand
Improvement of thermal insulation	
Natural ventilation	
Other Strategies: Night ventilation, Airtightness of the building and operation pattern of the building	

This project in Tangerang, Indonesia, features low-E single-pane glass, resulting in a 40% reduction in cooling demand. Additionally, it emphasizes improved thermal insulation, solar shading, and natural ventilation to enhance energy efficiency and occupant comfort.

CaseStudy:
https://drive.google.com/file/d/1bxUcn0XeK6xOtnJmtBAAHgmnaF4hS8l0/view?usp=drive_link

3.2 Massing and Zoning

3.2.1 Description

Building massing refers to the three-dimensional form, shape, and arrangement of a building. By carefully considering the building massing, designers can optimize the building's response to the local climate and minimize heat gain. Compact building shapes with reduced exposed surface area-to-volume ratios are preferred as they minimize the external surface area exposed to heat gain. This Passive cooling strategy has been implemented in the projects like Indira Paryavaran Bhawan Ministry of Environment and Forest in India, NUS School of Design & Environment in Singapore, Bayalpata Hospital Achham in Nepal, PT-Ungaran Sari Garments in Indonesia, Humanscapes Habitat Urban Living in India, Arthaland Century Pacific Tower in Philippines and the details are added in the Appendix.

3.2.2 Strategy Application

To determine the optimal massing option for a building, designers must carefully consider site-specific factors such as topography, surrounding buildings, and vegetation that can impact the building's performance. Additionally, the appropriate massing and zoning strategies are influenced by the building's intended use and the type of occupants it will accommodate.

The designer can deploy the following strategies for optimizing massing and zoning for a project.

- The massing can be designed to minimize the solar incidence and mitigate the impact of harsh summer winds, thereby reducing heat gain within the building
- By staggering the building form, self-shading opportunities can be maximized, providing natural shading, and reducing direct sunlight penetration into the interior spaces
- Organizing the interior spaces strategically, with intermittently used areas such as stairs, restrooms, and corridors located on the eastern and western sides of the building, can help minimize solar exposure and heat gain.

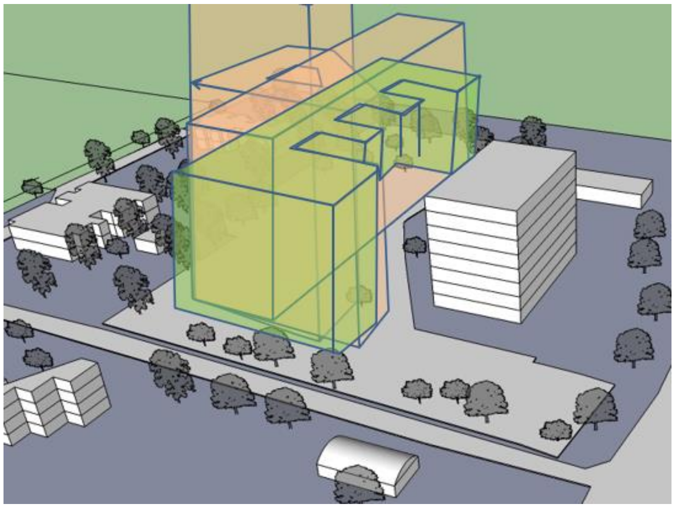


Figure 13 Building massing

3.2.3 Analysis Tools

The massing analysis tool should include capabilities of 3D modelling, solar analysis, energy performance analysis, wind analysis and effective visualization of results. Some of the tools that can be used for the massing study of a project are Autodesk Revit, SketchUp, Rhino Grasshopper with Ladybug plugin, Design Builder, EnergyPlus, IES VE etc.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the massing PCS.

Building Details	NUS School of Design & Environment
Location	Singapore
Building Typology	Educational
No. of Floors	G+5
Climatic Zone	(ASHRAE) Extremely hot and humid CDD - 6427, HDD - 0
Implementation Agency	Serie Architects & Multiply Architects
Recognition	Green Mark Platinum Certification

Passive Cooling Strategies	Impacts in the building
Extended roof projection	Reduced cooling demand of 24%
Perforated aluminium panels	
Landscape with matured trees	
High-performance double-glazed units	
Other Strategies: Overhangs, Blinds and Light shelves	

Passive cooling strategies for this project encompass extended roof projections, perforated aluminum panels, landscape integration with matured trees, and high-performance double-glazed units. These initiatives efficiently reduce cooling demands and enhance indoor comfort in an extremely hot and humid climatic zone. The project's Green Mark Platinum Certification recognizes its commitment to sustainable design.

CaseStudy:
https://drive.google.com/file/d/1WCft3rbQ0rY99gGGY80u0hhRFax_jzu4/view?usp=drive_link

3.3 Wind Orientation

3.3.1 Description

Wind orientation is a key consideration in PCS as it determines the direction and flow of air movement around a building. By understanding the prevailing wind direction and speed of a specific location, architects and designers can optimize building design to maximize natural ventilation. This can be achieved by strategically locating openings such as windows, vents, and air intake to capture and channel the prevailing winds into the building. On flat ground, the unobstructed wind speed depends on ground surface roughness and height. The other factors affecting the wind patterns are site topography, ground-water temperature differences near to sea or lake and obstructions like buildings and trees.

3.3.2 Strategy Application

In tropical climates, designers must balance wind orientation to provide shelter from hot winds while allowing for cool winds. Consideration of wind speed and direction is crucial when designing the spatial configuration of multiple buildings for optimal airflow.

To enhance cross ventilation and airflow in streets, it is recommended to orient primary avenues at an angle of around 20° to 30° relative to the prevailing summer breeze. Buildings that rely on cross ventilation should be spaced at seven times their height to ensure sufficient airflow, especially if they are positioned directly behind one another.

Optimal ventilation access can be achieved by positioning buildings at an angle of 30 to 45° to the prevailing wind direction, enabling enhanced airflow along the facades. In projects with buildings of varying heights, arranging them in ascending order towards the direction of cool winds can further improve ventilation. Additionally, elevating buildings on stilts can enhance ventilation at the occupant level[7].

[7] Sustainable building design for tropical climates. (2014). Nairobi UN Habitat

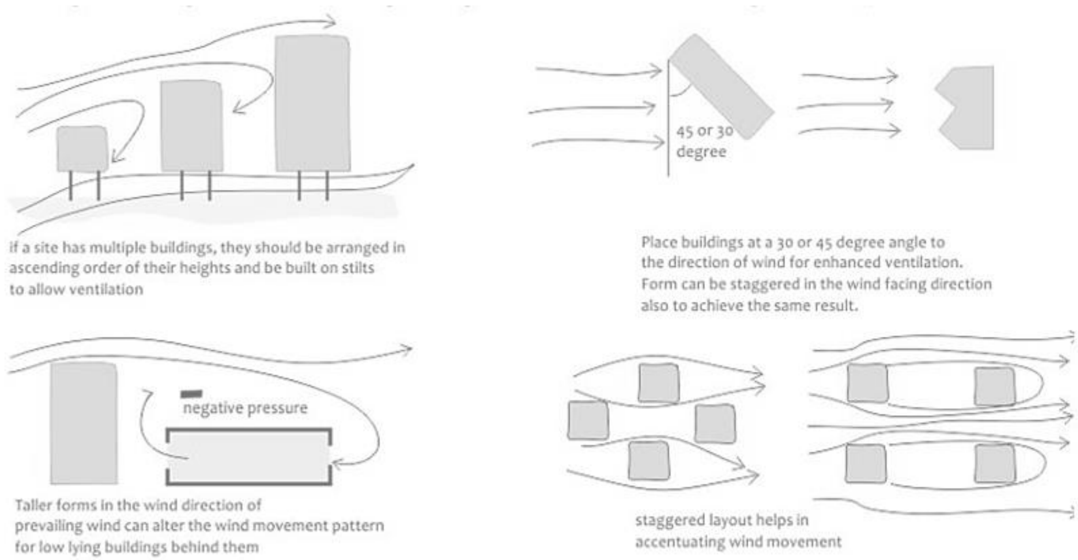


Figure 14 Urban-level strategies for optimal airflow[8]

Cambodia has a 443 km long coastline, and the locations near this coastline experience the influence of land and sea breezes. Along tropical coastlines, sea breezes are commonly observed. The intensity of the breeze is determined by the temperature difference between the land and the sea, while its velocity is influenced by the prevailing wind direction and the temperature contrast between the land and the sea.

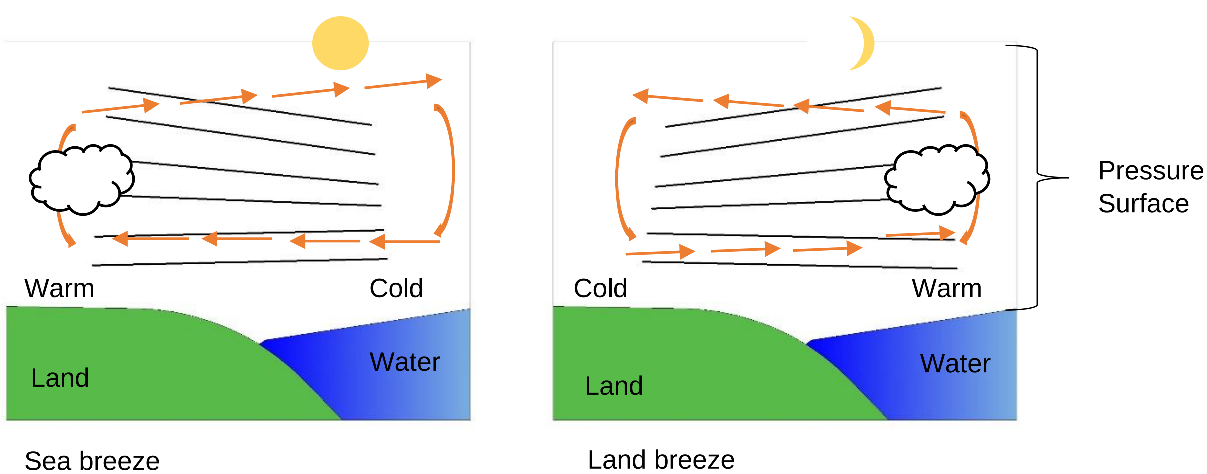


Figure 15 Land and sea breeze

3.3.3 Analysis Tools

The wind movement analysis tool should be capable of performing wind rose analysis and macro-level wind flow simulation using computational fluid dynamics. Some of the tools capable of performing wind-rose analysis are Climate Consultant, Rhino-Grasshopper with Ladybug plugin,

[8] "Form & Orientation."

WindRose PRO, Design Builder and IES VE. The tools widely used for wind flow analysis are Envi-met, DesignBuilder, IES VE

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the wind movement PCS.

3.3.4 Implementation Examples

PT - Ungaran Sari Garments in Semarang, Indonesia, employs a North-South building orientation to reduce heat gain and achieve natural cross-ventilation with two courtyards. Glass facades and light shelves enhance daylighting while operable windows provide thermal comfort. Arthaland Century Pacific Tower maximizes natural daylight through strategic site orientation. Detailed case studies have been mentioned in annexure.

Building Details	PT - Ungaran Sari Garments
Location	Semarang, Indonesia
Building Typology	Industrial
No. of Floors	G+1
Climatic Zone	(ASHRAE) Extremely Hot and Humid, CDD 6580, HDD 0
Implementation Agency	NC Design & Associates, Bali
Recognition	LEED Platinum

Passive Cooling Strategies	Impacts
Double glazed windows	40% reduction in cooling demand
Façade and envelope	
Cool roofs	
Rock wool insulation	
Landscape Design	

The passive cooling strategies employed for this location include the use of double glazed windows, which have contributed to a remarkable 40% reduction in cooling demand. The building's façade and envelope, cool roofs, and rock wool insulation have been effectively utilized to enhance thermal comfort. Additionally, thoughtful landscape design has played a role in creating a more energy-efficient and comfortable indoor environment.

CaseStudy:
https://drive.google.com/file/d/136jxxxs6GkIo6bvtnOrDX_mbyynw_HM8/view?usp=drive_link

3.4 Stack Ventilation

3.4.1 Description

The stack effect, also known as the chimney effect, results from natural heat transfer. Warmer air, being less dense, rises to the upper parts of buildings, chimneys, or towers. Stack ventilation can function as an independent system or be supplemented by various devices and ventilation strategies to enhance its effectiveness in building operations.

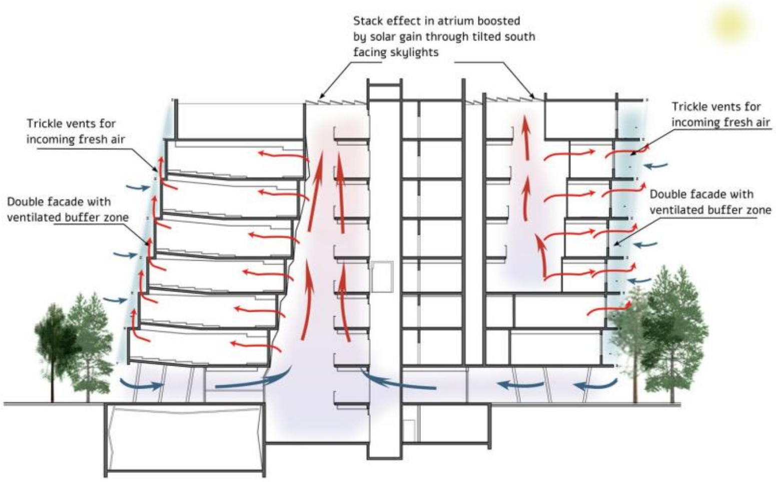


Figure 16 Stack ventilation cross-sectional view

3.4.2 Strategy Application

The implementation of stack ventilation in a building typically involves a feasibility study to understand whether stack ventilation is a viable option for the building. The designers can use the following guidelines to incorporate stack ventilation in their projects

- Taller buildings and spaces tend to experience a stronger stack effect. Designing taller buildings and spaces with proper ventilation systems can help utilize the stack effect for natural air movement.
- Providing vertical openings such as stairwells, atriums, or shafts within the building can facilitate the upward movement of warm air and the downward flow of cool air.
- Strategically placing ventilation openings, such as windows or vents, at various levels of the building can facilitate the stack effect by allowing air to enter at lower levels and exit at higher levels.
- The overall building configuration should consider the stack effect. Positioning openings and air paths to take advantage of the natural airflow can enhance the stack effect.
- Proper sealing and insulation of the building envelope are crucial to prevent unintended air leakage that can disrupt the stack effect. Attention should be given to doors, windows, joints, and other potential leakage points.
- The stack effect's effectiveness may vary depending on the climate. Designers should consider local climate conditions, prevailing wind directions, and temperature differentials to optimize the implementation of stack effect strategies.
- Integrating mechanical ventilation systems with the stack effect can further enhance airflow control and distribution within the building. This includes the use of fans, dampers, and controls to optimize natural ventilation along with mechanical systems.

3.4.3 Analysis Tools

The stack effect analysis tool requires multizone modelling, air-flow network modelling, differential pressure calculations, air leakage modelling, and effective result visualization. Tools like Rhino-Grasshopper with Honeybee plugin, Design Builder, IDA-ICE, and IES VE can perform stack effect analysis effectively.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the stack ventilation PCS.

3.4.4 Implementation example

Indira Paryavaran Bhawan employs a courtyard and jaalis to promote cross and stack ventilation, enhancing air movement within the building. The Logan House in Tampa, USA, utilizes stack ventilation, aided by elevated structure and clerestory windows, efficiently removing 15,000 Btuh of cooling capacity and reducing indoor temperatures by 2°F to 5°F.Detailed case study is mentioned in Annexure.

Building Details	The Logan House
Location	Tampa, Florida, USA
Building Typology	Residential
No. of Floors	G+1
Climatic Zone	(ASHRAE) Hot and Humid, CDD 4339, HDD 454
Implementation Agency	Dwight Holmes, of Rowe Holmes Associates
Occupancy	2

<table>
<tr><td>Passive Cooling Strategy</td><td>Impacts</td></tr>
<tr><td>Cross Ventilation</td><td rowspan="6">Capable of removing 15,000 Btuh (1.3 tonnes cooling capacity)
Temperature difference of 2°F to 5°F</td></tr>
<tr><td>Stack Ventilation</td></tr>
<tr><td>Raised Floor Level</td></tr>
<tr><td>Landscape</td></tr>
<tr><td>Open Decks</td></tr>
<tr><td>Other Strategies: 2.4 m raised main floor, Open decks in east and west, Elevated operable clerestory windows.</td></tr>
</table>

Passive cooling methods, like cross ventilation, stack ventilation, and landscaping, employ natural principles to cool buildings without relying on energy-intensive systems. For example, cross ventilation can remove 15,000 Btuh (1.3 tonnes cooling capacity) with a 2°F to 5°F temperature difference. These strategies offer energy-efficient solutions for comfortable indoor environments, particularly useful in hot and humid climates like Tampa, Florida.

CaseStudy:
https://drive.google.com/file/d/16IIHFrjBA8RJI4er5HWNjtr_iXZSB384/view?usp=drive_link

3.5 Natural and Cross Ventilation

3.5.1 Description

The term "natural ventilation" refers to the deliberate airflow that occurs through purposefully designed openings such as windows, doors, or vents, without the need for mechanical fans. This leads to reduced CO_2 levels ensuring a fresh indoor environment and cooler temperatures in summer. It relies on pressure differentials created by wind and/or temperature differences between the building's interior and exterior.

3.5.2 Strategy Application

Designers can use the following strategies to integrate natural and cross-ventilation in their building projects.

- The relative placement of the inlet and outlet openings plays a crucial role in maximizing the effectiveness of natural airflow. Optimal air flow patterns influenced by wind are achieved when the outlet opening is positioned higher and wider compared to the inlet, ensuring efficient ventilation and air exchange within a building.
- A horizontal overhang positioned above an opening redirected the airflow upward. When the overhang is spaced away from the wall, the airflow is deflected at a height that is half the distance between the overhang and the wall.
- When the inlet and outlet openings are aligned, cross ventilation is facilitated by the wind. Parallel alignment of the openings to the wind direction results in airflow through a limited space area, causing minimal air movement. However, when the wind blows at an angle, the ventilation covers a wider zone, inducing more significant air movement and enhancing the effectiveness of natural ventilation.
- Wing walls can enhance natural ventilation when adjacent walls have openings, significantly increasing their effectiveness.

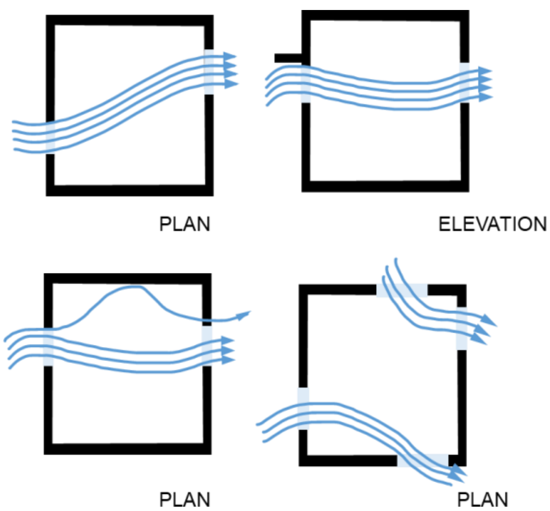


Figure 17 Cross ventilation

3.5.3 Analysis Tools

The ventilation analysis tool should be capable of multizone modelling, air-flow network modelling, differential pressure calculations, air leakage modelling, window operation logic definition and effective result visualisation. Some of the tools capable of performing ventilation analysis are Rhino-Grasshopper with Honeybee plugin, Design Builder, IDA-ICE and IES VE.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the natural and cross-ventilation PCS.

3.5.4 Implementation examples

These PCS have been installed on building level in various projects. These exemplary buildings showcase innovative building-level ventilation strategies to enhance indoor comfort and energy efficiency. From cross-ventilation through courtyard jaalis at Indira Paryavaran Bhawan to wind catchers and earth-cooling tubes at CIC Zero Carbon Park, each project demonstrates the power of thoughtful design. Vertical operable vents in the Office Room, Tangerang, and an oversailing roof in Diamond Lotus Riverside, Ho Chi Minh, further optimize airflow, reducing cooling loads and promoting natural ventilation. For further details refer to annexure.

Building Details	CIC Zero Carbon Park
Location	Hong Kong
Building Typology	Multipurpose - Office, Exhibition, Ecological Park
Climatic Zone	(ASHRAE) Extremely Hot and Humid, CDD 4782, HDD 213
Implementation Agency	Ronald Lu & Partners, Ove Arup & Partners HK Ltd
Recognition	Hong Kong’s first zero carbon building

<table>
<tr><th>Passive Cooling Strategy</th><th>Impacts</th></tr>
<tr><td>Cross-Ventilated Layout</td><td rowspan="7">Various passive design measures lead to 20% energy saving compared to a similar building</td></tr>
<tr><td>Wind Catcher</td></tr>
<tr><td>Earth Cooling Tube</td></tr>
<tr><td>Insulated Roof</td></tr>
<tr><td>Light Pipes</td></tr>
<tr><td>Heat Reflecting Shade</td></tr>
<tr><td>High Performance Glazing</td></tr>
<tr><td>Other Strategies: Light Shelves, Light Pipes</td><td>Ensure proper daylight in space</td></tr>
</table>

Incorporating a cross-ventilated layout, along with passive design measures such as wind catchers, earth cooling tubes, insulated roofs, light pipes, heat reflecting shades, and high-performance glazing, results in significant energy savings of up to 20% when compared to similar buildings. These strategies not only enhance natural ventilation but also harness elements like wind and earth cooling, while ensuring ample daylight and reducing heat gain.

CaseStudy:
https://drive.google.com/file/d/1yMtR4zZ3dWe_tu6SkAJwhOwkO_0MJ_5d/view?usp=drive_link

3.6 Night Cooling

3.6.1 Description

Night cooling also known as night flushing or purging, optimizes a building's ventilation by utilizing the natural decrease in ambient temperature during the night. This strategy effectively refreshes internal spaces, enhancing their readiness for the following day. While mechanical fans can be employed, the buildings can adopt natural ventilation systems to efficiently expel heat during the night.

3.6.2 Strategy Application

Night Cooling utilizes the building's thermal mass to absorb and release heat, promoting natural cooling. Building owners and operators can use the following approach to facilitate night cooling in their buildings.

- Evaluate the building's thermal properties, including insulation levels, thermal mass, and ventilation systems, to determine its suitability for night cooling.
- Use temperature sensors or weather forecasts to track outdoor temperatures during the night. Identify nights with cooler temperatures suitable for night cooling.
- Before the onset of cooler nighttime temperatures, close windows, blinds, and curtains during the day to minimize heat gain. Ensure the building's thermal mass is exposed to indoor spaces to absorb heat.
- In the evening, open windows, vents, or louvres strategically to allow fresh air to enter the building. Promote natural airflow by considering prevailing wind directions and creating effective air pathways.
- Utilize cross ventilation potential by opening windows on opposite sides of the building to facilitate airflow and maximize cooling.
- Implement automated controls or programmable timers to manage the opening and closing of windows and ventilation systems based on preset temperature thresholds.
- Ensure that outdoor air quality meets acceptable standards for indoor air quality. Consider using filters or purifiers, if necessary.
- Educate occupants about the benefits and operation of night cooling. Encourage them to adjust their clothing or bedding to adapt to cooler indoor temperatures during the night.
- Continuously monitor indoor temperatures and comfort levels during night cooling operations. Adjust the ventilation strategy as needed to maintain optimal comfort and energy efficiency.

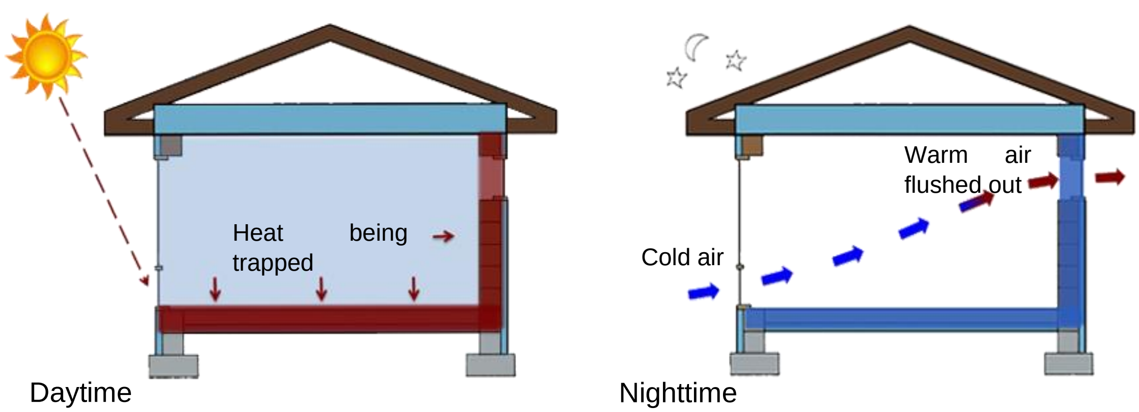


Figure 18 Night Cooling

3.6.3 Analysis Tools

The night cooling tool should be capable of multizone modelling, air-flow network modelling, differential pressure calculations, air leakage modelling, window operation logic definition, and effective result visualization. Tools like Rhino-Grasshopper with Honeybee plugin, DesignBuilder, IDA-ICE, and IES VE can perform night cooling analysis.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the night cooling PCS.

3.6.4 Implementation example

Krushi Bhawan in Odisha, India, incorporates a night purging system at the building level. This innovative ventilation strategy allows for the efficient flushing out of accumulated heat and pollutants during the cooler nighttime hours, contributing to enhanced indoor air quality and thermal comfort. Detailed case study in mentioned in annexure.

Building Details	Krushi Bhawan
Location	Bhubaneswar, India
Building Typology	Office
No. of Floors	G+3
Climatic Zone	(ASHRAE) Extremely Hot and Humid, CDD 6666, HDD 0
Implementation Agency	Studio Lotus
Occupancy	600

Passive Cooling Strategies	
Night - Purging system	
Louvered screens	80% of the cooling demand is reduced
Staggered masses	
Stilt level optimal air circulation	
Deeply recessed windows	

Passive cooling strategies like louvred screens, night purging, staggered masses, stilt level circulation, and deeply recessed windows offer innovative ways to combat heat in Bhubaneswar's hot and humid climate. Notably, louvred screens contribute to an impressive 80% reduction in cooling demand. These strategies, along with self-shading systems, optimal air circulation, and thoughtful window design, collectively enhance energy efficiency and comfort in the office building while aligning with the challenging climatic conditions.

Case Study: https://drive.google.com/file/d/1NWAw_2ODxRVmcDyDjlg9HuAgQgNS-Sa8/view?usp=drive_link

3.7 Window Wall Ration (WWR)

3.7.1 Description

The Window-to-Wall Ratio (WWR) represents the proportion of the fenestration area to the total above-grade wall area. In conventional buildings, a significant part of the cooling load is associated with heat gains from the windows. Optimizing the window-to-wall ratio (WWR) for various orientations of building facades can significantly minimize the heat gain from windows.

3.7.2 Strategy Application

The optimal window-to-wall ratio (WWR) should be carefully considered during the initial building design phase, considering the building's form, orientation, window distribution, and dimensions.

- In hot climates, minimize the WWR on the west and east sides to reduce solar heat gain
- Deploy varying WWRs based on daylighting needs, privacy concerns, or views
- Enhance the insulation of opaque walls to compensate for any reduction in the WWR.
- Use building energy simulation tools and parametric analysis to assess different WWR scenarios and their impact on energy efficiency, daylighting, and occupant comfort.
- Incorporate shading devices such as overhangs, fins, or louvres to control solar heat gain and glare. Select high-performance glazing with appropriate shading coefficients and insulation properties to improve thermal comfort and energy efficiency.

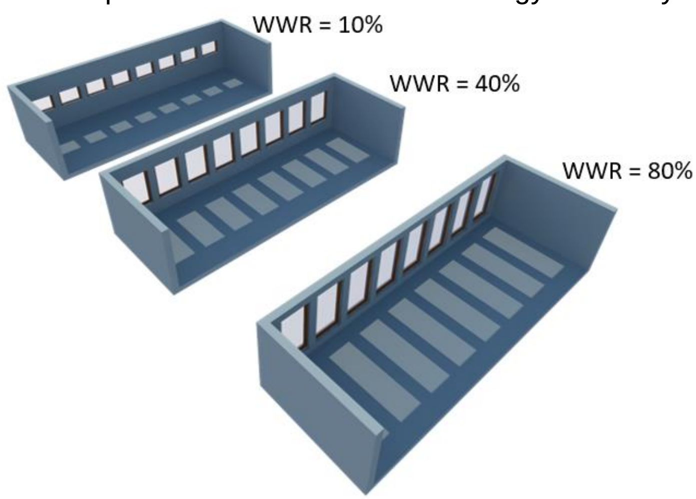


Figure 19 Whole building WWR

3.7.3 Analysis Tools

The tools capable of analysis of WWR thermal performance should be able to perform dynamic annual energy simulation to estimate heat transfer (gains and losses) from the window opening. Some of the tools capable of performing WWR thermal performance analysis are EQuest, Rhino-Grasshopper with Honeybee plugin, DesignBuilder, IDA-ICE and IES VE.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the WWR PCS.

3.7.4 Implementation example

TNG Song Kong Factory in Thai Nguyen, Vietnam, achieves a 21.5% energy reduction through a reduced window-to-wall ratio of 17.5%, effectively minimizing heat gain through the building's facades. Similarly, Krushi Bhawan in Odisha, India, employs a minimized window-to-wall ratio to reduce heat gain and enhance energy efficiency within the building. Detailed case study is mentioned in Annexure.

Building Details	TNG Song Kong Factory
Location	Thai Nguyen, Vietnam
Building Typology	Industrial
No. of Floors	G

Climatic Zone	(ASHRAE) Very Hot and Humid, CDD 5408, HDD 132
Implementation Agency	Green Viet Consultancy Co., Ltd.
Occupancy	15,000
Recognition	LOTUS Silver

Passive Cooling Strategy	
Window to Wall Ratio	21.5% energy reduction
Cross Ventilation	
Glass Wool Insulation	
Landscape Design	
Courtyards	82.7% reduction in LPD (Lighting Power Density)

Passive cooling strategies such as optimizing the window-to-wall ratio for better energy efficiency, promoting cross ventilation, employing glass wool insulation, integrating thoughtful landscape designs, and incorporating courtyards contribute to effective cooling solutions. Additionally, courtyards offer an impressive 82.7% reduction in lighting power density, enhancing both energy savings and indoor comfort.

CaseStudy:
https://drive.google.com/file/d/1kFm_jLlbfGJUcM4ZIEaUWSwjASUjmXhH/view?usp=drive_link

3.8 Mutual Shading

3.8.1 Description

Mutual shading is a design strategy in buildings that involves positioning and orienting elements to provide shade to adjacent buildings. It is a function of latitude, location with respect to the other buildings, height of the context buildings, and distance between the buildings. This strategy maximizes the use of natural shading to reduce solar heat gain, improve thermal comfort, and minimize the need for mechanical cooling.

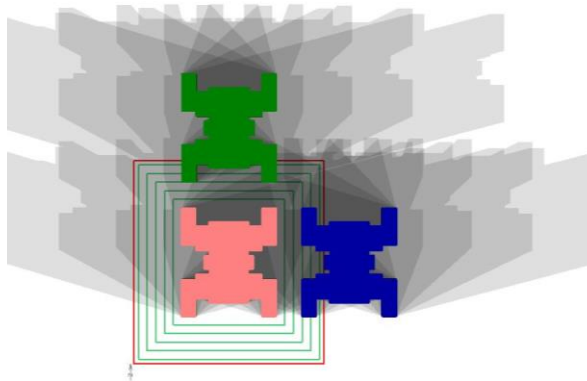


Figure 20 Mutual shading between two buildings

3.8.2 Strategy Application

The Strategy Application for assessing mutual shading typically involves the effects of shading on building facades or roofs. The designers can use the following strategies for the deployment of an effective mutual shading strategy in the project.

- Analyze the latitude and sun path to determine the optimal spatial configuration of the building to utilize the benefits of mutual shading.
- Arrange buildings in a way that minimizes direct sunlight exposure to windows and facades.
- Use building setbacks and staggered heights to create shading between buildings.
- Employ advanced simulation tools to assess shading patterns and optimize building layouts for maximum mutual shading.

3.8.3 Analysis Tools

The mutual shading assessment tool should encompass sun path analysis, shadow analysis, solar irradiance calculation, energy performance modelling, and effective result visualization. Tools like Autodesk Revit, SketchUp with Solar Analysis extensions, Rhino Grasshopper with Ladybug plugin, and Design Builder can be utilized for mutual shading analysis.

Note: There are multiple other tools available, the designers can utilize the validated software for evaluating the mutual shading PCS.

4 Materials/Technologies-oriented Passive Cooling Strategies

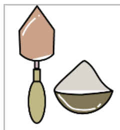
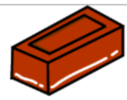
PCS utilize materials/technologies in the building envelope to mitigate heat gain, employing insulation, shading, and ventilation techniques for effective thermal management. These strategies focus on optimizing building components to enhance the thermal comfort and energy efficiency of indoor spaces.

4.1 Wall

4.1.1 Hollow Brick Wall (Business As-Usual Construction)

4.1.1.1 Description

Hollow walls are renowned for their versatility, enduring strength, and aesthetic value, making them a timeless choice for construction projects in Cambodia, offering durability and visual appeal.

			**Thickness: 230 mm** **U-Value: 1.85 W/m^2.K**
Cement Plaster	Hollow Red Brick	Cement Plaster	

Technical Specification:

- Specific Heat: 0.8 kJ/kg.K
- Heat Capacity: 800 J/kgK
- Conductivity: 0.36 to 0.7 W/m.K
- Density: 1120 to 2400 kg/m^3
- Size: 190 mm x 90 mm x 90 mm
- Shape: Uniform rectangular shape with smooth faces, straight and sharp edges and free from cracks
- Colour: Well, burnt brick is available in red color.
- Applicable mostly for residential buildings but can be used even for commercial buildings.

4.1.1.2 Strategy Application

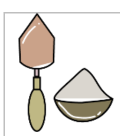
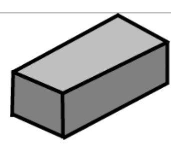
Table 3 Strategy Application of hollow brick block

Bricks	Bricks for masonry construction must meet standard specifications for quality.
Mortar	For cement mortar, cement should be Ordinary Portland Cement, sand should be sharp, clean, and free from organic and foreign matters. Coarse sands should be used for rich mortar, and fine sand can be used for weak mortar.
Soaking of bricks	Continue soaking until the cessation of air bubbles is observed.
Laying of bricks	Unless otherwise specified, ensure that bricks are laid in English bond and properly bonded.
Curing of bricks	The brickwork should be kept wet for a period of at least 20 days after laying.

4.1.2 Autoclaved Aerated Concrete (AAC) Wall

4.1.2.1 Description

AAC is a lightweight, precast, foam concrete building material made from sand, cement, lime, gypsum, water, and a foaming agent. The material is moulded in blocks and cured in an autoclave, which creates a highly porous structure with a uniform cellular structure. They are lightweight, which reduces the weight of the building and the load on the building's structural system.

			**Thickness: 230 mm** **U-Value: 0.96 W/m^2.K**
Cement Plaster	AAC block	Cement Plaster	

Technical Specification:

- Specific Heat: 0.84 kJ/kg.K
- Heat Capacity: 1000 J/kgK
- Conductivity: 0.2 W/m.K
- Density: 640 to 800 kg/m^3
- Size: 600 mm x 200 mm x 100 mm, 600 mm x 200 mm x 200 mm, 600 mm x 200 mm x 300 mm
- Shape: Uniform rectangular shape with smooth faces, straight and sharp edges and free from cracks
- Colour: Greyish white
- Applicable for both commercial and residential buildings

4.1.2.2 Strategy Application

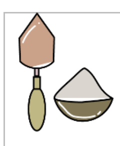
Table 4 Strategy Application of AAC Block

AAC	Blocks for masonry construction must meet standard specifications for quality.
Mortar	For cement mortar, cement should be Ordinary Portland Cement, sand should be sharp, clean, and free from organic and foreign matters. Coarse sands should be used for rich mortar, and fine sand can be used for weak mortar.
Soaking of bricks	Continue soaking until the cessation of air bubbles is observed.
Laying of bricks	Unless otherwise specified, ensure that bricks are laid in English bond and properly bonded.

4.1.3 Terracotta Hollow Wall

4.1.3.1 Description

The terracotta hollow wall is a type of wall construction made of terracotta blocks that have a hollow core or cavity. They are lightweight, which reduces the load on the structural system of the building. They also have good thermal insulation properties due to the air-filled cavity in the material, which helps to reduce energy consumption for cooling.

			**Thickness: 290 mm** **U-Value: 1.7 W/m².K**
Cement Plaster	Terracotta Hollow Block	Cement Plaster	

Technical Specification:

- Specific Heat: 0.88 kJ/kg.K
- Heat Capacity: 1000 J/kgK

- Conductivity: 0.5 to 1.0 W/m.K
- Density: 1700 to 1900 kg/m^3
- Size: 190 mm x 90 mm x 90 mm, 290 mm x 90 mm x 90 mm and 290 mm x 140 mm x 90 mm
- Shape: Uniform rectangular shape with smooth faces, straight and sharp, hollow strips in the middle and free from cracks
- Colour: Red
- Applicable mostly for residential buildings but can be used even for commercial buildings.

4.1.3.2 Strategy Application

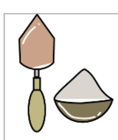
Table 5 Strategy Application of terracotta block

Terracotta hollow blocks	Blocks for masonry construction must meet standard specifications for quality.
Mortar	For cement mortar, cement should be Ordinary Portland Cement and sand should be sharp, clean, and free from organic and foreign matters. Coarse sands should be used for rich mortar, and fine sand may be used for weak mortar.
Soaking of blocks	Continue soaking until the cessation of air bubbles is observed.
Laying of blocks	Unless otherwise specified, ensure that bricks are laid in English bond and properly bonded.
Curing of blocks	The blockwork should be kept wet for a period of at least 20 days after laying.

4.1.4 Concrete Hollow Wall

4.1.4.1 Description

A concrete hollow wall is a type of masonry wall made up of concrete blocks with hollow cores. Concrete hollow walls are made using a mixture of cement, water, and aggregates such as sand, gravel, or crushed stone. The mixture is poured into moulds to create blocks, which are then cured in a controlled environment to gain strength and durability.

			**Thickness: 230 mm** **U-Value: 0.83 W/m².K**
Cement Plaster	Concrete Hollow Brick	Cement Plaster	

Technical Specification:

- Specific Heat: 1.05 kJ/kg.K
- Heat capacity: 1000 J/kgK
- Conductivity: 0.188 W/m.K

- Density: 704 kg/m^3
- Size: 200 mm x 400 mm x 100 mm and 200 mm x 400 mm x 200 mm
- Shape: Uniform rectangular shape with smooth faces, straight and sharp edges at the right angle at corners, hollow strips in the middle and free from cracks
- Types: Fly Ash Brick, Cement Brick, Hollow Brick, etc.
- Applicable for both commercial and residential buildings

4.1.4.2 Strategy Application

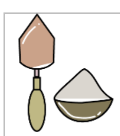
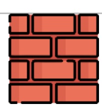
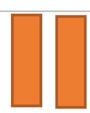
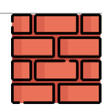
Table 6 Strategy Application of hollow concrete block

Concrete hollow blocks	Blocks for masonry construction must meet standard specifications for quality. It can be made of standard concrete with traditional sand and gravel aggregate held together with Ordinary Portland Cement. In addition, they can use lighter-weight materials, such as fly ash or coal cinders, instead of sand and gravel aggregate, in which case they are commonly called cinder blocks.
Mortar	For cement mortar, cement should be Ordinary Portland Cement and sand should be sharp, clean, and free from organic and foreign matters. Coarse sands should be used for rich mortar, and fine sand may be used for weak mortar.
Laying of blocks	Position the first course of cement block into the mortar and tap the blocks downward slightly to embed them in the foundation mortar. Begin the wall with a corner unit, then "butter" the flanges at the end of each subsequent block with mortar before joining it to the previous block.
Smoothening	To provide a sturdy and aesthetically pleasing finish, cement block walls are commonly capped by layering mortar, incorporating metal reinforcement strips, and adding solid concrete cap blocks. It is essential to fill the joints between cap blocks with mortar and ensure a smooth surface using a finishing tool.

4.1.5 Cavity Wall

4.1.5.1 Description

Cavity wall construction involves two distinct walls with a gap or cavity between them. The two walls are typically constructed using masonry materials, such as brick. The inner and outer walls of a cavity wall are tied together using metal ties or clips, which hold them in place and prevent them from separating.

					**Thickness: 255 mm (25 mm cavity)** **U-Value: 0.63 W/m².K**
Cement Plaster	Wall	Air Cavity	Wall	Cement Plaster	

Technical Specification:

- Specific Heat: 1.005 kJ/kg.K
- Heat capacity: 1400 J/kgK
- Conductivity: 0.026 W/m.K
- Density: 704 kg/m^3
- Applicable for both commercial and residential buildings

4.1.5.2 Strategy Application

Table 7 Strategy Application of cavity wall

Bricks	Bricks for masonry construction must meet standard specifications for quality.
Mortar	For cement mortar, cement should be Ordinary Portland Cement and sand should be sharp, clean, and free from organic and foreign matters. Coarse sands should be used for rich mortar, and fine sand may be used for weak mortar.
Soaking of bricks	Continue soaking until the cessation of air bubbles is observed.
Laying of bricks	The wall leaves are connected using wall ties, typically spaced at 900 mm vertically and 450 mm horizontally in every sixth staggered course. These wall ties are made from mild steel wires of 3 to 4 mm diameter or Mild Steel (MS) bars and fabricated to shapes.
Curing of bricks	The brickwork should be kept wet for a period of at least 20 days after laying.

4.1.6 Insulated Wall

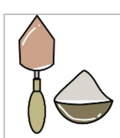
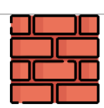
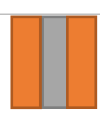
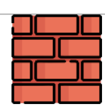
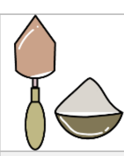
Diverse types of insulation-

4.1.6.1 Fibreglass Insulation

4.1.6.1.1 Description

Fibreglass is an extremely thin material made of glass fibres and is widely used in insulation applications. It is used in many different forms of insulation:

- Blanket (batts and rolls)
- Loose-fill
- Rigid boards

					**Thickness: 255 mm (25 mm insulation in the cavity)** **U-Value: 0.82 W/m².K**
Cement Plaster	Wall	Fibreglass Insulation	Wall	Cement Plaster	

Technical Specification

- Specific Heat: 0.84 kJ/kg.K
- Heat Capacity: 1000 J/kgK
- Conductivity: 0.043 to 0.048 W/m.K
- Density: 8 to 14 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.1.2 Strategy Application

Table 8 Strategy Application of Fibreglass

Preparation	Clean and prepare the area where the insulation will be installed. Measure and cut the fibreglass insulation to the desired size and shape using a saw or other cutting tool.
Installation	Install fibreglass insulation into the designated areas. Secure the fibreglass insulation in place using fasteners, such as staples or metal straps.
Maintenance	Once the insulation is installed, cover it with a suitable material, such as drywall or panelling, to protect it from damage and provide a finished appearance.

Figure 21 Fiber glass insulation application procedure[9]

4.1.6.2 Mineral Wool Insulation

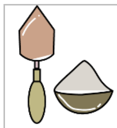
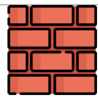
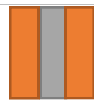
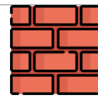
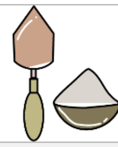
4.1.6.2.1 Description

The term "mineral wool" commonly refers to two types of insulation materials:

- Rock wool: Basalt or diabase are natural minerals that are used to make rock wool.
- Slag wool: A manufactured material from blast furnace slag (the waste matter that forms on the surface of molten metal).

[9] https://www.bitfelt.com/resources/is-fiberglass-insulation-safe/

A mineral wool product typically contains 75% post-industrial recycled content. There is no need for chemical additives to make it fire-resistant, and it is in blankets (batts and rolls) and loose-fill insulation.

					**Thickness: 255 mm (25 mm insulation in the cavity)** **U-Value: 0.74 W/m².K**
Cement Plaster	Wall	Mineral wool Insulation	Wall	Cement Plaster	

Technical Specification

- Specific Heat: 0.84 kJ/kg.K
- Heat Capacity: 870 J/kgK
- Conductivity: 0.035 to 0.04 W/m.K
- Density: 16 to 130 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.2.2 Strategy Application

Table 9 Strategy Application of mineral wool

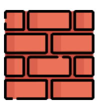
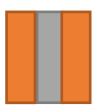
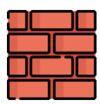
Preparation	Clean and prepare the area where the insulation will be installed. ensure and cut the mineral wool insulation to the desired size and shape using a saw or other cutting tool.
Installation	Install mineral wool insulation into the designated areas. Ensure the mineral wool insulation is in place using fasteners, such as staples or metal straps.
Maintenance	The insulation is installed, and covered with a suitable material, such as drywall or paneling, to protect it from damage and to provide a finished appearance.

Figure 22 Mineral wool insulation application procedure[10]

4.1.6.3 Cellulose Insulation

4.1.6.3.1 Description

The recycled material content of cellulose insulation ranges from 82% to 85% and is made of recycled paper, primarily newsprint. Some natural fibers including cotton, sheep's wool, straw, and hemp are also used as insulation materials.

					Thickness: 255 mm (25 mm insulation in the cavity) U-Value: 0.81 W/m².K
Cement Plaster	Wall	Cellulose Insulation	Wall	Cement Plaster	

Technical Specification

- Specific Heat: 0.84 kJ/kg.K
- Heat Capacity: 1381 J/kgK
- Conductivity: 0.042 to 0.049 W/m.K
- Density: 55 to 95 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.3.2 Strategy Application

Table 10 Strategy Application of Cellulose

Preparation	To prepare the paper, it is initially fragmented into small pieces and subsequently fiberized, resulting in a product that tightly fills building cavities when packed.

10 https://www.buildwithrise.com/stories/what-is-mineral-wool-insulation

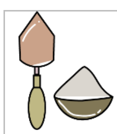
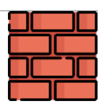
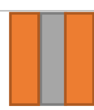
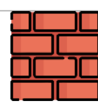
Installation	To guarantee fire and insect resistance, manufacturers incorporate the mineral borate, occasionally mixed with the more affordable ammonium sulfate, into the product.
Maintenance	When cellulose insulation is installed at appropriate densities, it does not undergo settling within a building cavity. In the case of damp-sprayed cellulose, it is typically ready for wall covering within 24 hours of installation. Alternatively, cellulose insulation can be blown in a dry state into netting that is stapled over building cavities

Figure 23 Cellulose insulation application process[11]

4.1.6.4 Polystyrene Insulation

4.1.6.4.1 Description

Polystyrene is a colourless, transparent thermoplastic. It is commonly used to make foam board or beadboard insulation, concrete block insulation, and a type of loose-fill insulation consisting of small beads of polystyrene. Moulded expanded polystyrene (MEPS), commonly used for foam board insulation, is also available as small foam beads. Other polystyrene insulation materials are expanded polystyrene (EPS) and extruded polystyrene (XPS).

					**Thickness: 255 mm (25 mm insulation in the cavity)** **U-Value: 0.56 W/m².K**
Cement Plaster	Wall	Polystyrene Insulation	Wall	Cement Plaster	

Technical specification-

- Specific Heat: 1.47 kJ/kg.K
- Heat Capacity: 1380 J/kgK
- Conductivity: 0.022 to 0.039 W/m.K

[11] https://cellulose.org/how-to-update-insulation-in-walls-of-old-homes/

- Density: 15 to 40 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.4.2 Strategy Application

Table 11 Strategy Application of Polystyrene

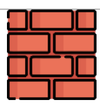
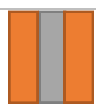
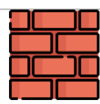
Preparation	The application of polystyrene insulation typically involves several steps. First, the surface to be insulated is prepared by cleaning and smoothing it out. Next, the insulation boards are measured and cut to size using a saw or knife
Installation	The boards are then placed in position and fixed in place using adhesive and mechanical fixings, such as screws or nails
Maintenance	It is important to ensure that the boards fit tightly together and that there are no gaps, as this will help to maximize the insulation's effectiveness. Finally, a protective layer, such as plasterboard or drywall, is added to complete the insulation system. It is important to follow the manufacturer's instructions throughout the process to ensure that the insulation is applied correctly and performs as intended.

Figure 24 Polystyrene insulation application procedure[12]

4.1.6.5 Polyisocyanurate Insulation

4.1.6.5.1 Description

Polyisocyanurate, also known as polyiso, is a thermosetting plastic characterized by a closed-cell foam structure that incorporates a low-conductivity gas, free from hydrochlorofluorocarbons, within its cells. It is offered in various forms such as liquid, sprayed foam, and rigid foam boards. Furthermore, it can be transformed into laminated insulation panels with a wide range of facings. Research findings suggest that most of the thermal drift takes place during the initial two years following the manufacturing of the insulation material.

					**Thickness: 255 mm (25 mm insulation in the cavity)**

12 https://www.aboutmechanics.com/what-is-polystyrene-insulation.htm

Cement Plaster	Wall	Polyiso-cyanurate Insulation	Wall	Cement Plaster	**U-Value: 0.51 W/m².K**

Technical Specification

- Specific Heat: 1.47 kJ/kg.K
- Heat Capacity: 900 J/kgK
- Conductivity: 0.019 to 0.027 W/m.K
- Density: 25 to 65 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.5.2 Strategy Application

Table 12 Strategy Application of Polyisocyanurate

Preparation	The application of polyisocyanurate insulation is like that of polystyrene insulation. The first step is to prepare the surface that you want to insulate by cleaning it thoroughly and ensuring that it is smooth and free from debris.
Installation	Next, the insulation boards are measured and cut to size using a saw or knife. The boards are then placed in position and fixed in place using adhesive and mechanical fixings, such as screws or nails.
Maintenance	It is important to make sure that the boards fit tightly together and that there are no gaps between them. Finally, a protective layer, such as a gypsum board or metal cladding, is installed to complete the insulation system. As with any insulation material, it is crucial to follow the manufacturer's instructions carefully to ensure that the insulation is applied correctly and achieves the desired level of thermal performance

Figure 25 Polyisocyanurate foam board insulation application procedure[13]

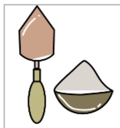
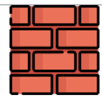
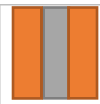
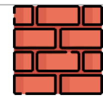
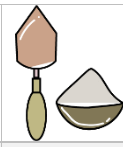
4.1.6.6 Polyurethane Insulation

4.1.6.6.1 Description

Polyurethane is a type of thermoset foam insulation material that incorporates a low-conductivity gas within its cells. It is offered in both closed-cell and open-cell formulations. With closed-cell

[13] https://www.iko.com/comm/non-permeable-polyiso-wall-insulation/

foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. There is less density in open-cell foam cells and more air inside, so the insulation has a spongy texture and lower R-value than closed-cell foam.

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td rowspan="2">Thickness: 255 mm (25 mm insulation in the cavity)

U-Value: 0.57 W/m².K</td></tr>
<tr><td>Cement Plaster</td><td>Wall</td><td>Polyurethane Insulation</td><td>Wall</td><td>Cement Plaster</td></tr>
</table>

Technical specifications

- Specific Heat: 1.47 kJ/kg.K
- Heat Capacity: 1400 J/kgK
- Conductivity: 0.026 to 0.042 W/m.K
- Density: 6 to 55 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.6.2 Strategy Application

Table 13 Strategy Application of Polyurethane

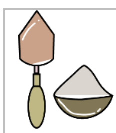
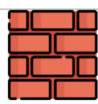
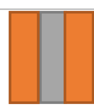
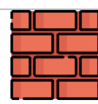
Preparation	Ensure that the area to be insulated is clean, dry, and free from any debris or obstacles that may hinder the application process. Remove any existing insulation or materials that may interfere with the installation.
Installation	If using spray foam, this involves using a spray gun to apply the foam in a uniform layer onto the desired surfaces. If using rigid foam boards, measure and cut them to fit the designated areas. Apply an appropriate adhesive to the back of the boards and press them firmly against the surface.
Maintenance	Depending on the specific project requirements, you may need to cover the insulation with a protective layer, such as drywall, sheathing, or vapor barrier, to enhance its durability, maintenance and performance.

Figure 26 Polyurethane insulation application procedure[14]

4.1.6.7 Cementitious Foam Insulation

4.1.6.7.1 Description

Cementitious insulation material is a foam based on cement that is utilized for sprayed foam or foamed-in-place insulation purposes. One type of cementitious spray foam insulation known as aircrete contains magnesium silicate and has an initial consistency like shaving cream. Aircrete is pumped into closed cavities. The costs of cementitious foam are comparable to those of polyurethane foam, and it is nontoxic and nonflammable and is made from minerals (such as magnesium oxide) extracted from seawater.

					**Thickness: 255 mm (25 mm insulation in the cavity)** **U-Value: 0.77 W/m².K**
Cement Plaster	Wall	Cementitious foam Insulation	Wall	Cement Plaster	

Technical specifications

- Specific Heat: 1.38 kJ/kg.K
- Heat Capacity: 1400 J/kgK
- Conductivity: 0.039 to 0.045 W/m.K
- Density: 35 to 50 kg/m^3
- Applicable for both commercial and residential buildings

[14] https://www.thomasnet.com/articles/plastics-rubber/all-about-closed-cell-spray-foam/

4.1.6.7.2 Strategy Application

Table 14 Strategy Application of cementitious foam

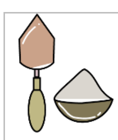
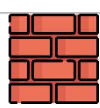
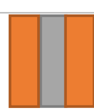
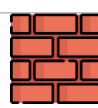
Preparation	The surface to be insulated should be cleaned and free of any debris, dust, or oil. The cementitious foam insulation material is mixed with water according to the manufacturer's instructions. The mixture should be thoroughly mixed to ensure that the foam is consistent and has the desired density.
Installation	The insulation mixture is then sprayed onto the surface to be insulated using specialized spray equipment. The foam should be sprayed evenly and at the recommended thickness, usually between 25 to 75 mm. The foam is left to cure and harden for the recommended amount of time
Maintenance	Once the foam has cured, any excess material can be trimmed or removed using a saw or other cutting tool.

Figure 27 Cementitious foam insulation application procedure[15]

4.1.6.8 *Phenolic Foam Insulation*

4.1.6.8.1 Description

Phenolic foamed-in-place insulation employs air as its foaming agent. However, a significant drawback of phenolic foam is its potential shrinkage of up to 2% post-curing, leading to its decreased popularity in modern times. Phenolic foam is a versatile material used in a wide variety of applications where thermal performance, moisture resistance, fire performance and even structural strength are key performance criteria, excellent fire resistance performance, low smoke emission, stability, superior thermal performance, extremely sound insulating property & structural strength performance. Therefore, it has been named the Third-Generation insulation material.

					**Thickness: 255 mm (25 mm insulation in the cavity)**
Cement Plaster	Wall	Phenolic foam Insulation	Wall	Cement Plaster	**U-Value: 0.52 W/m². K**

15 https://www.buildinggreen.com/news-analysis/what-about-air-krete-deeper-look-insulation-alternative

Technical specification

- Specific Heat (Insulation): 1.47 kJ/kg.K
- Heat Capacity: 1400 J/kgK
- Conductivity (Insulation): 0.019 W/m.K
- Density: 65 kg/m^3
- Applicable for both commercial and residential buildings

4.1.6.8.2 Strategy Application

Table 15 Strategy Application of phenolic foam

Preparation	The surface to be insulated should be cleaned and free of any debris, dust, or oil. Phenolic foam insulation boards can be easily cut and sized using a hand saw, electric saw, or other cutting tools.
Installation	A suitable adhesive is applied to the surface to be insulated, as well as to the back of the insulation board. The insulation boards are then pressed firmly against the adhesive-coated surface and held in place until the adhesive sets
Maintenance	Any joints between insulation boards should be sealed with suitable tape or sealant to prevent air leakage and improve the insulation's thermal performance. A finishing material may be applied over the insulation to provide additional protection and aesthetic appeal.

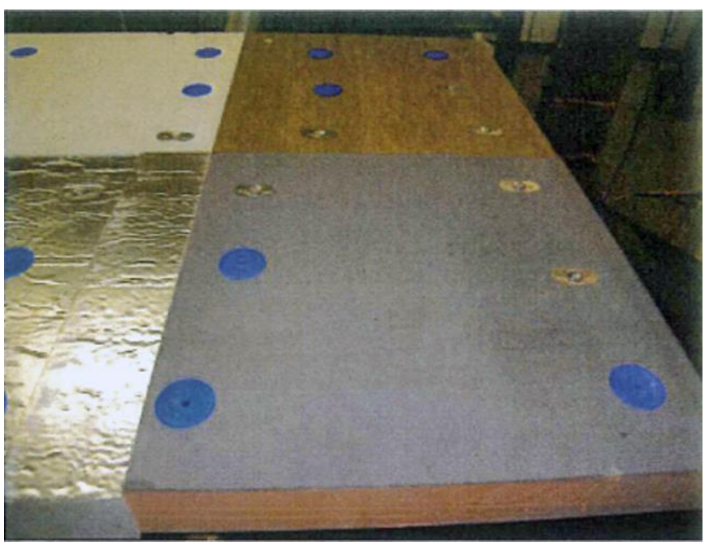


Figure 28 Phenolic Foam insulation application procedure[16]

Building Detials	Star Garment Innovation Center
Location	Katunayake, Sri Lanka
Building Typology	Industrial
No. of Floors	G+1

[16] https://www.greenbuildingadvisor.com/article/phenolic-foam-insulation-revisited

Climatic Zone	(ASHRAE) Extremely Hot and Humid, CDD 6337, HDD 0
Implementation Agency	Jordan Parnass Digital Architecture
Recognition	LEED Platinum, EnerPHit Pilot Project Certification

Passive Cooling Strategy	
Double Glazed Windows	70% reduction in cooling demand, Maintains a near constant temperature of 24°C
Façade and Envelope	
Cool Roofs	
Exterior Insulation Finishing System	
Stained Glass	
Extended Overhangs	
Tall Windows	
Glazed Façade	Ample Amount of Natural Daylight

CaseStudy:
https://drive.google.com/file/d/1Mk2ZpI8TF_UxdM9uMB9C_44cvS8koA_k/view?usp=drive_link

4.2 Roof

4.2.1 Reflective/ Cool Roof

4.2.1.1 Description

The application of Reflective Paint is intended to enhance sunlight reflection and minimize heat absorption compared to a typical roof, resulting in reduced roof temperatures. By using a white reflective roof coating, it is possible to potentially decrease up to 60% of the heat entering from the ceiling.

Reflective Tiles are designed to reflect more sunlight. Its application reduces roof temperature. A white reflective roof tile can potentially reduce up to 90% of the heat coming in from the ceiling. Tiles on the roof and facades of the building can reduce the inside temperature by 10 to 15%.

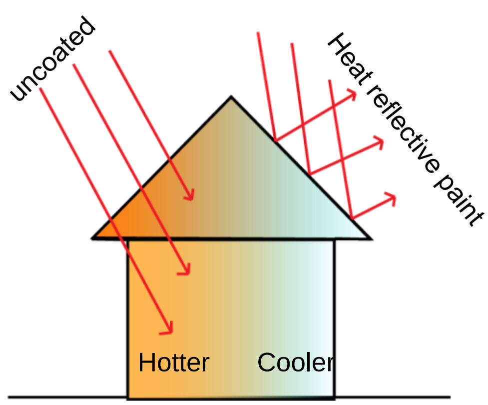


Figure 29 Reflective paint

4.2.1.2 Strategy Application

Table 16 Strategy Application of cool tiles

Preparation	The roof surface should be cleaned and inspected to ensure that it is free of debris and any damage that needs to be repaired before installing the cool tiles. A layer of underlayment, such as felt or synthetic material, should be installed on the roof surface before installing the cool tiles.
Installation	The cool tiles are installed similarly to traditional roofing tiles. Ridge and hip tiles, which are used to cover the intersections of the roof, should also be installed using cool tiles to ensure consistent reflectivity across the entire roof surface.
Maintenance	Sealants, such as caulk or silicone, may be used to seal any gaps or joints where the tiles meet. It is important to maintain the roof by cleaning it periodically to ensure that the reflective properties of the cool tiles are not compromised by dirt or debris.

Figure 30 Reflective/ cool paint application procedure[17]

4.2.2 Roof Insulation

4.2.2.1 Description

Roof Insulation refers to the layer of material installed in the roof space or between the roof and ceiling of a building to reduce the amount of heat transfer between the interior and exterior of the building. There are several types of roof insulation materials available, such as fibreglass, rock wool, cellulose, and foam, each with different performance characteristics and installation requirements. The choice of roof insulation material and method of installation will depend on factors such as climate, building type, and energy efficiency goals.

Roof insulation can be classified under two categories-

i. **Over-deck Insulation**: Using Overdeck Insulation, which is applied on the upper side of the roof of the structure, is one of the best ways to maintain the structure's temperature. The insulation is then covered with a cement screed or roof tiles.

[17] https://www.attainablehome.com/what-is-cool-roof-coating/

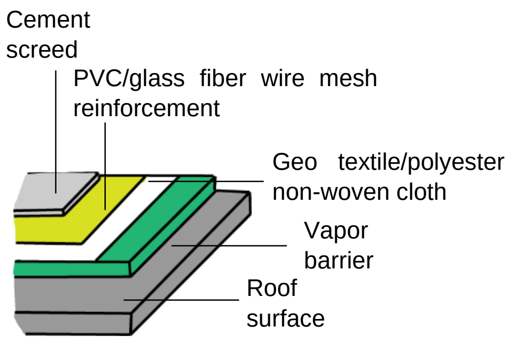


Figure 31 Over-deck insulation

ii. **Under-deck insulation** involves placing the insulation layer below the roof slab. It also stops the radiant heat from entering inside the houses which increases the indoor discomfort.

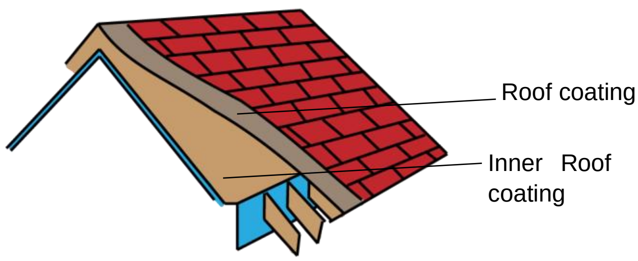
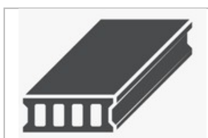
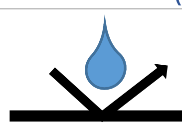


Figure 32 Under-deck insulation

4.2.2.2 Insulation with Polyurethane Foam (PUF) spray

				**Thickness: 220 mm (25 mm insulation)** **U-Value: 0.93 W/m².K**
Reinforced Cement Concrete (RCC) slab	Insulation	Waterproof membrane	Cement Plaster	

Technical specifications

- Specific Heat: 1.47 kJ/kg.K
- Heat Capacity: 1400 J/kgK
- Conductivity: 0.026 to 0.042 W/m.K
- Density: 6 to 55 kg/m^3
- Applicable for both commercial and residential buildings

4.2.2.2.1 Strategy Application

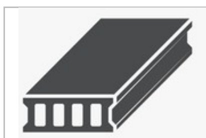
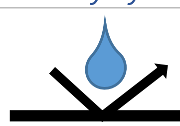
Table 17 Strategy Application of PUF Spray

Preparation	The application process for PUF spray insulation involves spraying the polyurethane foam mixture onto the underside of the roof. First, the area

	to be insulated must be cleaned and prepared to ensure good adhesion of the foam.
Installation	The PUF spray is then applied evenly and at a consistent thickness to the underside of the roof in a series of passes until the desired thickness is achieved. Once the foam has cured, any excess material is trimmed away, and the surface can be finished with a layer of protective coating or left exposed.
Maintenance	PUF spray insulation is a quick and efficient method of roof insulation, providing excellent thermal performance and air-sealing properties.

Figure 33 PUF spray insulation application procedure[18]

4.2.2.3 Insulation with Extruded Polystyrene (XPS)

				**Thickness: 220 mm (25 mm insulation)** **U-Value: 0.83 W/m².K**
RCC slab	Insulation	Waterproof membrane	Cement Plaster	

Technical Specifications

- Specific Heat: 1.47 kJ/kg.K
- Heat Capacity: 1380 J/kgK
- Conductivity: 0.022 to 0.039 W/m.K
- Density: 15 to 40 kg/m^3
- Applicable for both commercial and residential buildings

[18] https://colonyroofers.com/learningcenter/spray-foam-roofing-cheaper

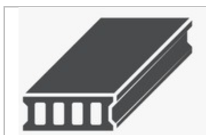
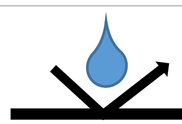
4.2.2.3.1 Strategy Application

Table 18 Strategy Application of XPS

Preparation	The application process for XPS insulation typically involves laying the boards in a staggered pattern across the roof surface, with joints tightly butted together and edges sealed with a compatible adhesive
Installation	The boards should be mechanically fastened to the roof deck using appropriate fasteners and plates, with spacing and layout determined by the manufacturer's specifications. Additional layers of XPS insulation may be added comparably to achieve the desired thermal performance, with all seams and joints properly sealed.
Maintenance	Finally, a suitable roofing membrane or protective layer should be installed over the XPS insulation to provide weather resistance and protect against damage.

Figure 34 XPS insulation application procedure[19]

4.2.2.4 Insulation with glass wool

				**Thickness: 220 mm (25 mm insulation)** **U-Value: 1.44 W/m².K**
RCC slab	Insulations	Waterproof membrane	Cement Plaster	

Technical Specifications

- Specific Heat: 0.92 kJ/kg.K
- Heat Capacity: 670 J/kgK
- Conductivity: 0.040 to 0.043 W/m.K
- Density: 69 to 189 kg/m^3
- Applicable for both commercial and residential buildings

[19] https://www.atlasmoldedproducts.com/blog/can-you-use-eps-as-an-alternative-to-rigid-insulation

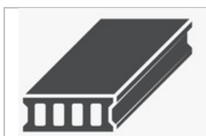
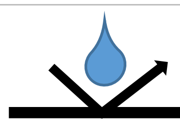
4.2.2.4.1 Strategy Application

Table 19 Strategy Application of Glass Wool

Preparation	The application process involves measuring the area to be insulated and cutting the glass wool batts or rolls to the appropriate size.
Installation	The insulation is then laid out over the roof structure, ensuring that the entire area is covered and there are no gaps. The glass wool is then compressed to ensure a tight fit, which helps to prevent any air pockets from forming.
Maintenance	Once the insulation is in place, a vapour barrier is added on top of it to prevent moisture from entering the roof.

Figure 35 Glass wool insulation application procedure[20]

4.2.2.5 Insulation with rock wool

				**Thickness: 220 mm (25 mm insulation)** **U-Value: 1.54 W/m².K**
RCC slab	Insulation	Waterproof membrane	Cement Plaster	

Technical Specifications

- Specific Heat: 0.84 kJ/kg.K
- Heat Capacity: 670 J/kgK
- Conductivity: 0.043 to 0.047 W/m.K
- Density: 92 to 150 kg/m^3
- Applicable for both commercial and residential buildings

[20] https://gharpedia.com/blog/glass-wool-and-its-applications/

4.2.2.5.1 Strategy Application

Table 20 Strategy Application of rock wool

Preparation	The application process of rock wool insulation involves first measuring the roof area to determine the amount of insulation required. The insulation is then cut to the appropriate size and shape to fit snugly between the roof joists or over the roof deck.
Installation	The insulation is then placed on the roof surface and secured using mechanical fixings such as screws or nails or using adhesive. Care must be taken to ensure that there are no gaps or voids in the insulation, as this can compromise its effectiveness.
Maintenance	Once the insulation is installed, a protective layer such as a roofing membrane or felt may be added to provide additional weather resistance. The proper installation of rock wool insulation can improve the energy efficiency and comfort of a building.

Figure 36 Rock wool insulation application procedure[21]

Building Details	Surat Cool Roofs Program
Location	Surat, Gujarat, India
Building Typology	Urban Level
Climatic Zone	(ASHRAE) Extremely Hot and Humid, CDD 6365, HDD 16
Implementation Agency	Surat Municipal Corporation, ACCRN

Passive Cooling Strategy	
Cool Roofs	Reduction in cooling demand

CaseStudy:
https://drive.google.com/file/d/1Mb2woyvnDNgyqrvOumTD63iYIYmNwCzM/view?usp=drive_link

[21] https://www.nuralite.co.nz/products/rockwool-insulation.html

4.3 Fenestration

Fenestration refers to the arrangement, design, and construction of windows, doors, skylights, and other openings in a building's envelope. Fenestration design can impact a building's energy consumption and comfort level by controlling the amount of solar heat gain, thermal loss, and natural ventilation. The design and placement of windows are especially important in the design aspect and the material selection will further add up to the whole building’s performance.

4.3.1 Glazing

4.3.1.1 Description

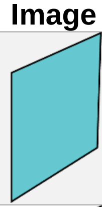
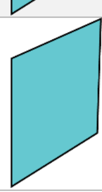
Glazing refers to the use of glass or transparent materials in windows, doors, skylights, and other openings in a building's envelope. The term "glazing" can refer to both the glass or transparent material itself and the act of installing it in a window or other opening.

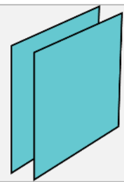
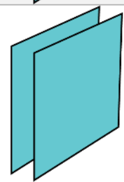
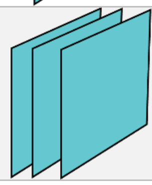
Different types of glazing materials and technologies are available to meet various design and performance requirements. Some examples include single-pane glass, double-pane insulated glass, low-e coatings, and laminated glass. A few parameters that can be used for assessing glazing types are-

i. U-value: This parameter measures the rate of heat transfer through a glazing. The lower the U-value, the better the insulating properties of the glazing.

ii. Solar Heat Gain Coefficient (SHGC): This parameter measures the amount of solar radiation that passes through the glazing. A low SHGC value means that the glazing blocks more solar heat, while a high SHGC value means that more solar heat is transmitted into the building.

Table 21 Glass type with U-value and SHGC

Glass Type	**Image**	**U-Value**	**SHGC**
Single glazing		5.6 W/$m^{2.}$.K	0.9
Single glazing with low-e coating		5.6 W/$m^{2.}$.K	0.75 to 0.61

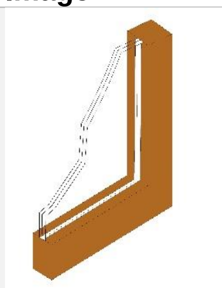
Double Glazing		1.8 W/m^2.K	0.8 to 0.7
Double High-Performance Glazing (Low-e coating)		1.5 W/m^2.K	0.6 to 0.25
Triple glazing		0.5 to 0.8 W/m^2.K	0.6 to 0.1

4.3.2 Frames

4.3.2.1 Description

The frames of windows are a vital component of the window system and play a critical role in the overall performance and functionality of the window. The key reasons why frames are important in windows are because of its support to host glazing, thermal insulation, security, water tightness, airtightness and aesthetics. Frames can be made of diverse types of materials based on their usage and requirements. The following is the list of most commonly used frame types with their U-values respectively.

Table 22 Frame type with U-value

Frame Type	Image	U-Value
Wooden frame		1.2 and 2.4 W/m^2.K

Unplasticized Poly Vinyl Chloride (UPVC) frame		1.2 and 1.6 W/m².K
Aluminium frame		6.0 to 7.0 W/m².K

4.3.2.2 External Shading

Shading is deployed to reduce radiative solar heat gain in the building. Although shading the whole building is beneficial, shading the windows is crucial. The shading devices to the window can be either installed outside or inside. External shading devices are better at preventing heat transfer than internal shading devices.

External shading can be classified under two categories:

i. Static shading device: Static shading devices are architectural elements or devices that are installed on the exterior of a building to reduce the amount of solar heat gain and glare that enters the building's interior spaces. They remain in a fixed position and do not move or adjust.
ii. Movable shading device: Movable shading devices can be manually or automatically controlled, depending on the specific design and technology used.

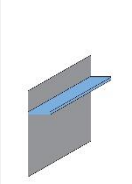
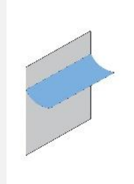
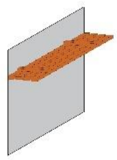
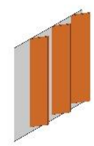
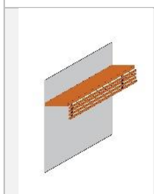
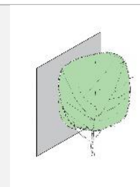
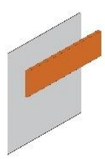
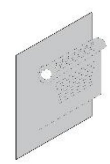
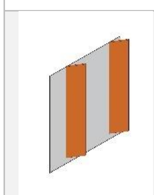
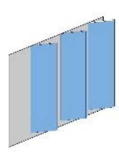
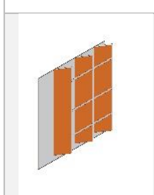
Image	Static Shading Devices	Applicable Orientation	Image	Moveable Shading Devices	Applicable Orientation
	Overhang horizontal panel or awning	South and North		Overhang awning	South and North
	Overhang horizontal louvres in the horizontal plane	South and North		Overhang rotating horizontal louvres	South, North, East, and West
	Overhang horizontal louvres in the vertical plane	South and North		Deciduous plants, trees, vines	South, North, East, and West
	Overhang vertical panel	South, North, East, and West		Exterior roller shade	South, North, East, and West
	Vertical fin	East and West			
	Vertical fin slanted	East and West			
	Eggcrate	East and West			

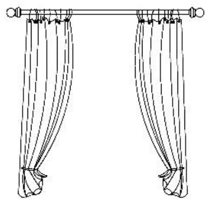
Table 23 Fixed and moveable external shading devices

4.3.2.3 Internal Shading

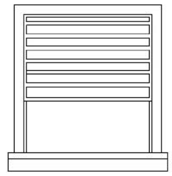
An interior shading device is a structure or material used to block or filter sunlight from entering an indoor space. Interior shading devices like blinds, curtains and internal louvre are typically used to reduce glare, control the amount of natural light, and provide privacy.

Interior shading devices can be manually or automatically controlled, depending on the specific design and technology used. They can be made from a variety of materials, such as fabric, plastic, or metal, and can be designed to match the style and decor of the room or building. Interior shading devices can also be used in combination with other techniques, such as insulation or ventilation, to improve energy efficiency and reduce energy costs.

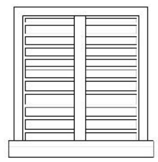
Curtain



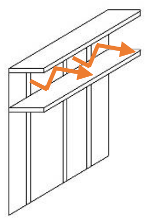
Roller shades



Venetian blinds



Light shelf



4.4 Green Envelope Features

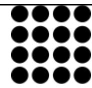
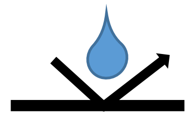
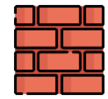
Green walls and green roofs are innovative green features that offer multiple benefits for buildings and the environment. Green walls provide insulation, shade, and aesthetic appeal. They improve air quality, reduce noise, and contribute to biodiversity. Green roofs, on the other hand, involve covering the roof with vegetation, which helps regulate temperature, reduce stormwater runoff, and enhance energy efficiency. Green feature also help in reducing the urban heat island effect.

4.4.1 Green Wall

4.4.1.1 Description

A green wall, also known as a living wall, is a vertical structure covered in plants that are grown using a variety of techniques. Green walls can be installed indoors or outdoors and are often used for their aesthetic and environmental benefits.

Green walls can be designed to suit different environments and purposes and can include a range of plant species, such as ferns, mosses, succulents, and flowering plants. They can also be used in conjunction with other sustainable design strategies, such as rainwater harvesting or renewable energy.

					
Plant	Vegetation Layer	Drainage Mat	Irrigation Line	Waterproof membrane	Wall

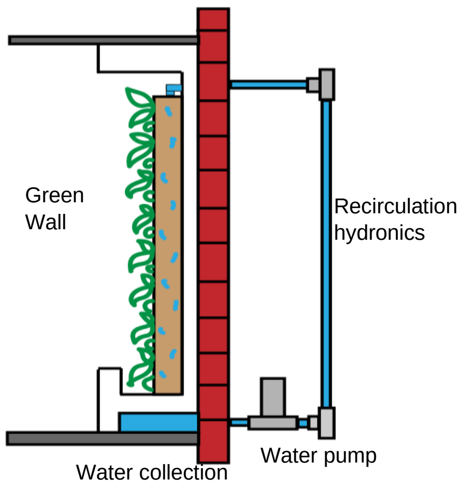


Figure 37 Green wall sectional view

4.4.1.2 Strategy Application

Table 24 Strategy Application of green wall

Conduct Preliminary Assessment	A site feasibility assessment for installing a green wall involves evaluating factors such as available space, structural capacity, sunlight exposure, access to water, and maintenance requirements. It is essential to consider the building's location, climate, and potential impact on surrounding infrastructure.
Installation and maintenance	The installation of green wall is summarized in following four integrated steps (i) the structural integrity of the wall needs to be assessed and reinforced if necessary. (ii) a suitable irrigation system must be installed to provide water to the plants. (iii) The selection and planting of appropriate plant species follow, considering factors like sunlight exposure and maintenance requirements. (iv) regular monitoring and maintenance ensure the long-term health and vitality of the green wall.

Building Details	Osaka Urban Central Area
Location	Osaka, Japan
Climatic Zone	(ASHRAE) Warm Humid, CDD 2703, HDD 1828

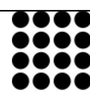
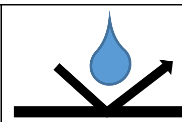
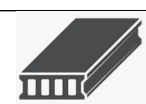
Passive Cooling Strategies	
Increasing Green Spaces	Reduction of air temperature by 6°C to 10°C at the urban level
Restoration of Waterfront Spaces	
Preparing Public Transportation Systems	Enhancement of public transportation systems
Wind Movement	

CaseStudy:https://drive.google.com/file/d/1HsZVCI9xYjKOrTf-HH-_kgVUDNskVC2Y/view?usp=drive_link

4.4.2 Green Roof

4.4.2.1 Description

As the name implies, green roofs are specially engineered roofs designed to support plants while protecting the roof's structural integrity. They can also be referred to as vegetated roofs, rooftop gardens or eco-roofs. A green roof acts like a lawn, meadow, or garden by intercepting and absorbing a portion of the rain that falls on it.

					
Plant	Vegetation Layer	Drainage Mat	Irrigation Line	Waterproof membrane	RCC slab

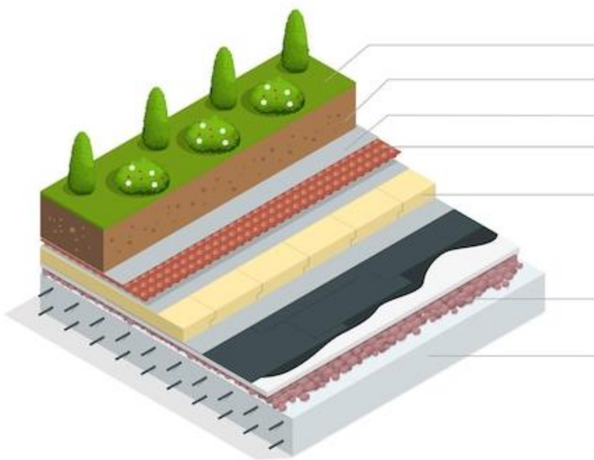
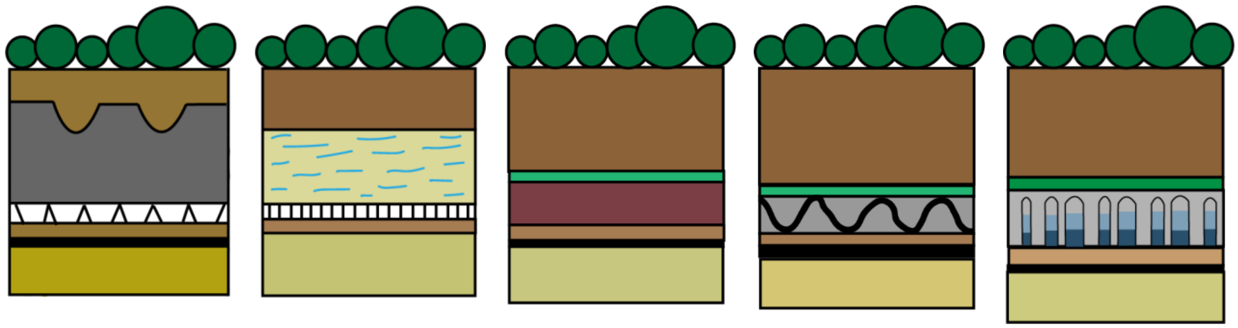


Figure 38 Sectional view of green roof

4.4.2.2 Strategy Application

Table 25 Strategy Application of green roof

Perimeter	Inspection of the perimeter is done to confirm the dimensions are acceptable and check for a wind uplift of green roof layers or other types of structural damage.
Filter bed/ Growing media area	The green roof surface is composed of a filter bed (i.e., growing medium area) covered by a mixture of vegetation and either flat or gently sloping
Vegetation	Plantings should be adapted to the harsh conditions (i.e., minimal soil depth, seasonal drought, high winds, and strong sun exposure) prevalent on rooftops
Overflow outlets	Flows exceeding the storage capacity are conveyed to an adjacent drainage system via an overflow outlet structure and the roof drainage system
Irrigation system	During the initial two-month establishment period, regular irrigation is often necessary for most green roofs.
Protective layers	Green roofs typically contain one or more layers designed to protect the roof deck and insulation from water damage, including a water-proofing membrane layer, and a root barrier.
Leak detection System	leak detection systems should be used to periodically check for the presence of leaks in the waterproofing membrane.



Tray Plastic box one size fits all concepts are only grass and flowering plants.	Layered sponging element seamless from wall-to-wall concept only grass and flowering plants.	Layered granular drainage is seamless from wall to wall with endless variations from grass, flowering plants, herbs, and shrubs.	Layered drainage board seamless from wall to wall with limited variations from grass, flowering plants, herbs, and shrubs.	Monolithic platform based seamless from wall to wall with endless variations from grass, flowering plants, herbs, large shrubs and trees.
Low diversity High costs	Low diversity High costs	High diversity Low costs	Medium diversity Medium costs	Highest diversity High costs

Figure 39 Cross-sectional view of diverse types of green roof

Building Details	Diamond Lotus Riverside
Location	Ho Chi Minh, Vietnam
No. of Floors	G+21, 3 towers
Climatic Zone	(ASHRAE) Very Hot and Humid, CDD 5408, HDD 132
Implementation Agency	Vo Trong Nghia Architects
Occupancy	720 families

Passive Cooling Strategy	
Double Glazed Windows	- 40% reduction in cooling demand
Façade and Envelope	
Cool Roofs	
Rock Wool Insulation	
Landscape Design	

Passive cooling strategies, like double glazed windows, façade enhancements, cool roofs, insulation, and landscape design, offer effective ways to reduce cooling needs in hot climates. For example, double glazed windows can cut demand by 40%. These strategies contribute to energy efficiency and comfort, crucial in locations like Ho Chi Minh, Vietnam.

CaseStudy:
https://drive.google.com/file/d/1tN3HUo63oQWyXaQfvfLm3734nNCd3raw/view?usp=drive_link

5 Passive Cooling Strategies matrix

	Residential – Condominiums	Residential – Borey (Landed Dwelling)	Residential – Affordable Housing	Offices	Educational Institutions	Hotels	Hospitals	Retail: shopping malls
Outdoor Vegetation: Tree Canopy								
Outdoor Vegetation: Green Corridor								
Water Features								
Pavements: Cool Pavements								
Pavements: Grass Pavements								
Solar Orientation								
Massing and Zoning								
Wind Orientation								
Stack Ventilation								
Natural and Cross Ventilation								
Night Cooling								
Window Wall Ration (WWR)								

Mutual Shading								
Wall								
Roof								
Fenestration								
Green wall								
Green roof								

The matrix displays passive cooling strategies on the Y-axis and building typology on the X-axis. Color-coded cells indicate the effectiveness of each strategy for different building types, offering a visual guide for optimal strategy selection in the report. This visual representation simplifies the decision-making process by highlighting which strategies are most effective for specific building typologies, enhancing the overall applicability of passive cooling solutions.

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