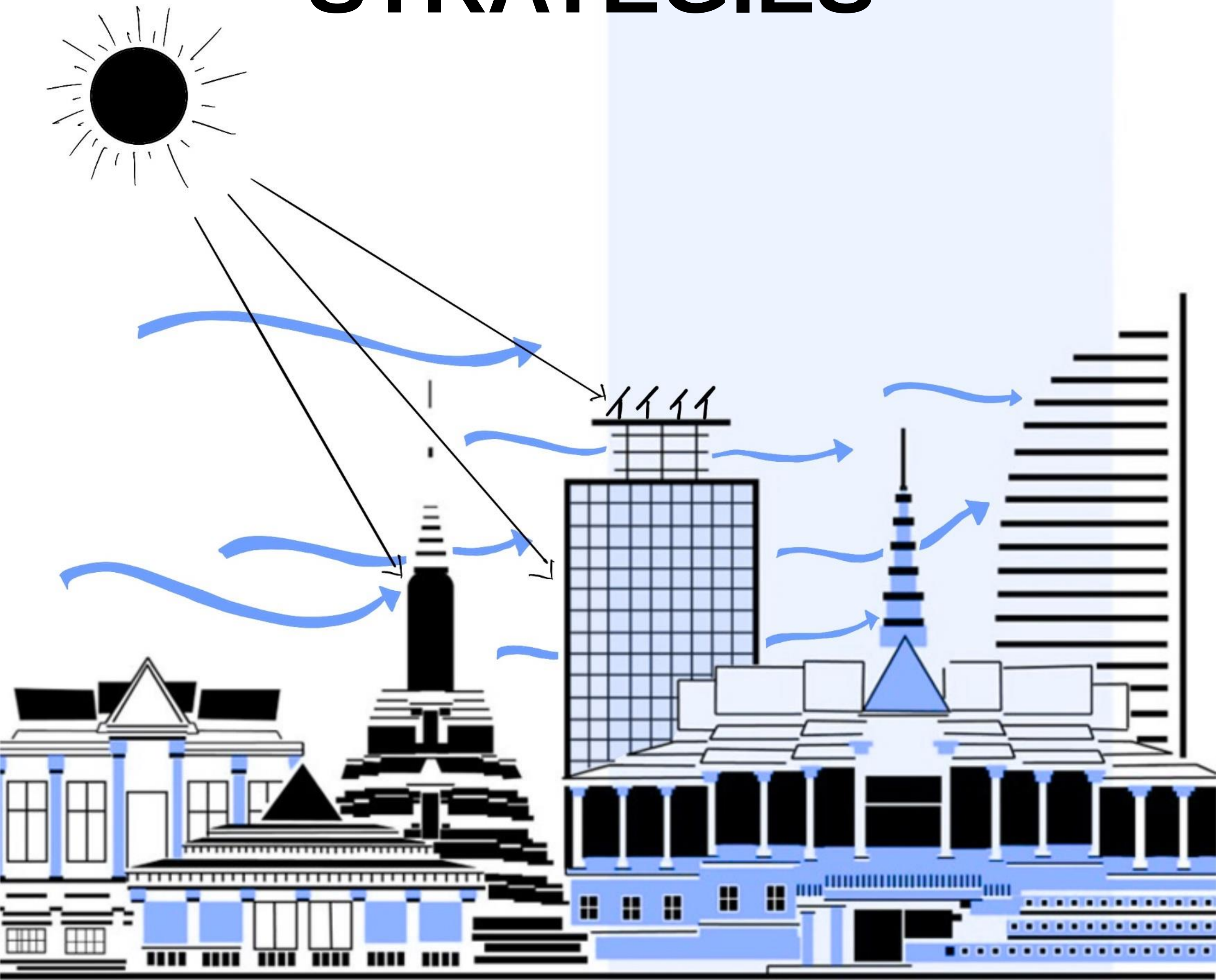
Cool Coalition
ESCAP
Economic and Social Commission for Asia and the Pacific
UN environment programme

ABRIDGED GUIDEBOOK ON PASSIVE COOLING STRATEGIES



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ABBREVIATIONS

ASHRAE	American Society of Heating Refrigerating and Air-Conditioning Engineers
DBT	Dry Bulb Temperature
HVAC	Heating, Ventilation and Air Conditioning
MRT	Mean Radiant Temperature
NDC	Nationally Determined Contribution
PCS	Passive Cooling Strategies
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity
UHI	Urban Heat Island
UTCI	Universal Thermal Comfort Index

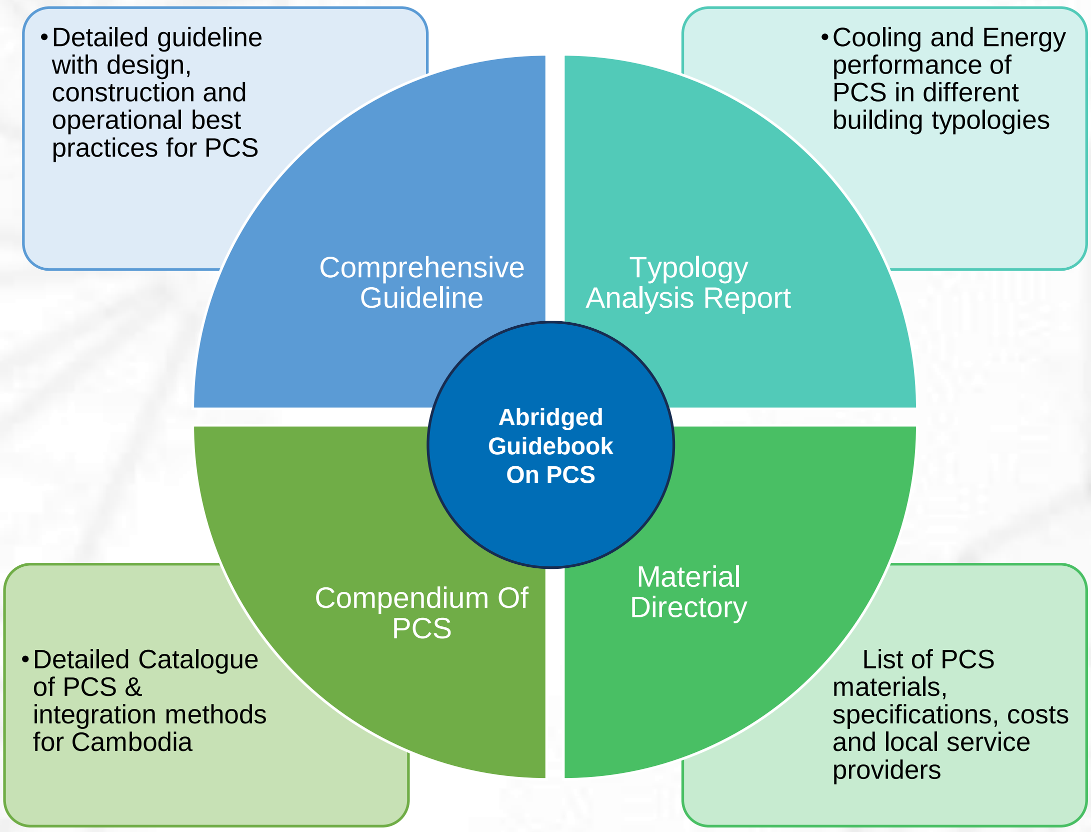
01 INTRODUCTION

In 2017, Cambodia's hot-humid climate and economic growth led to a 2% penetration rate of cooling equipment, with buildings accounting for over one-third of total energy consumption, and space cooling alone representing 45% of electricity usage. Cambodia's Nationally Determined Contribution (NDC) aims for a 29.7% reduction in electricity use for buildings by 2030 under the Paris Agreement.

Passive Cooling Strategies (PCS) offer significant potential for reducing electricity consumption at a higher rate in Cambodia. It involves natural methods to maintain comfortable indoor temperatures by reducing the need for mechanical cooling systems, minimizing energy usage and environmental impact.

The abridged guidebook offers practitioners guidelines for implementing PCS in Cambodia, leveraging natural methods like urban planning, shading, ventilation, insulation, and thermal mass. It serves as a decision-making tool, assisting in selecting suitable PCS through a tailored decision matrix, thus promoting sustainable building practices. Covering a wide range of PCS, each strategy is accompanied by concise specifications, applications, and benefits. The handbook emphasizes considering long-term energy-saving and provides essential technical details.

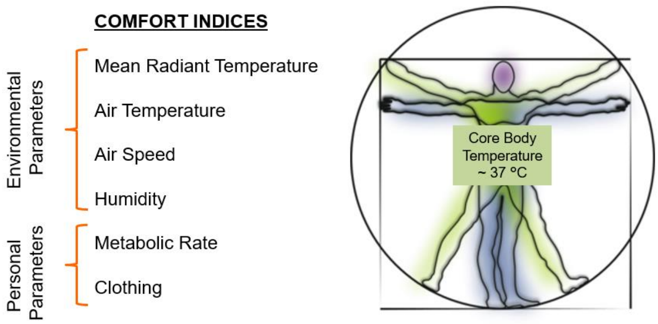
Complementing the larger guideline document, the abridged handbook serves as a foundational resource for technicians, architects, and designers, offering a basic understanding of PCS and its technical aspects. Links to related knowledge products, such as the compendium, typology, guideline, and directory of PCS, are provided for those seeking more detailed information and comprehensive resources.



02 BUILDING PHYSICS

THERMAL COMFORT

Thermal comfort, defined by American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55, is about feeling satisfied with the thermal environment. Achieving this involves factors like Mean Radiant Temperature (MRT), air temperature, humidity, and air speed, along with personal factors such as clothing and metabolic rate. MRT considers surface temperatures around individuals, while air temperature and humidity affect how we perceive heat. Air speed influences comfort by regulating airflow.



EVALUATION OF THERMAL COMFORT

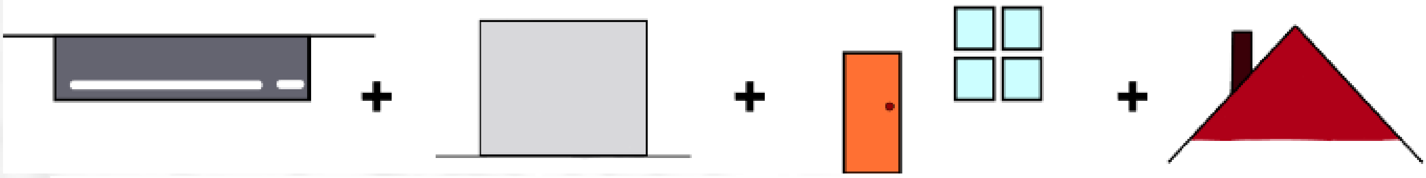
Thermal comfort of environments controlled with the Fanger method. The Predicted Mean Vote (PMV) method predicts the average thermal sensation of a group of people in a given environment based on factors like air temperature, humidity, clothing insulation, and activity level. The Predicted Percentage of Dissatisfied (PPD) method, derived from PMV, estimates the percentage of occupants likely to feel dissatisfied with their thermal environment based on predicted thermal sensations and individual comfort preferences.

No.	Sensation Vote	Acceptance Vote	Preference Vote
-3	Cold	-	-
-2	Cool	Very Unacceptable	Want Cooler
-1	Slightly Cool	Unacceptable	Want Slightly Cooler
0	Neutral	-	No Change
+1	Slightly Warm	Acceptable	Want Slightly Warmer
+2	Warm	Very Acceptable	Want Warmer
+3	Hot	-	-

The ASHRAE Standard 55 – 2020 Thermal Environmental Conditions for Human Occupancy is considered in the evaluation of thermal comfort conditions in the buildings. The Adaptive Comfort Model under this standard is a thermal comfort approach that considers people's ability to adapt to their surroundings, acknowledging cultural, behavioral, and individual differences in comfort perception. It recognizes that occupants can adjust their clothing, behavior, and expectations to achieve comfort in varying environmental conditions, providing a more flexible and contextually relevant framework for designing and evaluating indoor environments.

COMPONENTS OF BUILDING ENVELOPE

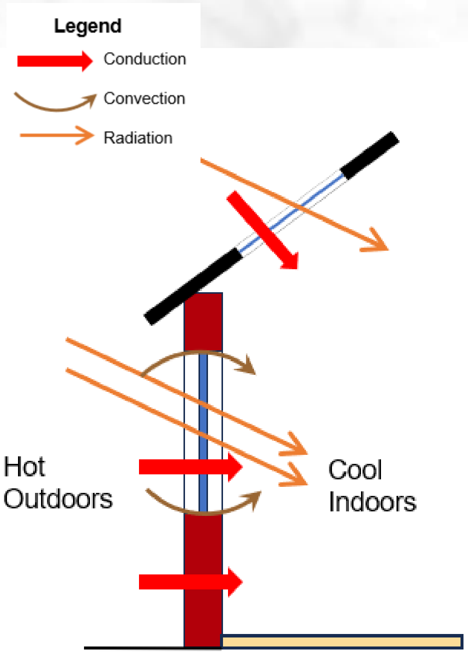
The building envelope refers to the exterior enclosure of a building that separates the interior conditioned spaces from the external environment. Opaque components include walls, roofs, slabs, basement walls and opaque doors.



FLOORING	WALL	FENESTRATION	ROOF
Flooring acts as a barrier between interior spaces and the ground. To optimize thermal performance, consider minimizing heat transfer at the flooring-ground interface.	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 includes transparent and translucent elements like windows, doors, skylights, and glass block walls in a building's envelope.	The roof is the topmost covering of a building, protecting the top floor from weather and external elements.

HEAT TRANSFER

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

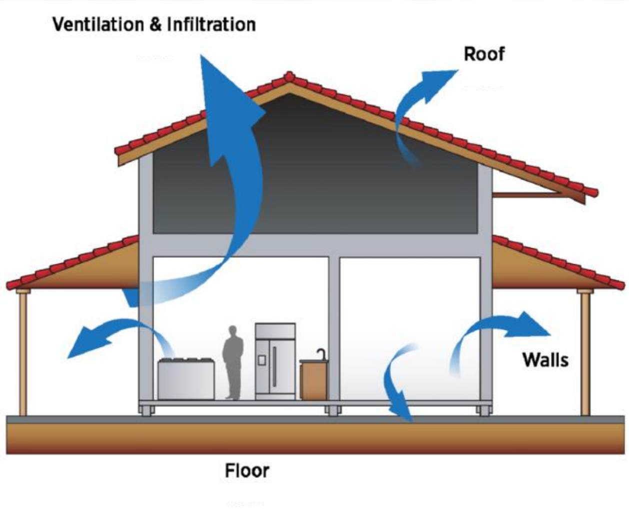


Conduction: The heat transfer through a solid medium due to the temperature difference. The two things required for conduction to take place are surface contact and temperature difference e.g., an uninsulated wall exposed to high outdoor temperatures can conduct heat into the building, causing increased 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. All bodies facing an air space, or a vacuum emits and absorbs radiant energy continuously e.g., sunlight passing through a window brings radiative heat into the room, contributing to an increase in indoor temperatures.

BUILDING ENVELOPE LOAD



https://www.researchgate.net/figure/Heat-loss-through-residential-building-envelope-Source-NREL_fig48_255380937

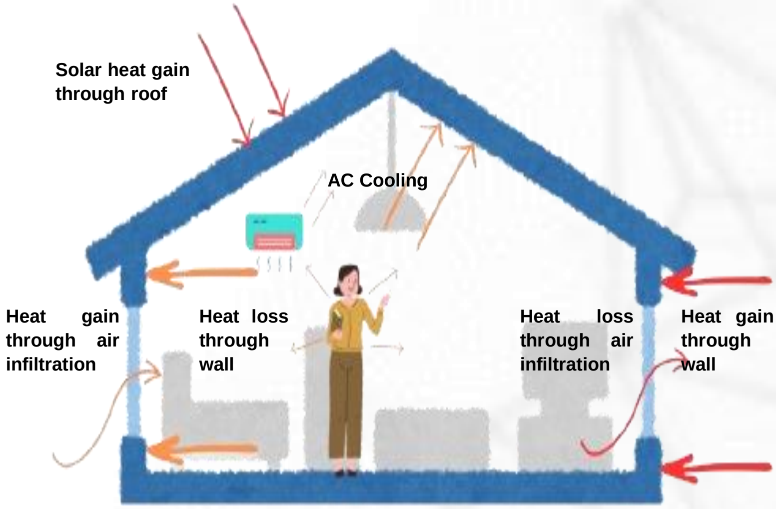
Infiltration is the uncontrolled leakage of air into and out of a structure through cracks, gaps, or openings in the building envelope. It adds to the building envelope load, which represents the thermal energy exchange between a building's interior and exterior through its surfaces, including walls, roofs, windows, and doors. It represents the heat gain or loss that must be managed by the building's heating, ventilation, and air conditioning (HVAC) systems to maintain desired indoor temperatures. Minimizing it through insulation, shading, and other passive cooling strategies is crucial for reducing energy consumption and improving overall building efficiency and comfort.

HEAT GAIN AND LOSS

In buildings, heat gain and loss impact thermal comfort, leading to increased use of heating and cooling systems. In Cambodia's tropical climate, the focus is primarily on managing the cooling load, which refers to the heat energy needing removal for comfort. Cooling load classifications are based on their effect on air temperature and moisture content.

Sensible cooling load: Heat load caused by changes in the air temperature and is felt as the warmth of the air. It includes conduction and radiation heat gain through the envelope and from the internal load.

Latent cooling load: Heat load caused by changes in the moisture content of the air without changing the temperature and is related to the amount of water vapor in the air. The main sources are from building occupancy, infiltration and equipment contributing to the addition of moisture content in the air.



RESOURCES

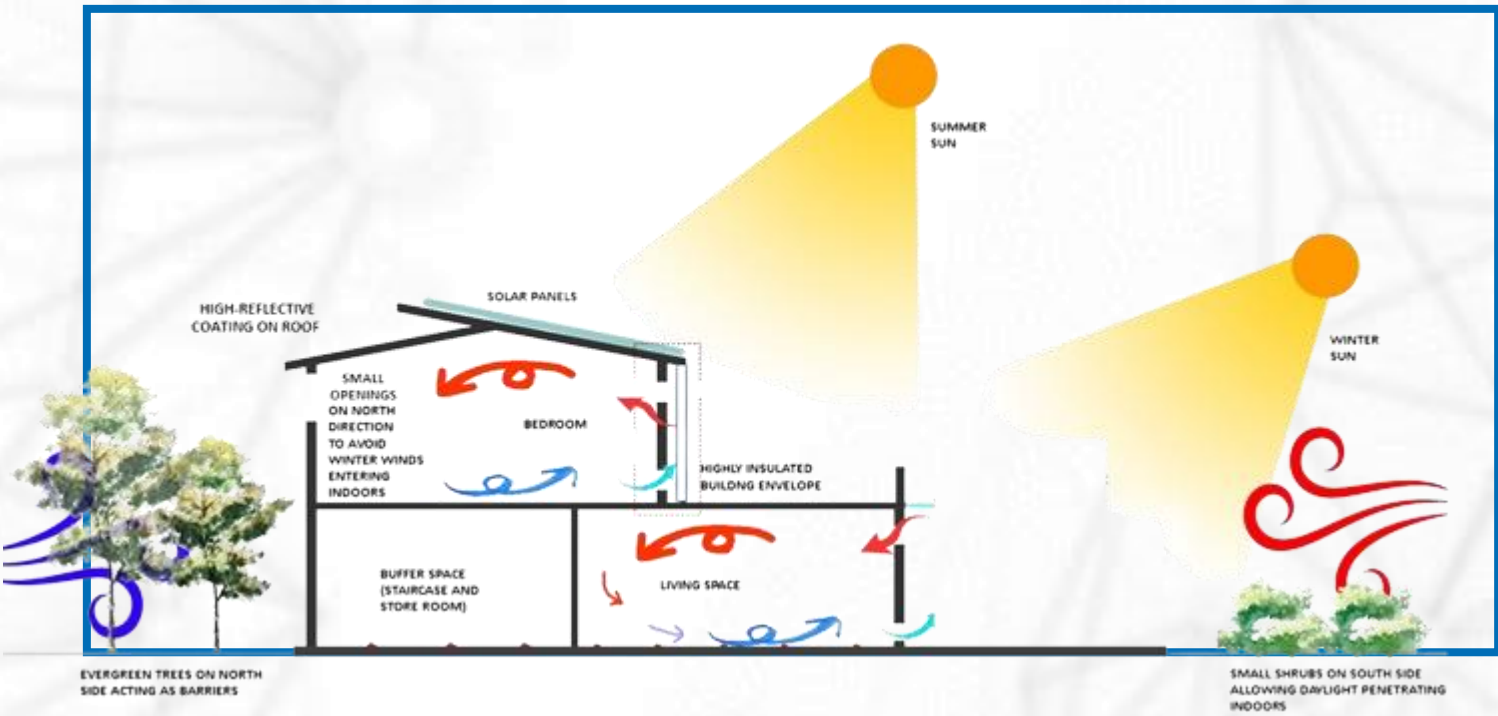
- Compendium Report

03 LIST OF PASSIVE COOLING STRATEGIES (PCS)

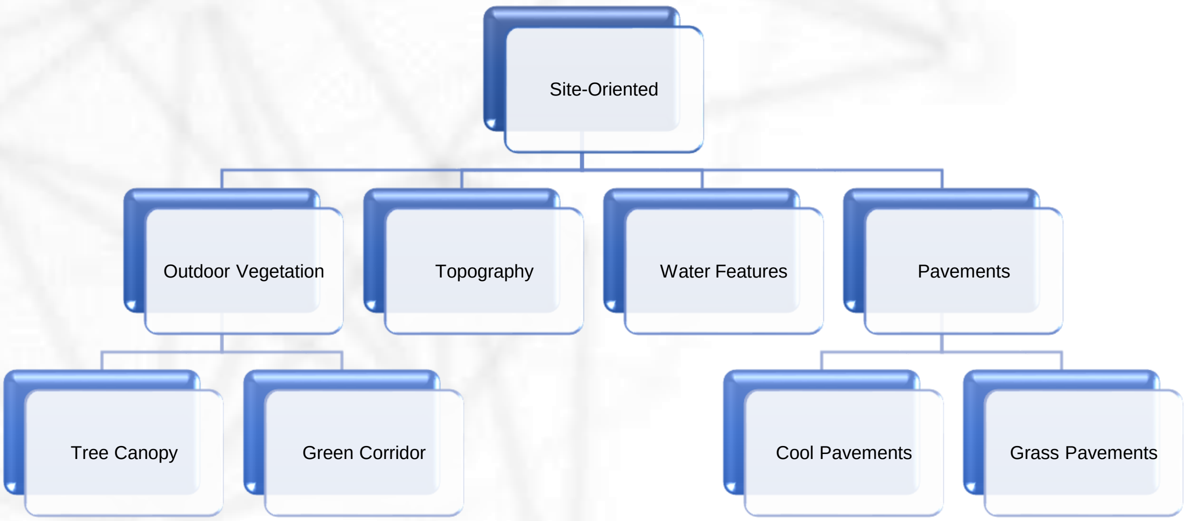
Site-oriented passive cooling strategies focus on leveraging the surrounding environment to minimize heat gain and maximize natural ventilation. This approach involves careful consideration of factors such as prevailing winds, solar exposure, and topography to optimize the building's orientation and layout. By strategically placing buildings to take advantage of shade from existing vegetation or natural land formations and orienting openings to capture cool breezes, site-oriented strategies can significantly reduce the need for mechanical cooling systems.

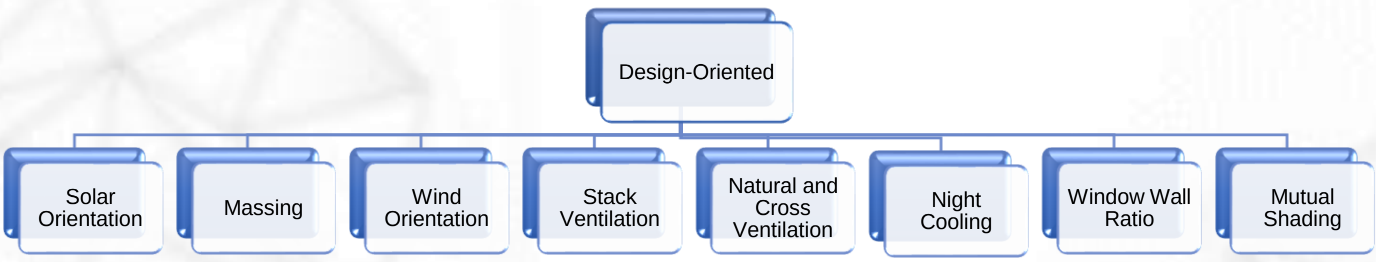
Building-oriented passive cooling strategies involve architectural design and features within the building envelope to enhance thermal comfort and minimize energy consumption. This includes incorporating elements such as shading devices, natural ventilation systems, and thermal insulation to regulate internal temperatures. Building orientation, window placement, and building massing are also critical considerations to maximize passive cooling potential. By optimizing building form and layout to minimize solar heat gain and promote airflow, building-oriented strategies can effectively reduce reliance on artificial cooling systems.

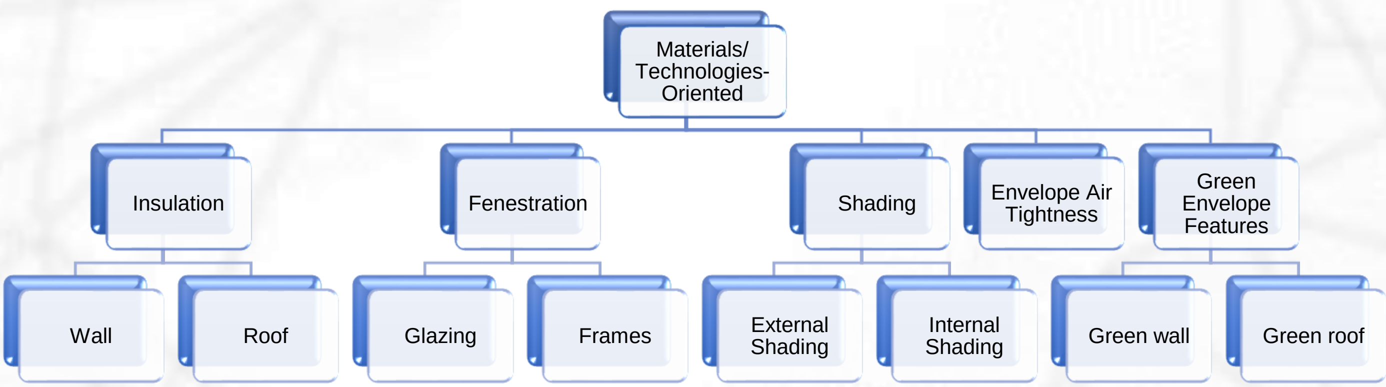
Component-oriented passive cooling strategies focus on specific building components and materials to mitigate heat transfer and enhance thermal comfort. This approach involves selecting materials with high thermal resistance for walls, roofs, and fenestration systems to minimize heat gain. Additionally, incorporating features like cool roofs, green roofs, and reflective surfaces can reduce surface temperatures and improve overall building performance. By targeting individual components and materials, component-oriented strategies contribute to energy efficiency and sustainability by reducing the building's overall cooling load.



Passive Cooling Strategies



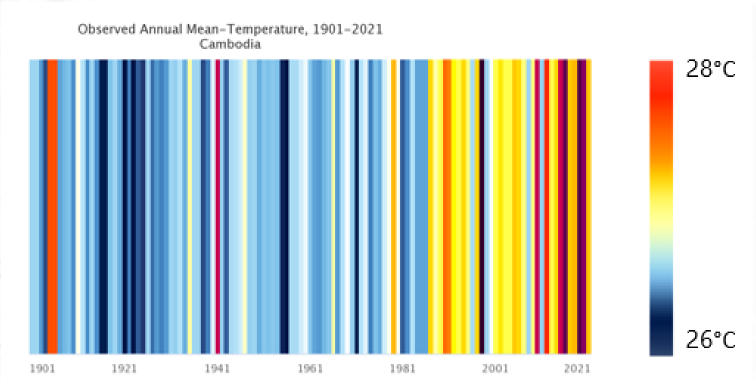




04 APPROACH

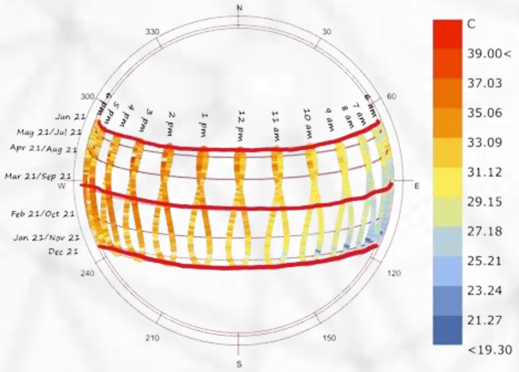
CLIMATE ANALYSIS

When selecting PCS, climate analysis plays a crucial role in determining the most effective approach. Firstly, understand the local climate, considering factors like temperature, humidity, and prevailing wind patterns. Next, identify passive cooling techniques suitable for the climate, such as natural ventilation, shading, thermal mass, and evaporative cooling. Assess the building's orientation and layout to maximize natural airflow and shade utilization. Implement strategies that leverage the local climate's natural cooling potential, reducing reliance on mechanical systems.



From the available EPW files of 7 provinces, the climate as identified as extremely hot and humid, as per ASHRAE standard of climate classification.

Climate Parameters	Phnom Penh	Kampot	Pursat	Siem Reap Angkor	Svay Rieng	Stung Treng	Kompong Cham
Direct radiation (Wh/m²)	430	396	437	420	436	425	451
Diffuse radiation (Wh/m²)	133	142	140	139	133	135	132
Dry bulb temperature (⁰C)	29	27	27	28	27	27	28
Dew point temperature (⁰C)	23	23	22	23	23	22	22
Relative Humidity (%)	71	81	76	74	77	78	75
Wind direction	South	South, West	South	South west	South, South west	South, East	South, South east
Wind speed (m/s)	3	3	2	2	2	2	2

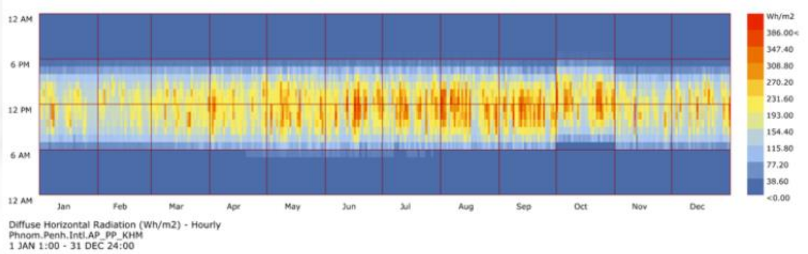


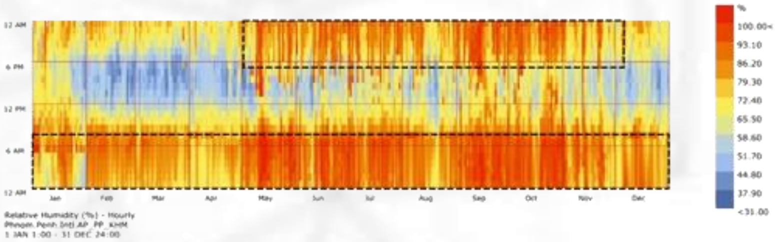
Sun Path Analysis

Cambodia experiences sun path variations throughout the year. During the Summer Solstice, the sun rises from NE and sets in NW. During the Winter Solstice, it rises from SE and sets in SW. Equinoxes balance these patterns. Solar intensity peaks from 11:00 am to 6:00 pm (Feb to Oct) and from 1:00 pm to 6:00 pm (Nov to Jan).

Radiation Analysis

Phnom Penh experiences moderate solar intensity, with direct radiation peaking at 921 Wh/m² and diffuse radiation at 386 Wh/m² from 6:00 am to 6:00 pm.



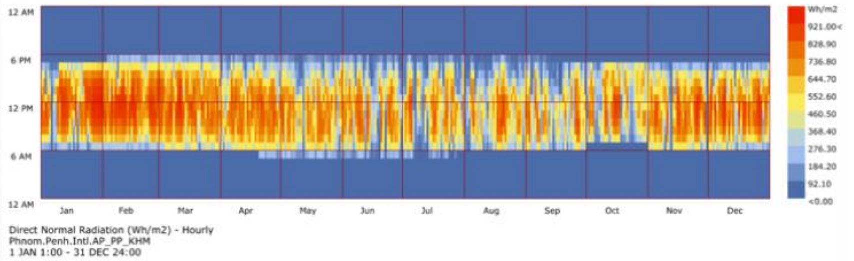


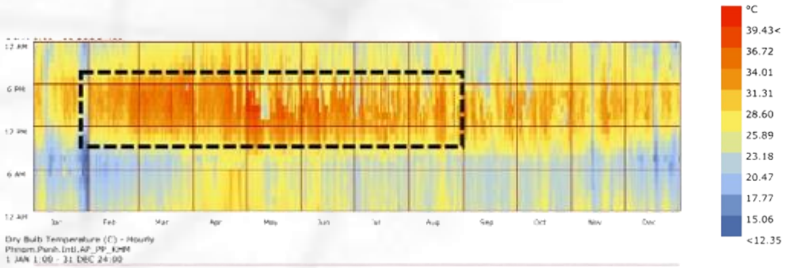
Dry Bulb Temperature (DBT)

Understanding DBT helps in the design of building components and in the sizing of HVAC system. Phnom Penh experiences high DBT exceeding 31°C from February to August (12:00 - 6:00 pm).

Relative Humidity (RH)

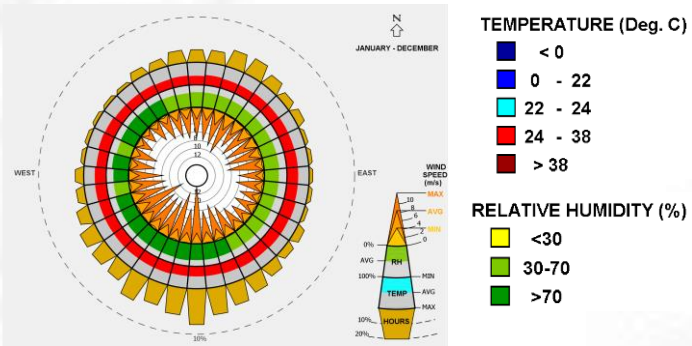
Higher RH affects thermal comfort by reducing perspiration. In Phnom Penh, the high RH levels are especially during May to October, affects outdoor and indoor comfort conditions.





Universal Thermal Comfort Index (UTCI)

The UTCI reveals felt temperatures (perceived temperature) above 31°C from April to July, September, and October, and from 12:00 pm to 12:00 am in other months.



Wind Rose

The wind frequency and speed is higher primarily in the southwest, south and southeast direction in the months of February to September, then in the north and northeast direction in the months of October to January. The humidity level is above 70% and the average temperature of the wind throughout the year is from 24°C to 38°C.

The strategy name

States what level of PCS – Site or Building or Component Level

STRATEGY

Title

Image to have a visual understanding about the Passive Cooling Strategy

This section helps you understand the structure of how this document is designed. Each section and its explanation are explained clearly.

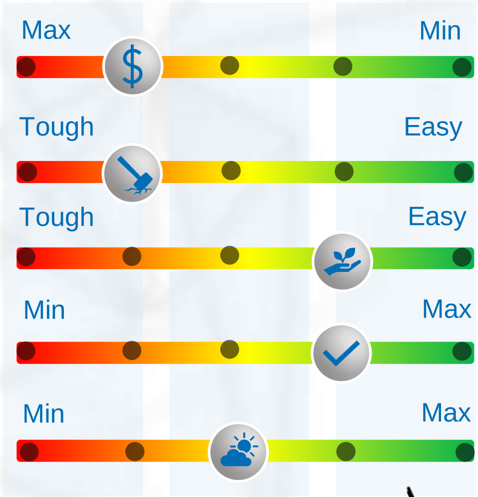
Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort



5-point scale. With red as first point, yellow as third point, and green as fifth point

BENEFITS

This section highlights six benefits of the strategy as a PCS, showcasing its effectiveness in saving energy, improving comfort, and supporting sustainability efforts.

APPLICATION

This section details the construction process or application methods for the primary passive cooling solution, providing practical guidance on implementation.

SPECIFICATIONS

This section provides specifications for the material or solution, offering brief on its composition, dimensions, and performance criteria.

RESOURCES

This section offers resources, and additional reading materials for further exploration.

This section offers resources, and additional reading materials for further exploration with respect to Cambodia.

IN CAMBODIA

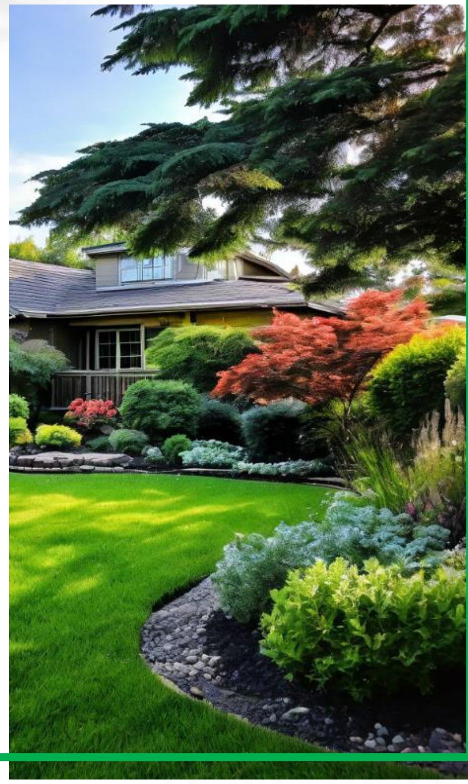
Design Guidelines: Cambodia

Approach

This section highlights general and crucial points to remember about the material or solution, serving as a handy reference for key considerations during implementation or decision-making processes.

Image depicting how to place the strategy

05 VEGETATION



Outdoor vegetation encompasses plants, trees, and greenery in outdoor areas like gardens and parks. It ranges from grass and shrubs to large trees, enhancing biodiversity and air quality while providing habitat for wildlife. Outdoor vegetation also mitigates urban heat island effects, promoting environmental health and well-being.

Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Air Quality: Outdoor vegetation purifies air by absorbing CO_2.

Heat Reduction: Trees provide shade and mitigate heat.

Mental Health: Reduce stress and improve mood.

Biodiversity: Supports diverse wildlife, for ecological balance.

Water Management: Absorb rainwater and reduce flooding.

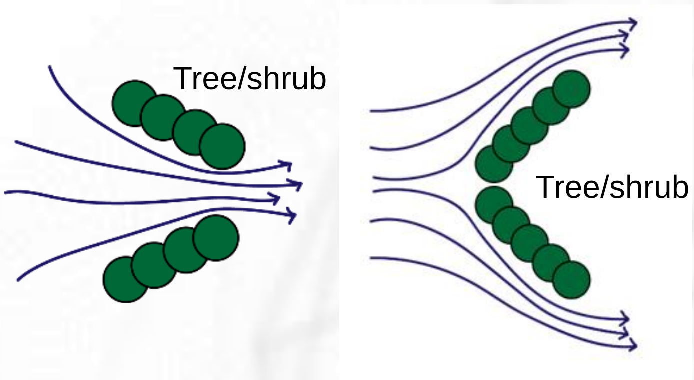
Aesthetics: Beautify outdoor spaces, foster community.

IN CAMBODIA

Design Guidelines:
[Cambodian Tree Species]

Approach

Strategic vegetation placement shades and ventilates, enhancing aesthetics and pollution control. Grass reduces glare, trees buffer noise and odors. Vegetation lowers temperatures and sun exposure. Architects use landscape design for efficient shading, reducing air conditioning needs.



06 TOPOGRAPHY

Topography utilizes natural land formations like hills and valleys to influence airflow and temperature regulation. It promotes natural ventilation and heat dissipation, optimizing shading and sun exposure for thermal comfort. This strategic site planning reduces reliance on mechanical cooling systems, enhancing energy efficiency in buildings.

Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Microclimates: Influences localized climate.

Visual Interest: Diverse elevations create dynamic landscapes

Natural Drainage: Guides water flow, prevents flooding.

Recreation: Slopes and hills offer hiking and skiing.

Erosion Control: Reduce soil erosion and promote stability.

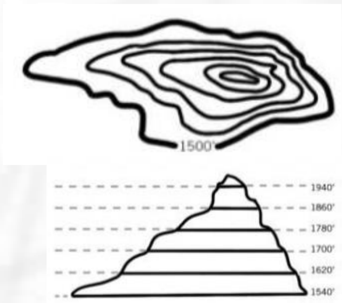
Natural Habitat: Supports diverse ecosystems.

IN CAMBODIA

Design Guidelines:
[Stocktaking & Analytical Options For Green Buildings In Cambodia]

Approach

Topography guides building design, influencing contours, slopes, and elevation changes to maximize site potential and inform foundation design. Building orientation optimizes views and natural light, while landscaping integrates built environments with nature, reducing energy consumption.



07 WATER

Water, as a passive cooling strategy, dissipates heat through evaporation. Features like fountains, ponds, or misting systems in outdoor spaces cool the air. Evaporative cooling lowers temperatures, enhances comfort, and reduces the need for mechanical cooling, promoting energy efficiency and sustainability.

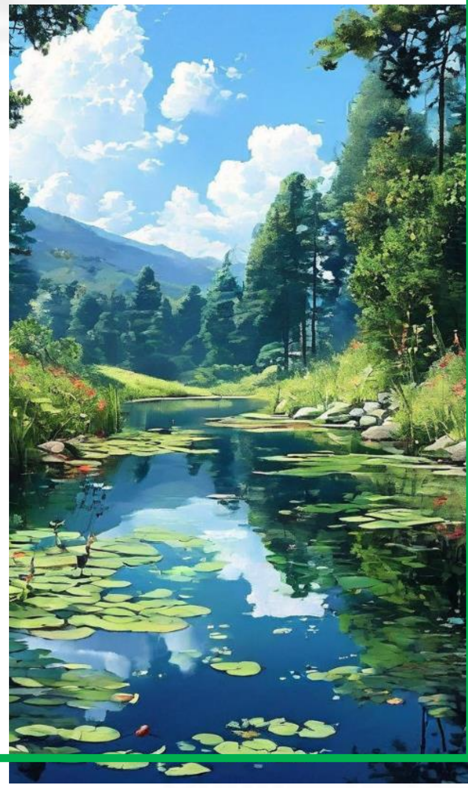
Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort



BENEFITS

Rainwater: Aid in sustainable water management.

Health: Foster a connection with nature, promoting well-being.

Noise Reduction: Flowing water masks unwanted noise.

Social Spaces: Foster community interaction.

Biodiversity: Water bodies attract wildlife, aiding biodiversity.

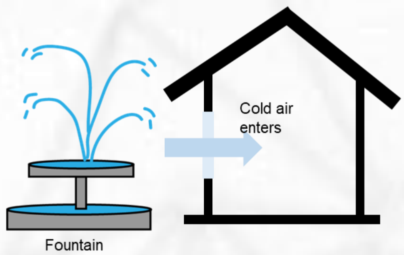
Passive Cooling: Reduce temperatures through evaporation.

IN CAMBODIA

Design Guidelines: Law On Clean Water Management

Approach

In Cambodia, large water bodies influence climate by absorbing and releasing heat, affecting temperature variation. They act as heat sinks, moderating temperatures and wind flow. In urban areas, they mitigate the UHI effect, lowering air temperature through evaporation. Designers can incorporate water features like fountains with recirculation systems for cooling, considering rainwater catchment for sustainability.



08 PAVEMENT

Cool pavement reduces heat absorption and urban heat island effects by reflecting sunlight and emitting less heat. Made of materials like light-colored concrete or special coatings, it lowers temperatures in urban areas, improves air quality, and enhances pedestrian comfort in hot weather.

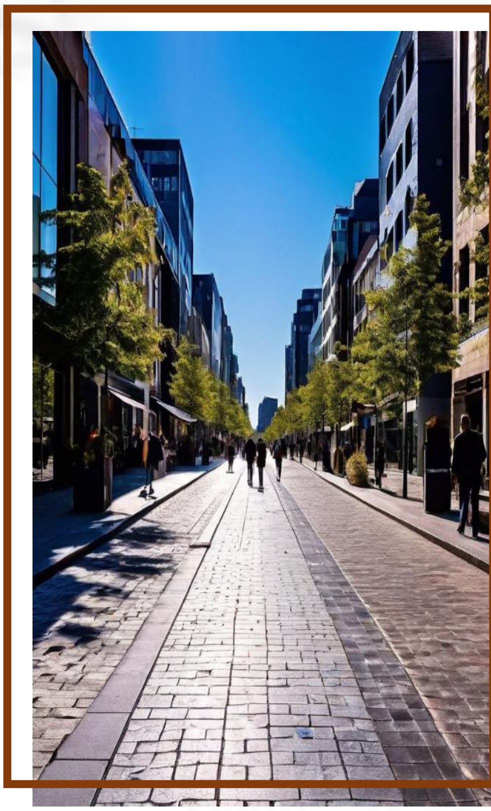
Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort



BENEFITS

Energy Savings: Decrease AC needs and reducing bills.

Health: Lower heat-related illness.

Air Quality: Mitigates ozone formation, promotes health.

Lifespan: Cool temperature, reduce maintenance costs.

Heat Reduction: Lower surface temperatures.

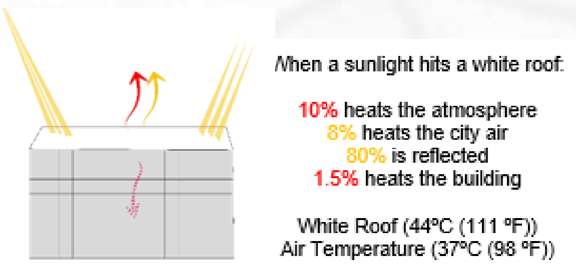
Climate: Mitigate heatwave impacts, enhancing climate.

IN CAMBODIA

Design Guidelines: [Compendium for PCS](#)

Approach

Pavements cover 60% of urban areas, absorbing 80% of sunlight and contributing to the urban heat island effect. Lighter-colored and reflective pavements, along with grass options, cool surfaces and improve water quality. Sustainable materials like warm-mix asphalt save costs and promote environmental conservation.



10 FORM & ORIENTATION

Form encompasses a building's shape, layout, proportions, and design elements, while orientation involves positioning it to optimize natural light, ventilation, and energy efficiency in relation to the sun and surroundings. Both factors are vital in architectural design, influencing a building's functionality, aesthetics, and sustainability.

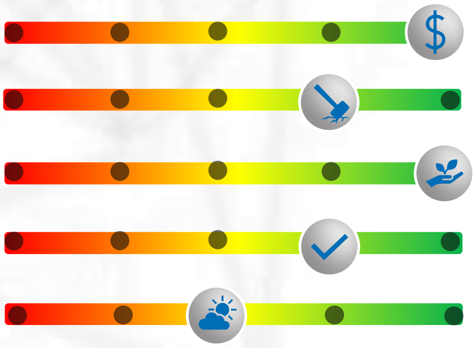
Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort



BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Health: Enhances lighting, and improved well-being.

Connectivity: Offers views and connect to outdoor.

Ventilation: Promotes airflow, enhancing IAQ.

Comfort: Minimizes direct sunlight, ensuring comfort.

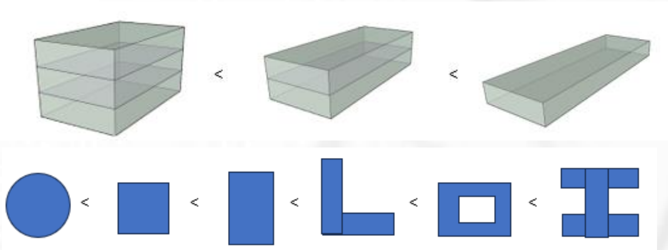
Sustainability: Support sustainable design, for health.

IN CAMBODIA

Design Guidelines: **Compendium for PCS**

Approach

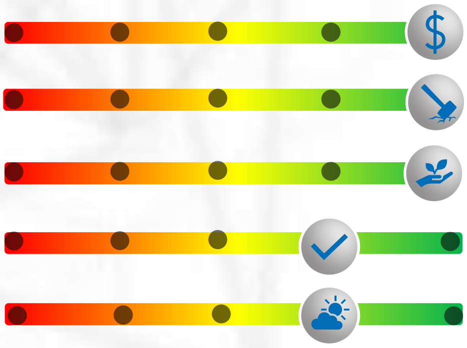
Optimizing building orientation in Cambodia minimizes heat gain by aligning longer facades north and south, reducing energy consumption. Compact shapes, such as cubes, minimize heating, cooling, and lighting needs, while smaller spaces are more energy-efficient in any climate.



Minimize surface to volume ratio in extreme climates. Increase compactness by reducing surface area for the same volume.

10 MASSING & ZONING

Massing encompasses a building's form, height, width, and depth, shaping its overall appearance. Zoning divides land into designated areas with regulations on land use, building height, and setbacks. Together, they influence urban planning and architecture, defining the spatial organization of built environments.



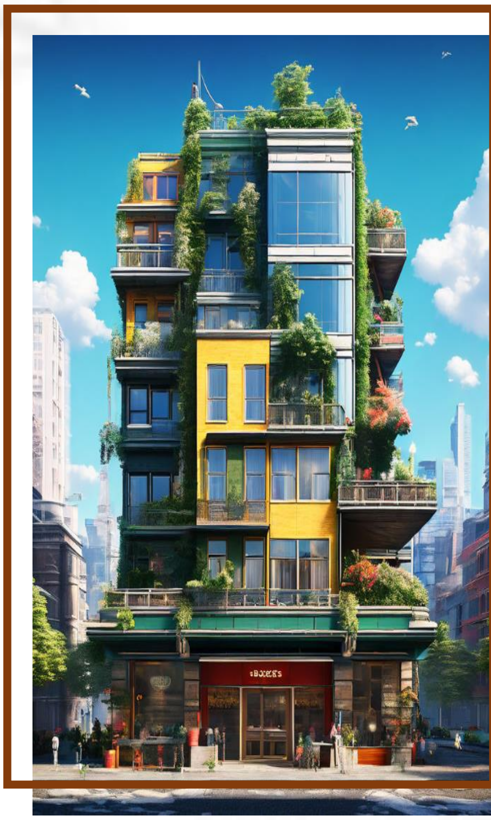
Cost

Installation

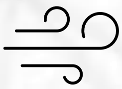
Solution Availability

Energy Saving

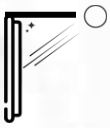
Thermal Comfort



BENEFITS



Natural Ventilation: Reduces reliance on mechanical systems.

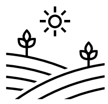


Shading: Thoughtful design minimizes solar heat gain.

Thermal Inertia: High thermal mass stabilize indoor temperatures.

Cross Ventilation: Strategic layouts promote airflow.

Microclimate: Optimizes comfort and reduces UHI.



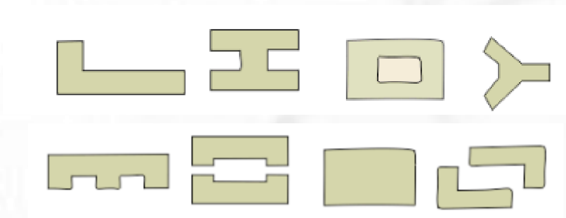
Passive Design: Minimizes summer cooling needs.

IN CAMBODIA

Design Guidelines:
Compendium for PCS

Approach

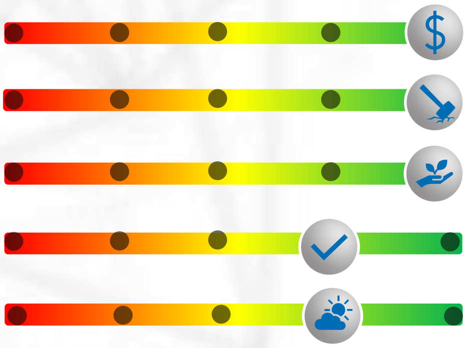
Massing and zoning optimize energy use. Sunlight maximized heating needs reduced. Buffers in heat-loss zones minimize heat transfer. Sunrooms store solar heat. Zoning prioritizes southern spaces. Thermal zoning improves airflow. In Cambodia, common areas face east, others face north and west.



Orient longer facades along the north. This will provide glare free light in summer from north without shading and winter sun penetration from the south.

11 SITE SHADING

Site shading strategically blocks or reduces direct sunlight on outdoor areas around buildings, creating shaded spaces for activities, reducing heat gain, and minimizing solar glare. Achieved through trees, pergolas, awnings, or other structures, it enhances outdoor comfort and usability while promoting energy efficiency.



Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Glare: Reduces direct sunlight glare, enhance visual comfort.

UV Protection: Shields interior furnishings from UV damage and fading.

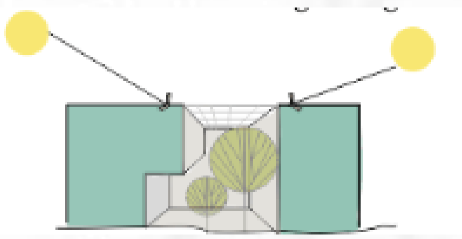
Daylight: Optimal daylight levels, reducing artificial lighting

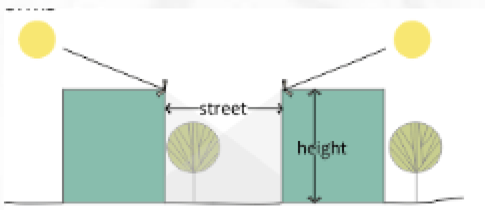
Occupant Comfort: Contribute to reduced indoor temperatures.

Outdoor Comfort: Creates shaded outdoor spaces.

IN CAMBODIA

Technology Provider:
Solar Feeds





Remember

Strategic building design reduces direct sunlight exposure, lowering cooling energy usage. Mutual shading impacts energy efficiency and comfort in urban environments, optimizing building design for improved performance and thermal comfort.

12 COOL WALL/ROOF

A cool wall/roof is designed to reflect sunlight and emit heat, reducing heat absorption and lowering indoor temperatures. These are coated with reflective materials or with light colors to enhance their cooling properties. It helps to mitigate urban heat island effects (UHI), improve building energy efficiency, and enhance occupant comfort by minimizing heat gain.

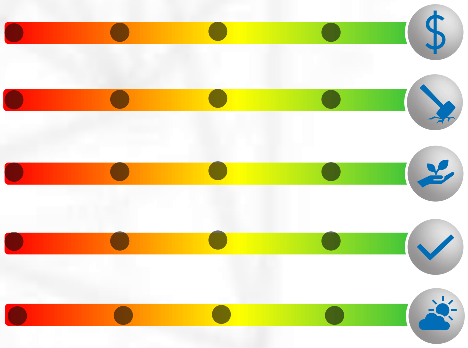
Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort



BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

UHI Mitigation: Lower surface temperatures in urban areas.

Low cost: Low application and maintenance costs.

Carbon Sequestration: Low GHG emission through less energy use.

Occupant Comfort: Contribute to reduced indoor temperatures.

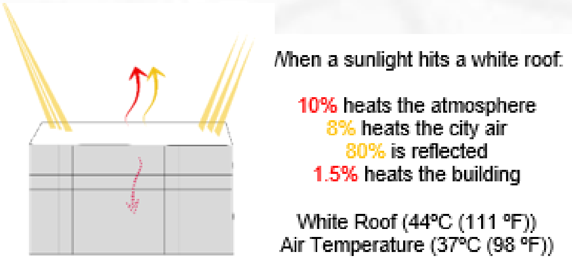
High Lifespan: Protect from environment stressors.

IN CAMBODIA

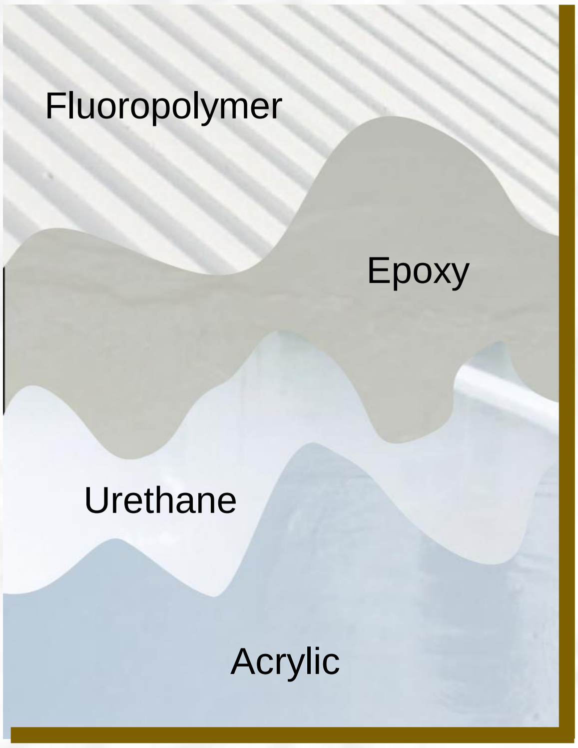
Design Guidelines: ***Cool Roof***

Remember

Cool walls/roofs reflect more sunlight and absorb less solar radiation, reducing building temperature and lessening the need for air conditioning. They mitigate urban heat island effects, smog, and peak electricity consumption while cutting emissions and contributing to global warming mitigation.



APPLICATION WALL

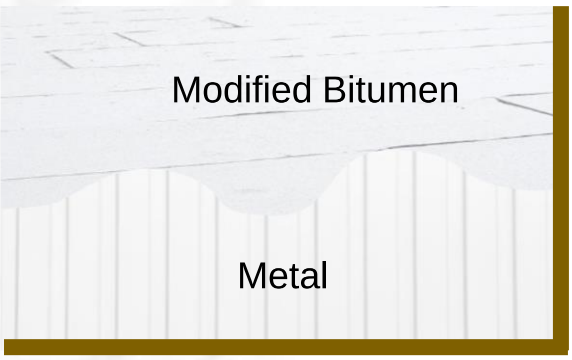


- **Acrylic Coatings:** Water-based, low-VOC options with good adhesion and durability, commonly used for moisture and stain protection in residential and commercial settings.
- **Epoxy Coatings:** Two-component chemical coatings providing excellent defense against physical and chemical abrasion, ideal for commercial use due to their resilience.
- **Urethane Coatings:** Solvent-based coatings with high resistance to chemical and abrasive wear, suitable for outdoor applications with UV protection.
- **Fluoropolymer Coatings:** Solvent-based options offering UV protection and corrosion resistance, ideal for outdoor wall applications with superior adhesion and durability.

APPLICATION ROOF

Flat Roof

- **Roof Coating:** Thoroughly cleanse the roof, mix and apply paint evenly, let the first coat to dry for 3-4 hours and the entire surface to dry for 48 hours.
- **Slate / Tile:** Prepare mortar mix (1:4) and spread onto roof, apply cement slurry, place wet tiles then clean with wet sponge, allow 48-hour drying, fill tile gaps.



Pitched Roof

- **Metal Roofing:** Clean roof surface, attach metal sheet with mechanical fasteners for durability, and apply white paint.
- **Modified Bitumen:** Clean the roof surface, align and secure the modified bitumen sheet using torch-down technique, and finish by applying a white coating.

SPECIFICATIONS

In addition to decreasing the outside air temperature, cool walls/roofs also impact pedestrians' thermal environment by:

a) raising the amount of solar radiation that strikes nearby pedestrians;

b) reducing the amount of longwave (thermal infrared) radiation incident on the pedestrian; and

c) decreasing the amount of solar radiation that strikes the pedestrian.

Human comfort models can be used to quantify the extent of these frequently conflicting effects on walkers; nonetheless, research suggests that the change in pedestrian thermal comfort caused by increasing wall solar reflectance is little (Pablo J. Rosado, 2024).

Albedo Values With Conventional Pigmentation

0.05	0.01	0.02
0.04	0.06	0.08

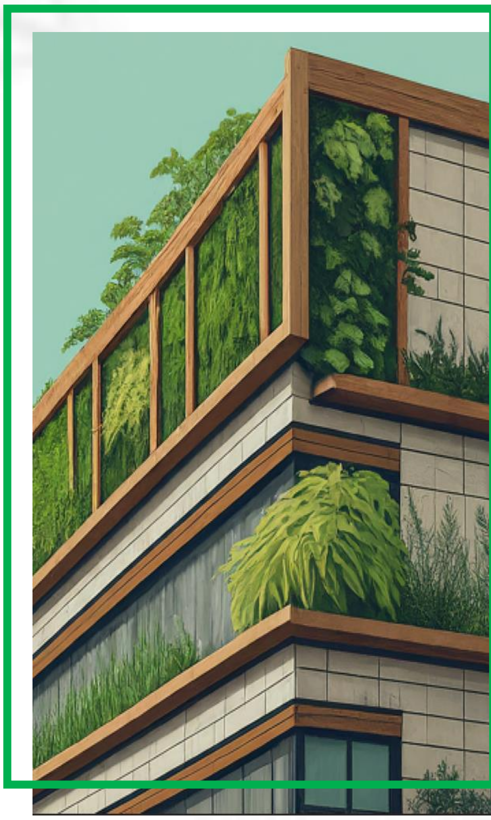
Ref.:https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-040-APP.pdf

RESOURCES

- ***Installation- wall***
- ***Installation – roof***
  - https://www.youtube.com/watch?v=K0z017YwBTU
  - https://www.youtube.com/watch?v=o4JfXmx-lc0
  - https://www.youtube.com/watch?v=-qLZYAv9CSo
  - https://www.youtube.com/watch?v=ZZGwMeHZthg
  - https://www.youtube.com/watch?v=Q3ASM7jxD6I
  - https://www.youtube.com/watch?v=2kZWMfpwmz8
- ***Maintenance-roof***

13 GREEN WALL/ROOF

Also known as a living wall/roof, is where vegetation is cultivated on vertical or horizontal surfaces of buildings. These installations provide insulation, improved air quality, stormwater management, and habitat creation. Green walls and roofs can mitigate UHI, by promoting biodiversity and reducing energy consumption.



Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

UHI Mitigation: Lower surface temperatures in urban areas.

Air Quality Improvement: Plants absorb pollutants.

Carbon Sequestration: Low GHG emission through less energy use.

Stormwater: Reduce runoff, easing strain on drainage systems.

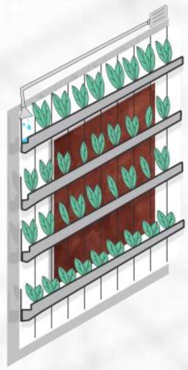
High Lifespan: Protect from environment stressors.

IN CAMBODIA

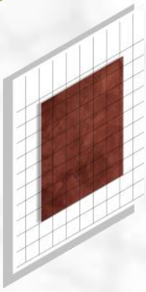
Design Guidelines: [Green Infrastructure Guide – Section 10]

Remember

Green roofs are a versatile and sustainable solution, offering a myriad of advantages while contributing to a greener and healthier urban environment. They offer a holistic solution for energy efficiency, environmental benefits, and sustainable urban development. Their diverse applications make them a valuable component in creating resilient and eco-friendly built environments.

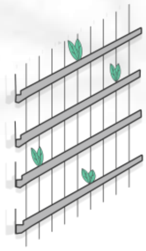


APPLICATION WALL

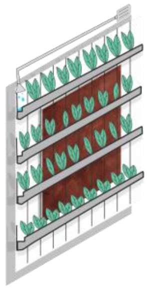


Frame: Use sturdy materials like metal, PVC, or wood for structural support.

Lining: Use waterproof liners such as weed cloth to prevent moisture damage.



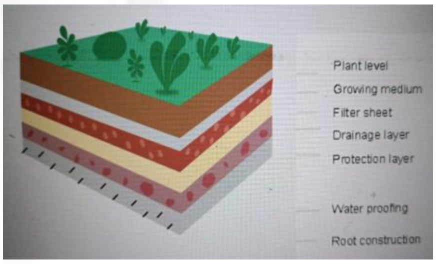
Planting Pockets: Create fabric, or prefabricated planters with drainage.



Irrigation: Drip systems for efficient watering.

APPLICATION ROOF

Structural Support: Important for bearing additional weight.



Layers: Waterproof membrane, root barrier, drainage, growing media, and plants.

RESOURCES

Design Guidelines: The Green Roof Code

Layers of a green roof

Green roof installation

SPECIFICATIONS

Moisture Level	U-Value (W/m².˚C) without Water Retention	U-Value (W/m².˚C) with Water Retention
0%	0.42	0.38
20%	0.46	0.41
80%	0.53	0.48

Type of Green Roof System	Limit	Thickness (in m)
Extensive	Max	0.1
Semi-Intensive	Max	0.12
Intensive	Max	>0.15

For types of Green Roof, refer: Guideline for PCS

14 INSULATED WALL

An insulated wall is a structural barrier designed with materials to minimize heat transfer between the building's interior and exterior. It typically incorporates layers of insulation material, within the wall assembly. Insulated walls help regulate indoor temperatures, by reducing heat loss or gain.

Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Durability: Barrier against moisture and pests.

Moisture: Prevents damage of structure.

Versatility: Reduced cooling cost through minimized heat transfer.

Insulation: Enhanced insulation due to air gap or insulation.

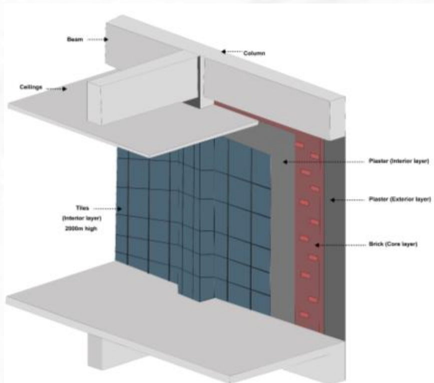
Noise Reduction: Reduce external noise from external sources.

IN CAMBODIA

Design Guidelines: Building Envelope

Remember

Walls regulate indoor temperature, reduce energy consumption, and minimize carbon emissions by controlling heat transfer, decreasing reliance on cooling systems. They provide defense against temperature fluctuations and moisture, enhancing durability. Hollow cores within blocks enhance insulation and reduce weight. Insulated walls optimize thermal regulation, energy efficiency, and resilience, ensuring occupant comfort and stable indoor environments.



WALL APPLICATION

Cavity Wall: It has a gap between two layers of masonry. Initially, an outer leaf is constructed, and then cavity wall ties are inserted. Following this, an inner leaf is built, creating a space in between. The wall is ultimately completed by applying a plaster finish.

Hollow Brick Wall: Bricks are initially laid level with appropriate mortar in the first course, and in the subsequent courses, staggered joints are introduced for increased stability. Upon reaching the desired height, mortar is used to fill gaps, reinforcing the overall structure.

INSULATION APPLICATION

PUF Board: Surface preparation comprises cleaning and priming. Adhesives are applied for attaching the board, ensuring uniform contact. The board is securely fastened with appropriate fasteners, and any gaps are sealed. It is crucial to verify complete coverage across the entire surface.

Cellulose Foam: For the installation of exterior walls, drill small holes between bricks from the outside and inject the wall with cementitious foam insulation. Power wash the house, and subsequently, fill the drilled holes with matching mortar to conclude the installation process.

RESOURCES

- Installation
- Maintenance

WALL SPECIFICATIONS

Parameter	Cavity Wall	Concrete Hollow Wall	Hollow Brick Wall	Terracotta Wall
Specific Heat (kJ/kg.°C)	Variable based on thickness of cavity between wall blocks	0.88 (concrete)	0.84 (clay brick)	0.84 (clay)
Thermal Conductivity (W/m.°C)	0.3 to 0.7 (depends on cavity size & materials)	0.7 to 1.2	0.7 to 1.2	0.9 to 1.3
Density (kg/m³)	1500 to 2200 (depends on materials)	1200 to 1800	1200 to 1800	1800 to 2200
Water Absorption (%)	5 to 15 (depends on materials)	5 to 15	5 to 15	10 to 20
Temperature Range (°C)	-40 to 150 (depends on materials)	-40 to 150	-40 to 150	-40 to 1300
R-Value (per 25 mm)	0.8 to 2.0	0.5 to 1.0	0.5 to 1.0	0.7 to 1.0

INSULATION SPECIFICATIONS

Parameter	Cellulose Foam	PUF Board	Mineral Wool Board	Phenolic Foam Board	Polystyrene Board
Specific Heat (kJ/kg.°C)	1.6	1.4	0.8	1.1	1.4
Thermal Conductivity (W/m.°C)	0.038 to 0.040	Less than 0.02	0.032 to 0.044	0.017	0.025 to 0.032
Density (kg/m³)	27 to 65	40 ± 5%	100 ±10%	35	1050
Water Absorption (%)	10% to 20%	1% to 3%	1% to 5%	1%	0.1% to 4%
Temperature Range (°C)	-50 to 350	-200 to 145	-50 to 750	-150 to 120	-50 to 85
R-Value (per 25 mm)	3.2 - 4	6.5	3 – 3.3	6.7 – 7.5	EPS 4, XPS 5

15 INSULATED ROOFS

Insulated roofs are designed with materials that minimize heat transfer between the building's interior and the external environment. It typically includes layers of insulation material, installed beneath the outer roofing layer. Insulated roofs help regulate indoor temperatures, reduce energy consumption for heating and cooling, and improve overall thermal comfort.

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Cost Savings: From reduced cooling demand.

Air Quality: Reduce pollutants from cracks.

Carbon Sequestration: Low GHG emission through less energy use.

Comfort: Reduces temperature fluctuations.

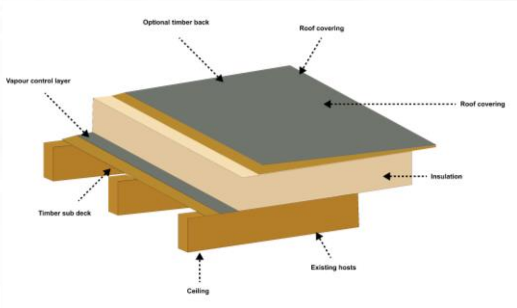
Noise Reduction: Reduce external noise from external sources.

IN CAMBODIA

Design Guidelines: [SPRA Guide]

Remember

Insulated roofs regulate indoor temperature, reduce energy consumption, and minimize carbon emissions. They diminish reliance on heating and cooling systems and offer protection against temperature fluctuations and moisture intrusion. Integrating insulated roofs into building designs fosters occupant comfort and well-being while mitigating environmental impact.



APPLICATION

PUF Spray: On-site combination of components A and B, waterproof closed-cell SPF applied. Drainage adjusted, then two layers of acrylic "elastomeric" coating, and reflective Cool Roof coating added for protection.

Insulated Boards: Ensure a dry, clean roof, then tightly install insulation between roof joists. Add a vapor barrier to prevent moisture penetration, and finish with a waterproof membrane or roofing tiles.

SPECIFICATIONS

Parameter	Glass Wool	PUF Board	PUF Spray	Rockwool	XPS
Specific Heat (kJ/kg.°C)	0. 8	1.4 to 1.5	1.4	1.0	1.7
Thermal conductivity (W/m.°C)	0.03	Less than 0.02	0.026 to 0.042	0.039	0.026 to 0.035
Density (kg/m³)	20	40 ± 5%	6 to 55	40 to 150	35 to 45
Water Absorption (%)	1% to 3%	1% to 3%	Less than 2%	1% to 3%	0.1% to 4%
Temperature Range (°C)	-50 to 230	-200 to 145	-180 to 120	-50 to 650	-50 to 75
R-Value (per 25 mm)	2.7	6.5	6.0	2.8	5

RESOURCES

- Installation
- Maintenance

16 SHADING

Shading is the process of blocking or reducing direct sunlight from reaching a building's interior or outdoor spaces. It can be achieved through natural elements, architectural features, or mechanical devices. Effective shading helps control heat gain, reduces glare, and enhances thermal comfort, contributing to energy efficiency and occupant well-being in buildings.

Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Glare Reduction: Improves visual comfort and productivity.

Temperature Regulation: Reduce solar heat gain.

UV Protection: Protection from UV rays, for health benefits.

Comfort: Reduces temperature fluctuations.

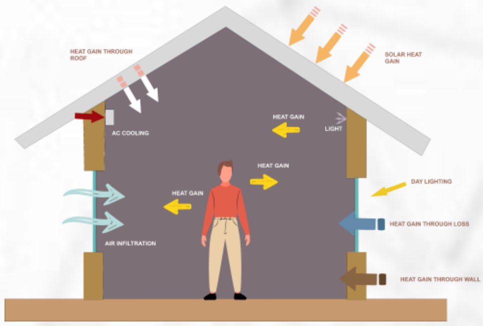
Landscape: Prevents overexposure to sunlight.

IN CAMBODIA

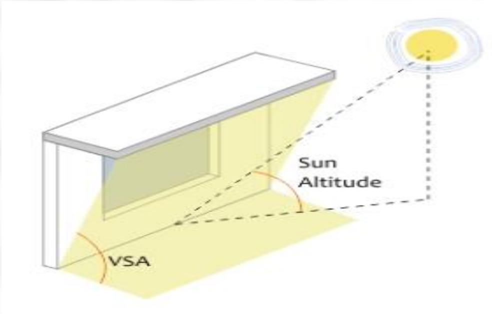
Design Guidelines:
Compendium for PCS

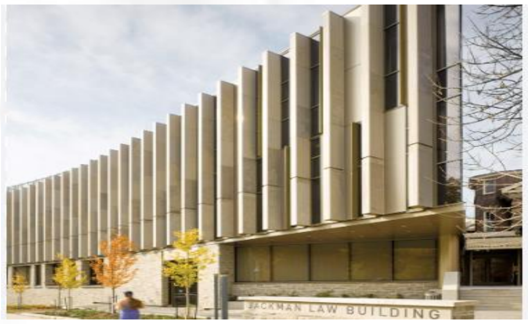
Remember

Shading systems in architectural design enhance comfort, energy efficiency, and sustainability. External devices like overhangs mitigate solar heat gain, reducing artificial cooling needs. Internally, solutions such as blinds control natural light and privacy. Integrating both internal and external shading creates spaces prioritizing occupant comfort.



APPLICATION - EXTERNAL STATIC SHADING





Horizontal Panel: The process encompasses measurement and layout planning, material selection and fabrication, securely installing support structures onto the building, and mounting panels onto the supports using suitable fasteners or adhesive methods.

Vertical Fins: The process entails precise measurement and layout planning, material selection, fabrication, installation of support structures, and securely mounting the fins onto the building.

APPLICATION - EXTERNAL MOVEABLE SHADING

Overhang Awning: The process includes measurement and layout planning, material selection and fabrication, installation of support structures, and secure mounting of the awning. Regular maintenance is essential to ensure longevity and sustained performance.

Rotating Horizontal Louvres: The process entails precise measurement and layout, material selection considering durability and weather resistance, installation of support structures with adequate load-bearing capacity and alignment, and securely mounting the louvres for smooth rotation.

INTERNAL SHADING APPLICATION

Curtain: The installation of curtains involves precise measurement and layout planning, the selection of suitable materials, and securely installing curtain rods or tracks onto walls or ceilings. Hang the curtains using appropriate hardware to ensure smooth operation and optimal coverage.

Light Shelf: Securely install support brackets onto the building facade, ensuring proper alignment and sufficient load-bearing capacity. Mount the light shelf onto the supports using fasteners. Ensure the stability and functionality of the installation.

DESIGN CONSIDERATIONS

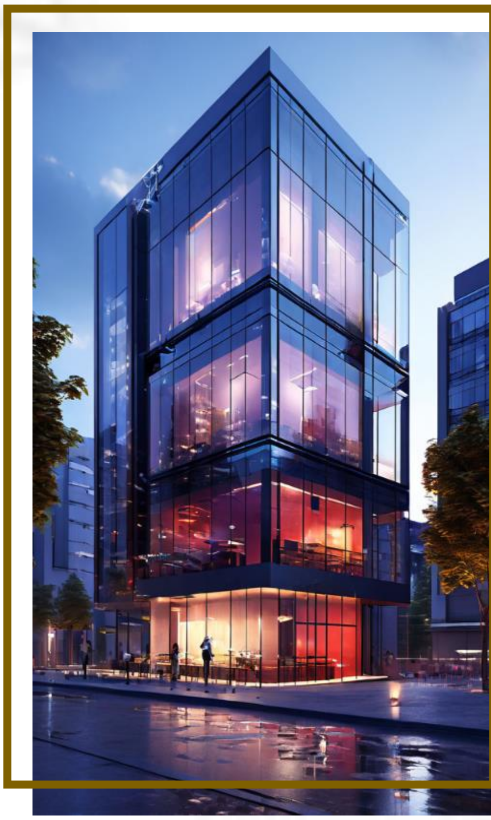
- The selection of materials is critical for ensuring durability and minimizing maintenance requirements for external shading devices.
- Choices in operational control have a direct impact on efficiency, with automated systems often proving more effective.
- Horizontal panel systems have the potential to reduce summertime thermal energy by up to 38.7%.
- Eggcrate shading systems can significantly decrease solar heat gain, achieving reductions of up to 80%.
- Effective shading strategies focus on preventing direct solar radiation from entering the building.
- Shading materials with high solar reflectance and low thermal emissivity are recommended for optimal performance.
- The incorporation of shading devices with thermal insulation properties contributes to improved energy efficiency and thermal comfort.

RESOURCES

- Installation
- Maintenance

17 FENESTRATION

Fenestration refers to the design and arrangement of windows, doors, and openings in a building. As a passive cooling strategy, optimized fenestration allows for natural ventilation and daylighting, reducing the need for artificial cooling and lighting, thus enhancing energy efficiency and indoor comfort.



Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Ventilation: Promote airflow, improve air quality and comfort.

Visual Connection: Connects with the surroundings.

Daylighting: Reduce energy costs.

Aesthetics: Enhance their visual appeal and overall design.

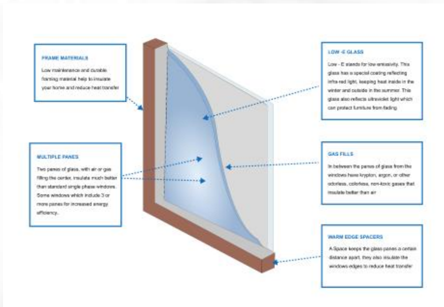
Natural Light: Reduce the need for artificial lighting.

IN CAMBODIA

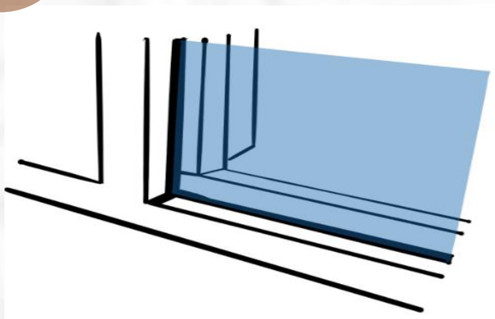
Design Guidelines: [Compendium for PCS]

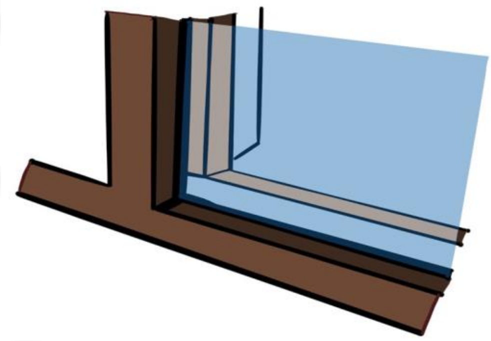
Remember

Fenestration enhances comfort, energy efficiency, and sustainability by regulating solar heat gain. External components like windows reduce reliance on artificial cooling, while internal solutions such as blinds control natural light and privacy. Integrating both internal and external fenestration elements in building design creates spaces prioritizing occupant comfort and energy efficiency, fostering sustainability.



APPLICATION





Glazing: The process involves the precise fitting of glass panels within frames. It commences with measurement and preparation, followed by the application of sealants for weatherproofing. Subsequently, panels are positioned and secured with fasteners or adhesives, ensuring proper alignment.

Frames: The installations are completed to ensure proper alignment and stability. Frames are carefully chosen considering durability and design requirements. It is crucial to conduct regular maintenance to extend their lifespan and guarantee structural integrity.

DESIGN CONSIDERATIONS

- Incorporate drainage features like glazing pocket weep holes.
- Slope sill flashings outward to facilitate water drainage.
- Utilise wet glazing seals to enhance water resistance.
- Adhere to safety standards for hazardous areas.
- Protect laminated glass edges from water exposure.
- Ensure the framing system provides strong structural support.
- Utilise anti-walk pads at window jambs.
- Design window frames with substantial return legs.

RESOURCES

- Installation
- Maintenance

18 VENTILATION

Ventilation, as a passive cooling strategy, utilizes natural airflow to remove heat and moisture from indoor spaces, enhancing thermal comfort without mechanical systems. It relies on design features like vents and openings to optimize airflow, reducing energy consumption and promoting sustainability.

Cost

Installation

Solution Availability

Energy Saving

Thermal Comfort

BENEFITS

Energy Efficiency: Reduce heat transfer, for energy savings.

Comfort: Regulates indoor temperature and humidity.

Mold Prevention: Prevents moisture buildup, reducing mold growth.

Allergens: Improve respiratory health for allergy sufferers.

Productivity: Improved cognitive function among occupants.

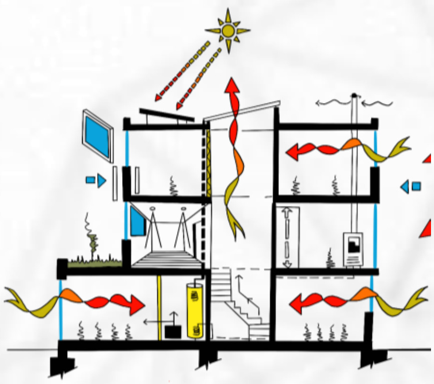
Air Quality: Remove pollutants, and excess moisture from indoor.

IN CAMBODIA

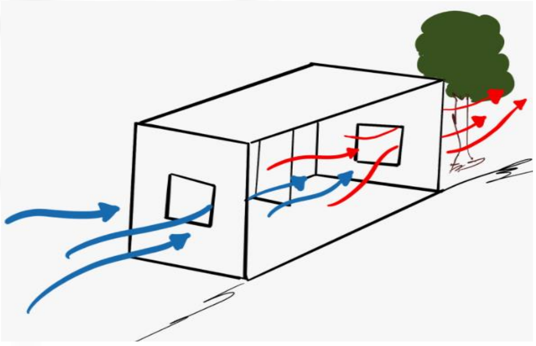
Design Guidelines:
Compendium for PCS

Remember

Enhances comfort, energy efficiency, and environmental sustainability. Regulates indoor air quality by eliminating pollutants and excess moisture. Natural ventilation, such as windows and vents, facilitates fresh air circulation, reducing reliance on mechanical cooling. Mechanical ventilation systems, including HVAC units, maintain consistent airflow for improved comfort and health. Integrating both natural and mechanical ventilation fosters spaces that prioritize occupant well-being.



APPLICATION



Stack Ventilation: Incorporates the placement of vertical shafts to draw warm air upwards, generating a natural airflow that expels stale air and introduces fresh air into the building. These shafts are strategically positioned to leverage temperature differentials and prevailing wind directions.

Cross Ventilation: Incorporates the strategic placement of windows on opposite sides of a building to establish a pathway for airflow, capitalizing on prevailing wind directions. The resultant natural flow of air through the building enhances ventilation, leading to improved indoor air quality and thermal comfort.

DESIGN CONSIDERATIONS

- Assess and determine the optimal size and placement of windows to facilitate airflow.
- Calculate the necessary openings to achieve effective air exchange.
- Take into account prevailing wind directions for intake and exhaust purposes.
- Design the building layout to promote cross ventilation.
- Install adjustable vents or louvers to control airflow as needed.
- Utilize thermal mass to regulate indoor temperatures.
- Ensure windows are operable and easily accessible for occupants.
- Implement insect screens and safety measures for open windows.

RESOURCES

- Installation
- Maintenance

19 DECISION MATRIX

POTENTIAL ENERGY SAVINGS FROM PCS IN RESIDENTIAL BUILDING TYPOLOGY

Option	Building Envelope	Composition	U-Value (W/m². ˚C)	SHGC	Cooling Energy Savings (%)
Baseline	Wall	(Outer) Cement plaster + 230 mm hollow red brick + Cement plaster (Inner)	1.07	NA	Energy savings for intermediate and high-performance values are based on the base case.
	Roof	(Outer) 50 mm plain cement concrete (PCC) + 100 mm RCC slab + 10 mm plaster (Inner)	2.46	NA	
	Fenestration	Single clear glass and aluminum frame	7.1	0.8	
Intermediate	Wall	(Outer) 15 mm cement plaster + 200 mm AAC block + 15 mm cement plaster (Inner)	0.77	NA	12 to 21%
	Roof	(Outer) 20 mm concrete laid + 50 mm concrete screed + 25 mm PUF over deck insulation + 150 mm RCC slab + 15 mm cement plaster (Inner)	0.74	NA	
	Fenestration	Double clear glass with 6 mm air gap and aluminum frame with thermal break	5.1	0.7	
High performance	Wall	(Outer) 5 mm reflective paint + 15 mm cement plaster + 100 mm AAC block + 50 mm PUF insulation + 100 mm AAC block + 15 mm cement plaster (Inner)	0.33	NA	22 to 31%
	Roof	(Outer) 5 mm reflective tile + 20 mm concrete laid + 50 mm concrete screed + 100 mm PUF over deck insulation + 150 mm RCC slab + 15 mm cement plaster (Inner)	0.23	NA	
	Fenestration	Double clear glass with 13 mm argon fill and low e coat and UPVC frame	3.1	0.25	
Best	Envelope	-	Better specifications than high performance		32 to 60%

RESOURCES

To know for other typologies, refer to,

- Typology Analysis Report

20 TOOLS

WHOLE BUILDING

- BETTER
- Building Controls Virtual Test Bed
- Building Energy Data Exchange Specification
- Building Performance Database
- Commercial Building Analysis Tool For Energy Efficient Retrofits
- Commercial Building Energy Saver
- EnergyPlus
- GenOpt
- HomeEnergySaver
- Labs21
- Modelica “Buildings” Library
- Standard Energy Efficiency Data Platform
- RM&V 2.0
- 50001 Ready Navigator
- EnPI Lite

OCCUPANT BEHAVIOUR

- Occupancy Simulator
- obXML
- obFMU

LIGHTING

- Radiance

WINDOWS & ENVELOPE

- COMFEN
- Optics
- RESFEN
- THERM
- Berkeley Lab WINDOW

COOL SURFACES

- Beyond White – Advances in cool colors (2008)
- Cool Roof Fact Sheet (2010)
- Cool Roof Q&A (2009)
- Cooling Our Communities
- Reducing Urban Heat Islands
- Cool Roofs and Pavement Toolkit
- Guidelines For Selecting Cool Roofs
- Roof Savings Calculator
- SRI Calculator

CITY AND DISTRICTS

- City Building Energy Saver