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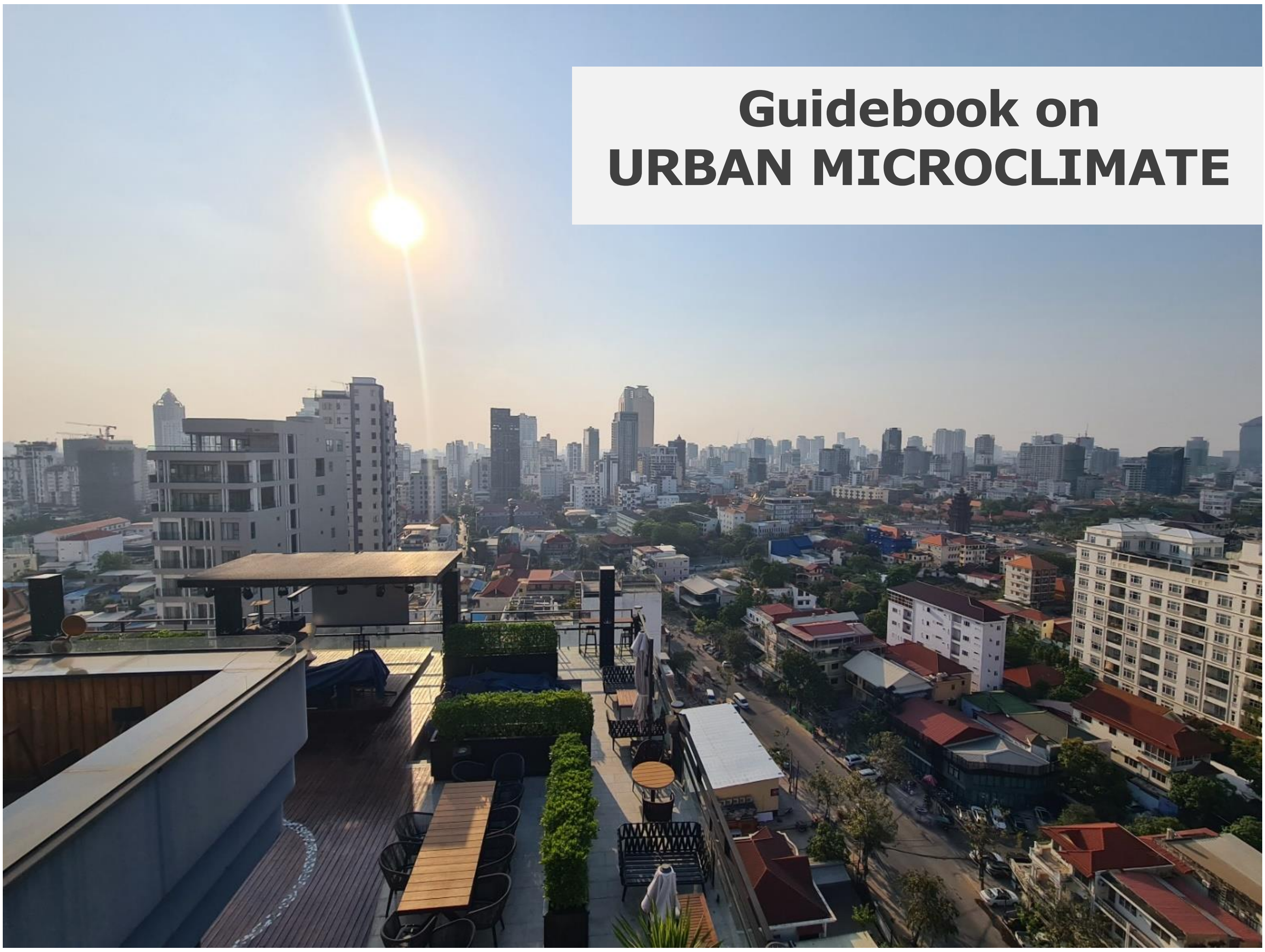
Guidebook on URBAN MICROCLIMATE



Scientific background and recommendations for

Urban Microclimate Design

in Phnom Penh, Cambodia

Guidebook on URBAN MICROCLIMATE

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Content

Message

Climate change is a critical global issue and extreme weather events are expected to increase. To mitigate the impact on Phnom Penh brought about by climate change such as extreme hot weather, adoption of urban and building designs with consideration of urban climate will be essential to improve the livability of the local built environment.

The Guidebook on Urban Microclimate puts forward guidelines and strategies to further help industry practitioners implement measures beneficial to both their own projects and the wider public. It provides a good summary of feasible approaches to good urban microclimatic designs.

This Guidebook is a valuable contribution to the environmental awareness and efforts in both the public and private sectors. The urban climate map (see Figure 1) is a mesoscale approach to understand Phnom Penh's climate interactions. Understanding climate on a microscale and adapt adequately will improve living conditions on the neighborhood level.

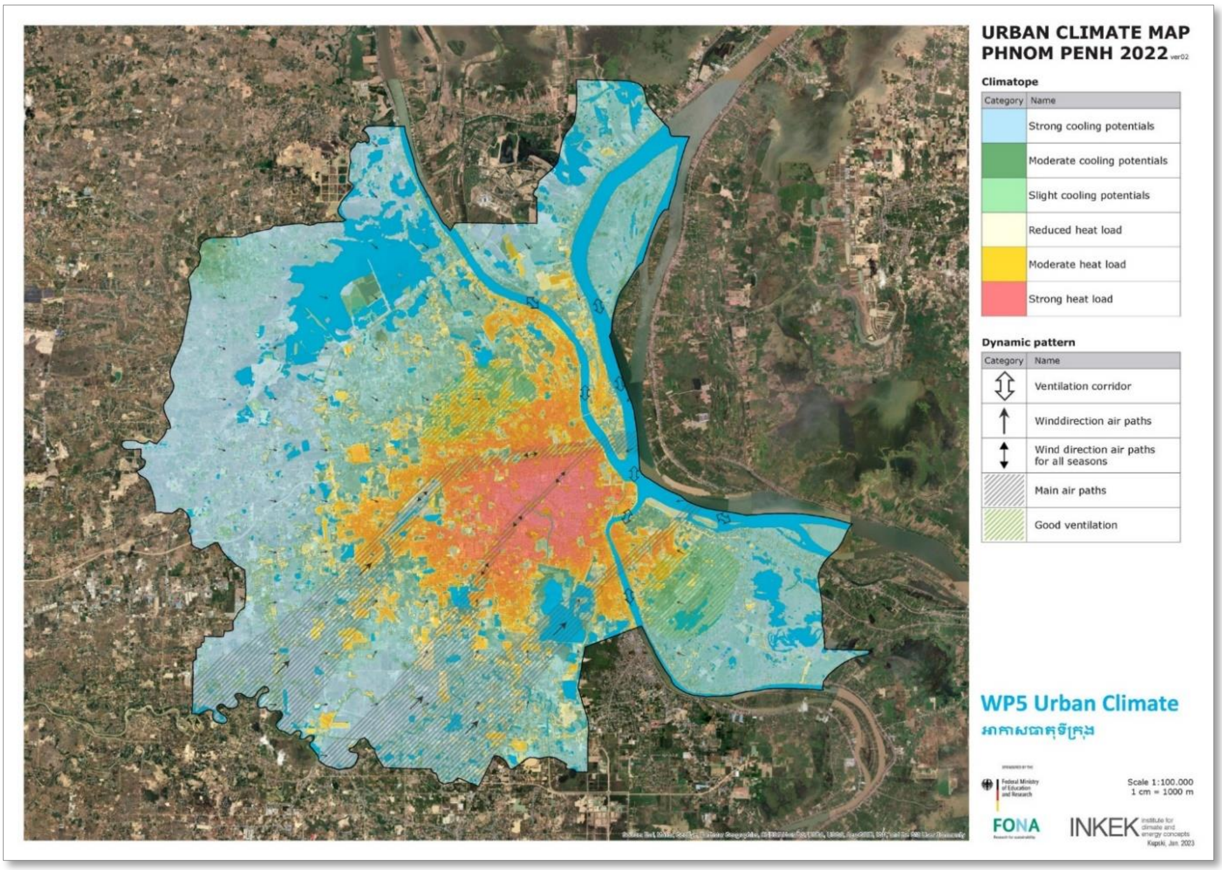


Figure 1: Urban Climate Map of Phnom Penh 2022 [4].

1 Introduction

In Phnom Penh's high-density and tropical environment, comfort is an important factor in people's use of the outdoor space. The intense Urban Heat Island (UHI) effect in Phnom Penh means high temperature in built-up areas and uncomfortable urban living. It leads to heat stress and other related health problems. The issues of health and comfort in the outdoor space become even more complicated in face of the challenges brought about by climate change.

The building industry plays an important role in the improvement of the urban microclimate, for example, by using lighter colors in façades, providing shading, and incorporating greenery. The improved and more pleasant outdoor environment will in turn attract more visitors, reduce energy use in buildings and enhance the enjoyment of natural ventilation indoors.

One basic tool to understand microclimatic conditions is the urban climate map of Phnom Penh developed within the research project Build4People in 2022 (see Figure 1).

It is the goal of this Guidebook to give the industry's professionals and practitioners the inspiration and knowledge to consider projects' impacts on the urban microclimate. The ideas introduced in the Guidebook will facilitate their communication with specialists.

In the Guidebook, the science and principles of urban microclimate studies will be introduced. Strategies to optimise the microclimate conditions will be stipulated and reflected on with both, local and overseas case studies, and good practices. Recommendations for further studies and policy adjustments will also be made.

In the Guidebook, we take urban microclimate design as a set of practices aiming to optimise the climate variables of a small-scale area within the urban canopy layer to achieve better human physical wellbeing and comfort. The technical terms involved in this definition will be duly explained in the next section.

The rest of the Guidebook takes readers through guidelines and examples that are particularly relevant to Phnom Penh's hot and humid subtropical climate. With better understanding of the dynamics between the built environment and the microclimate, and improved awareness in the building industry, Phnom Penh's urban living will become more comfortable and healthier.

1.1 Scientific background - key ideas

Climate is a generic term covering a wide range of spatial scales—from macro to micro (see Figure 2). Therefore, a mesoscale urban climatic map is essential for any local actions. While climate at the macro scale is determined by a range of global factors, urban microclimate is more about the interactions between the local built environment, human activities, and climates at larger scales. However, complicated it may sound and can get, the basic idea of urban microclimate can be summarised with the five elements below:

Scale:

The urban climate consists of the urban canopy layer (UCL) and the urban boundary layer (UBL) (see Figure 2). Urban microclimate happens within the UCL, where people live and work. Thus, urban microclimate affects people's quality of life significantly in terms of both, comfort and health. With regards to physical scales, the urban microclimate scale of 1m to 10m covers indoor climate and street canyon, while that of 10m to 1000m covers the neighborhood and the climatic variation.

Components:

Urban microclimate is determined by (a) local air velocity, temperature, and humidity; (b) solar radiation and reflection; (c) surface temperatures of buildings and ground, and (d) long-wave radiation exchange. The forms of urban development and human activities can change the energy balance, and thus climate, of an urban area.

Factors/Influences:

A city's location, metabolism, urban setting, time and weather all affect its urban microclimate, as explained in Figure 3. For example, compact urban development reduces urban air flow and results in poor ventilation. Urban heat and air pollutants will be trapped, and residents' health will consequently be jeopardized.

Well-known phenomenon:

Urban Heat Island (UHI) is an extensively studied microclimate phenomenon in dense urban areas. It refers to the relatively higher temperature in built-up areas compared to the surrounding rural parts. High UHI leads to higher energy consumption, thermal discomfort, and higher heat-related mortality in the summer.

Benefits:

The cumulative effect of localized measures over time will eventually benefit the whole city and people from all walks of life. In general, the outdoor environment will become more pleasant. Thermal comfort, especially under hot and humid conditions in summer, will be improved, and energy consumption will be reduced.

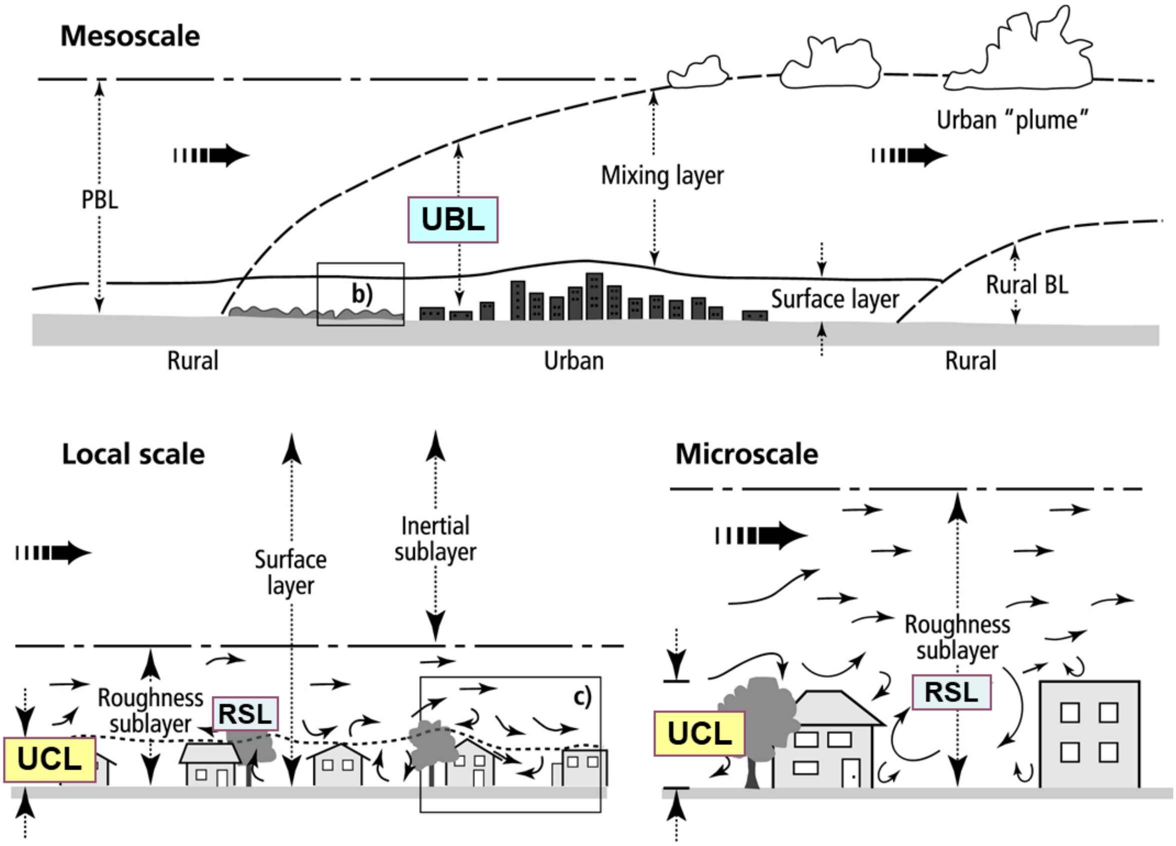


Figure 2: Urban climate scale (UCL = urban canopy layer; UBL = urban boundary layer) [1].

1.2 Why climate change matters

Climate change is mainly driven by the increased concentration of greenhouse gases in the atmosphere. It is extremely likely that greenhouse gas emissions by human activities are the main contributor of the warming trend. Climate change can bring serious threats to both the natural environment and human settlements. Key risks include heatwave and heat-related mortality, flooding, food and water security and urban poverty, as summarized in Table 1.

Cities are vulnerable to climate risks. In Phnom Penh, extreme weather events such as heatwaves could become more frequent, leading to rising electricity bills and health costs for both residents and businesses. Although climate change is often spoken of or projected at a broader scale, considerations at the local scale are equally important as that is where the impacts are most felt.

Cities present great opportunities for both adaptation and mitigation, particularly as the majority of the world population now lives in urban areas. When it comes to urban climate strategies, the focus is on adaptation. Through land use planning, building design and the use of urban greenery, heatwaves and heat-related mortality can be duly managed. At the same time, if the urban climate is well taken care of, energy use and carbon emissions in cities can be reduced, and the adverse impact of climate change can be minimized.

Table 1: Connection climate change and urban climate [1].

Key risks	Urban climate strategy
Heatwave and heat-related mortality	Urban land use Building design Urban vegetation
Flooding and related deaths, injuries, diseases	Urban infrastructure Seawall and drainage Water supply network
Food and water security	Urban planning Population control
Urbanization and urban poverty	Urban governance City planning and design
Global climate →	**Urban climate**

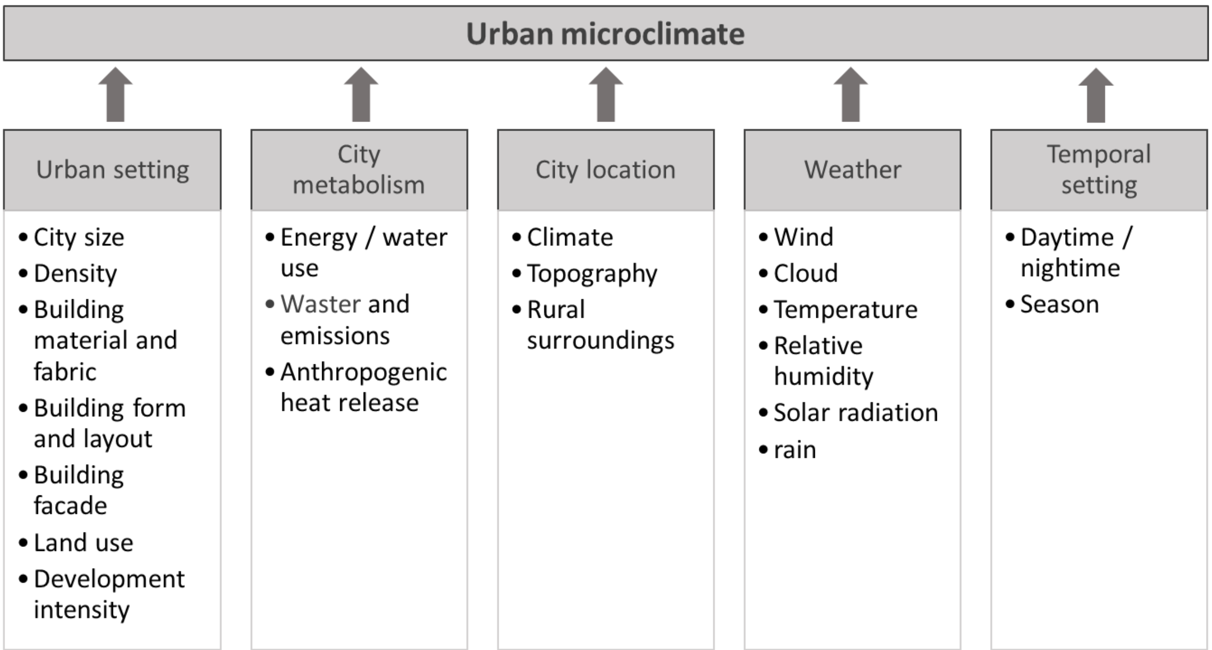


Figure 3: Factors influencing urban microclimate [1].

1.3 What is outdoor human thermal comfort?

A major objective of urban microclimate design is to enhance the outdoor environmental quality and to provide a thermally comfortable environment for pedestrians. To evaluate the urban microclimate of an outdoor space, human thermal comfort is commonly referred to. It describes the perception of the surrounding thermal environment in relation to the subject's satisfaction. It is determined by personal preferences and external climatic factors that interact with the human body, such as wind, solar radiation, humidity, temperature, clothing, and metabolic rate. Several scientific methods have been developed to estimate the level of human thermal comfort at an outdoor space at any given time. With the assumption of similar personal preferences, the evaluation of human thermal comfort can be simplified to consider only the climatic factors. A thermally comfortable outdoor space can be achieved through careful architectural and landscape considerations for the urban microclimate.

There are several widely accepted methodologies to measure outdoor human thermal comfort. Best for practical use in Phnom Penh can be the physiological equivalent temperature (PET), which is evaluated of outdoor thermal comfort.

Physiological equivalent temperature (PET)

PET is a widely used index for assessing the thermal environment. The analytical model is the thermal conditions of the human body in a physiologically relevant way. PET is applicable to any given place (both outdoor and indoor) and represents the equivalent air temperature at which, in a typical indoor setting, the heat balance of the human body is maintained with core and skin temperatures equal to those under the conditions being assessed.

PET thermal perceptions classifications are defined for both sub-tropical and temperate regions. In Phnom Penh, the classification for sub-tropical region is used, where a PET between 22°C and 34°C is considered comfortable (see Table 2).

Table 2: Thermal perception classification (TPC) and PET thermal comfort range [2].

Thermal perception	TPC for subtropical region	Range of thermal comfort
Very cold	< 14	Too cold
Cold	≥ 14 to < 18	
Cool	≥ 18 to < 22	Range of thermal comfort
Slightly cool	≥22 to < 26	
Neutral	≥ 26 to < 30	
Slightly warm	≥ 30 to < 34	
Warm	≥ 34 to < 38	Too hot
Hot	≥ 38 to < 42	
Very hot	≥ 42	

2 Recommendations for urban microclimatic design

Man's pursuit for a thermally comfortable environment through architecture dates back to ancient times. Over the years, valuable experience has been accumulated and the understanding of architecture and the environment has evolved. A set of factors has been found to have profound impact on urban microclimate and people's enjoyment of the outdoor environment. Considerations of these factors are becoming more important in the building industry not only because of its relation to the environment but also the added advantages of increased pedestrian activities and reduced energy use. This chapter provides a comprehensive tool set for designers to adopt microclimate friendly designs with concrete strategies and easy-to-understand illustrations. It also reminds practitioners of the importance of considering these measures at an early stage of design.

Wind, thermal radiation, temperature, and precipitation are key parameters affecting the comfort level and usability of an outdoor space.

(1) Wind

Increase ventilation with site planning.

Increase ventilation with building design.

(2) Thermal radiation

Reduce direct solar radiation.

Reduce surface temperature.

(3) Temperature

Increase evaporative cooling.

Reduce heat accumulation.

Reduce heat release.

(4) Precipitation

Provide rain protection.

2.1 Wind

Increase ventilation with site planning

Heat accumulation within the urban canopy, and thus air temperature, can be reduced by improving ventilation. The increased air speed around a person will also accelerate sweat evaporation and therefore induce a cooler sensation.

Breezeways are a crucial element of ventilation in dense urban areas. Major breezeways are typically formed by linear roadways and open spaces where the prevailing wind flows along. Minor breezeways are formed by building separation that allows wind to penetrate through the development. During site planning, careful consideration of the building layout is important to maintain major breezeways and leave sufficient gaps between buildings to facilitate wind penetration.

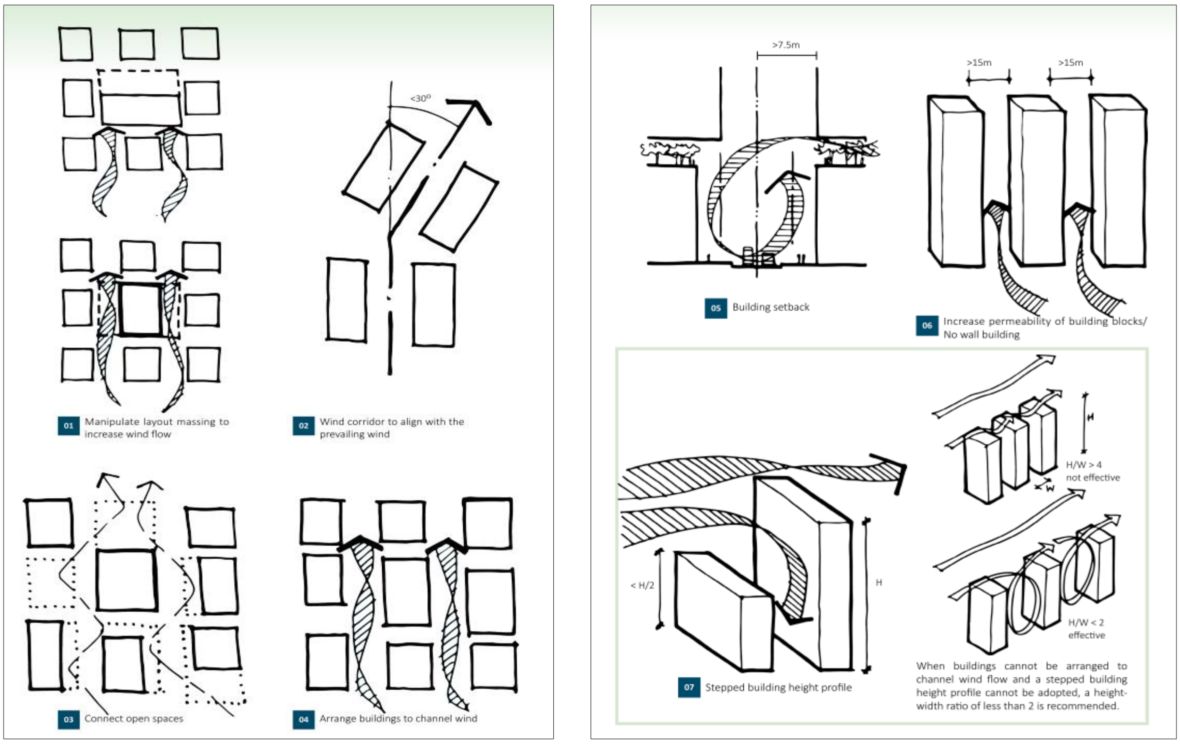


Figure 4: Ventilation flow in different site settings [3].

Increase ventilation with building design

In addition to site planning and master layout, the building design stage also offers many opportunities to improve wind penetration through the development by increasing building blocks' permeability. In this section, strategies aiming to increase ventilation with podium and tower designs are discussed. This section is particularly relevant to compact sites, where size constraints make ventilation enhancement through site planning difficult. Nonetheless, they are also applicable to large sites in the improvement of ventilation.

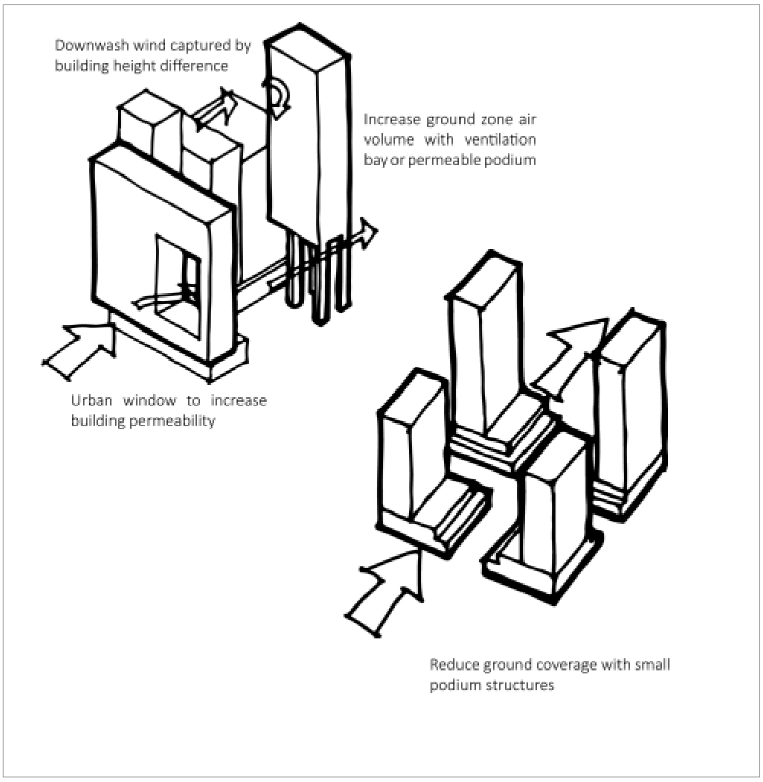


Figure 5: Ventilation flow at building level [3].

2.2 Thermal radiation

Reduce direct solar radiation

Direct solar radiation in the form of short-wave radiation plays an important role in outdoor thermal comfort. Pedestrians' direct exposure to solar radiation can be effectively reduced by making use of opaque shading devices. They can come in many forms, such as covers, tree canopies and building shade.

- **Provide shading for pedestrian activities**

  Shade offers the most effective remedy to thermal discomfort caused by direct solar radiation.

  Implementation
  Install opaque shading devices at open areas with frequent pedestrian access. The reduction in solar radiation can be up to almost 100% on a typical summer day. The reduction in solar radiation and impact on thermal comfort at different times of the year can be studied through computational analysis.

- **Provide tree canopies**

  Another way to reduce pedestrians' direct exposure to solar radiation is to shade them with tree canopies.

  Implementation
  Plant trees with large canopies in frequently used open spaces. Select plant species with high leaf density to maximise the shading effect. For large sites, provide tree coverage for over 25% of the total site area. For compact and single building sites, provide tree canopies in all frequently accessed outdoor spaces. The effectiveness depends on the crown size and leaf density.

- **Manipulate building façade design to provide shading**

  Pedestrian walkways are often located near or along the edge of a building. These walkways are often uncovered and exposed to direct solar radiation.

  Implementation
  Locate pedestrian walkways and open spaces adjacent to the building façade, which can act as a shading structure. Colonnade and cantilever structures are some examples of the design. The reduction in solar radiation and impact on thermal comfort at different times of the year can be studied through computational analysis.

- **Shade openness by building blocks**

  In a high-density high-rise urban environment, the shadows of building blocks often shade the surrounding ground space during different times of the day.

  Implementation
  Place outdoor open spaces at locations shaded by building blocks during certain periods of time in summer. Sun shadow analysis can be performed to determine the appropriate location of an open space.

Reduce surface temperatures

The rate of radiative heat transfer is proportional to the surface temperature of the heat source. Thus, strategies to reduce the surface temperature of the ground and surrounding building structures can help reduce heat stress on the pedestrians.

- **Use cool material for ground surface**

  Ground surface material absorbs solar heat and re-radiates it to the surrounding environment. Conventional pavements such as impervious concrete and asphalt can reach a surface temperature of 48-67°C. Cool materials with high solar reflectance (albedo) can help reduce the ground surface temperature.

  Implementation

  Use cool materials with an albedo index of at least 0.4, such as those of lighter colours, for outdoor ground surfaces. Researchers have estimated that a 10% increase in solar reflectance for ground surface pavement can reduce surface temperature by 3-6°C. Albedo can be increased from 0.1 to 0.5 by replacing asphalt with concrete, and that can reduce the surface temperature by 10-20°C.

- **Green wall to reduce façade surface temperature**

  Green walls can help lower façade surface temperature as the leaves and substrates reduce solar heat transfer to the building surface.

  Implementation
  Install green walls on building façades near open spaces that are exposed to a substantial amount of solar radiation in summer. Solar radiation analysis can be conducted to identify or confirm the façade receiving the most solar radiation. The thermal performance of a green wall depends significantly on leaf coverage. With a 100% leaf coverage, a green wall can reduce the façade's surface temperature by 3-6°C.

- **Increase albedo in buildings**

  'Albedo', means whiteness in Latin. In modern use, the albedo of a surface is defined as the fraction of the incident sunlight reflected from it. A high-albedo material demonstrates high reflectivity in both light and heat. Using such material will reduce thermal absorption by the building material.

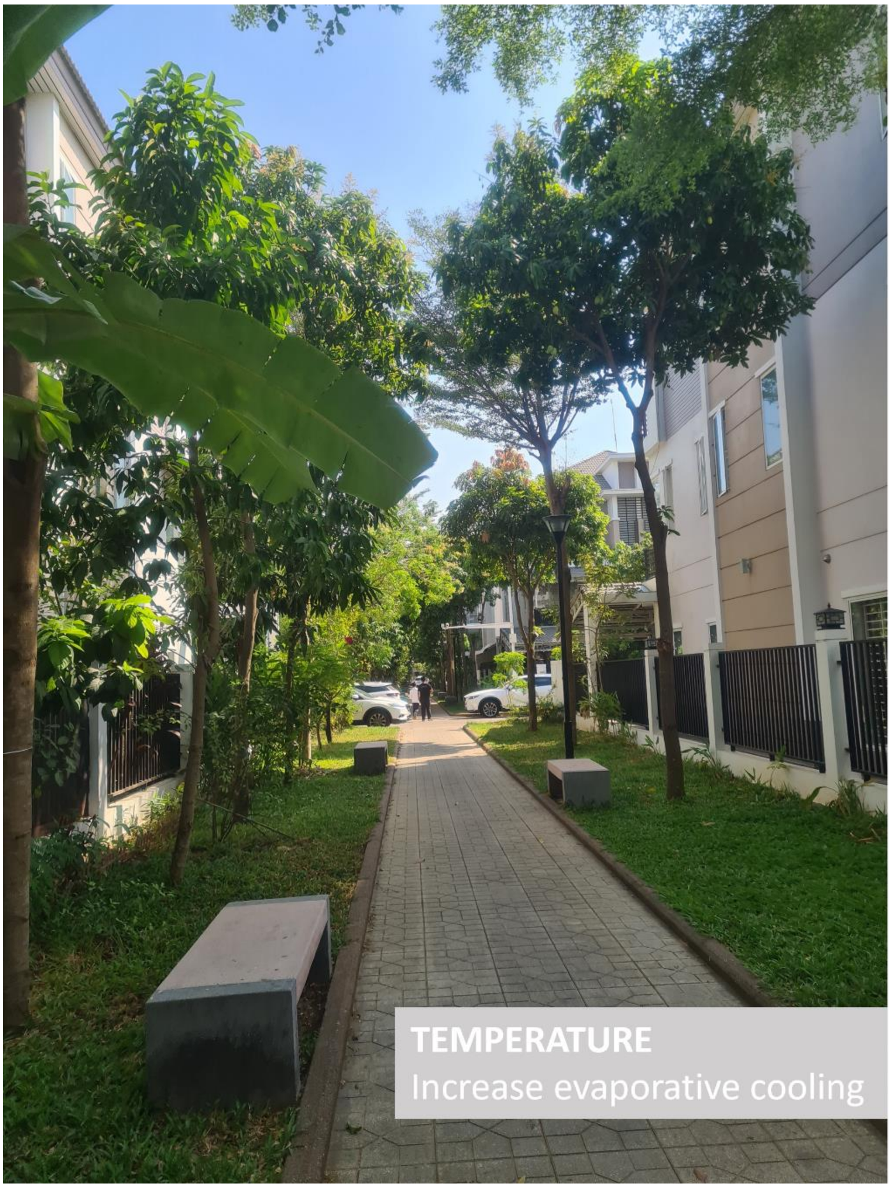
  Implementation
  A variety of measures, such as using light coloured surface paint or thermally treated surface material, can be adopted. Select high albedo building surface material of at least 0.4 to effectively lower the surface temperature and reduce radiative heat transfer to the surrounding environment. A light grey material with an albedo index of 0.5 will be 5-10°C cooler than a dark grey material of 0.2.

- **Increase sky view factor to improve night cooling**

  Sky view factor (SVF) is the percentage of the sky visible from the ground up. An SVF of 1 means the entire sky is visible, whereas an SVF of 0 implies the sky is completely obstructed from the viewpoint. On a clear night, heat is radiated to the sky from the earth surface. The higher the SVF, the greater is the heat transfer rate, and the faster the earth surface is cooled down by the night cooling effect during the hot summer season.

  Implementation
  During site planning, arrange building blocks to increase the SVF at the open space, such as by varying building heights of the development or widening the gap between building locks. SVF can be obtained via analysis with simulation tools.

2.3 Temperature



Increase evaporate cooling

A direct way to improve thermal comfort is to reduce the ambient temperature. The large latent heat of evaporation (2,260kJ per liter of water) makes evaporation an effective way to extract and carry away heat from the environment. Carefully designed features can take full advantage of evaporation.

- **Water features to increase evaporation**

  Water features help maintain a lower surrounding ambient temperature as water evaporation extracts heat from the surrounding environment.

  Implementation

  Provide water features in open spaces or landscape areas. Some effective examples are fountains, waterfalls and mist sprays. The water droplets they produce enhance the evaporation rate because of the increased surface area in contact with air. Static water features can reduce the ambient air temperature of the surrounding area within 3m by 0.2°C. For fountains and mist sprays, the ambient air temperature can be reduced by 3-5°C within the same distance.

- **Green wall to increase evapotranspiration**

Evapotranspiration refers to the process of moisture transferring from land and soil to the atmosphere by evaporation and transpiration. Green walls in general have a lower surface temperature than other materials on a building façade thanks to the effect. The rise in ambient air temperature from solar exposure near the green wall can also be reduced.

Implementation
Install green walls and covers on trellis panels at open spaces for communal use. There are broadly two types of plants commonly used in green walls: climbing and substrate based. Their cooling effect depends more on leaf coverage than plant types. With full leaf coverage, air temperature near the green wall can go down by 1°C.

- **Greening to increase evapotranspiration**

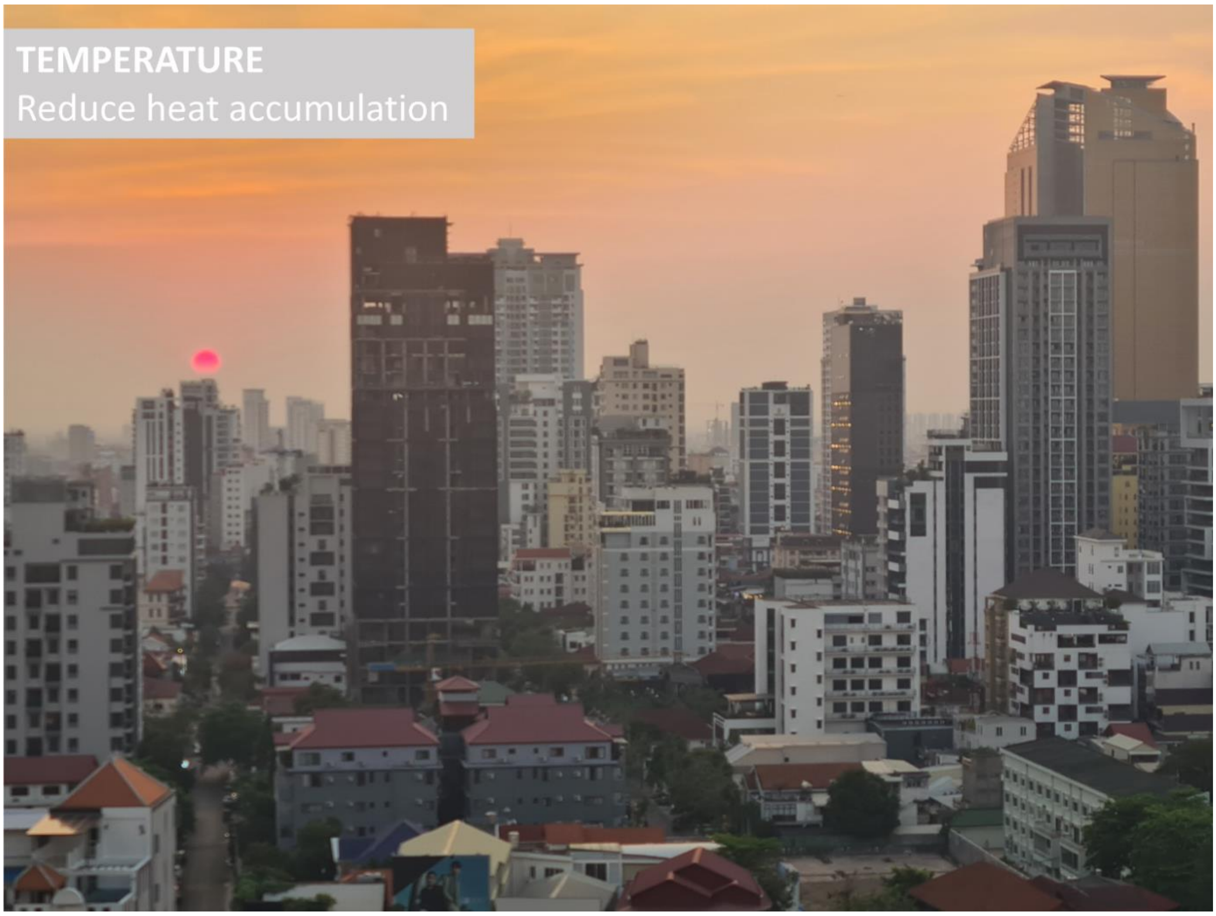
Vegetation offers an effective way to reduce the ambient air temperature by evapotranspiration.

Implementation
Provide vegetation at all outdoor spaces, especially those for communal use. Large trees are more effective than grass and smaller planters as the total leaf surface area is larger. A tree coverage of 30% will reduce air temperature by approximately 1°C.

- **Use permeable paving**

Permeable paving was originally designed for stormwater control. It allows air and water to enter the void of the material. The moisture content in the void reduces the ground surface temperature through evaporation and helps create a cooler near-ground environment.

Implementation
Use permeable paving in walkways and open spaces for communal use. Attention should be paid to the structural needs for the expected traffic loads. A permeable pavement saturated with water will reduce the air temperature 1m above it by 0.2°C.



Reduce heat accumulation

Poorly designed outdoor spaces can trap heat from nearby air conditioners and traffic, whilst improved ventilation can help increase the rate of heat dissipation. The introduction of cooler air from nearby mountains and water bodies is also helpful in the reduction of the ambient temperature.

- **Increase ventilation to carry away heat energy**

  Solar heat in the outdoor environment tends to be trapped in built-up areas, especially at open spaces surrounded by building blocks with weak ventilation. Localized ventilation can carry away the heated air and introduce cooler fresh air from the surroundings.

  Implementation
  Increase ventilation at open spaces frequently accessed by pedestrians. Locate them at wind paths. Avoid air stagnation under prevailing wind condition and ideally also under windless condition, such as by using mechanical ventilation. A minimum wind speed of 1m/s is recommended for a comfortable environment under shade during summer.

- **Allow thermal induced ventilation**

  During calm wind conditions, the temperature difference between the city fabric and vegetated slopes will induce a local air flow, known as katabatic wind. This air flow under tree canopies is approximately 1-2°C lower than the ambient air temperature. The slightly cooler and denser air on the vegetated slopes flows down the slope towards the urban area, permeating and cooling the streets. This strategy is not commonly adopted at the moment. However, as the Government plans to build at the urban fringes, considerations about the downhill wind flow will become more important in the future.

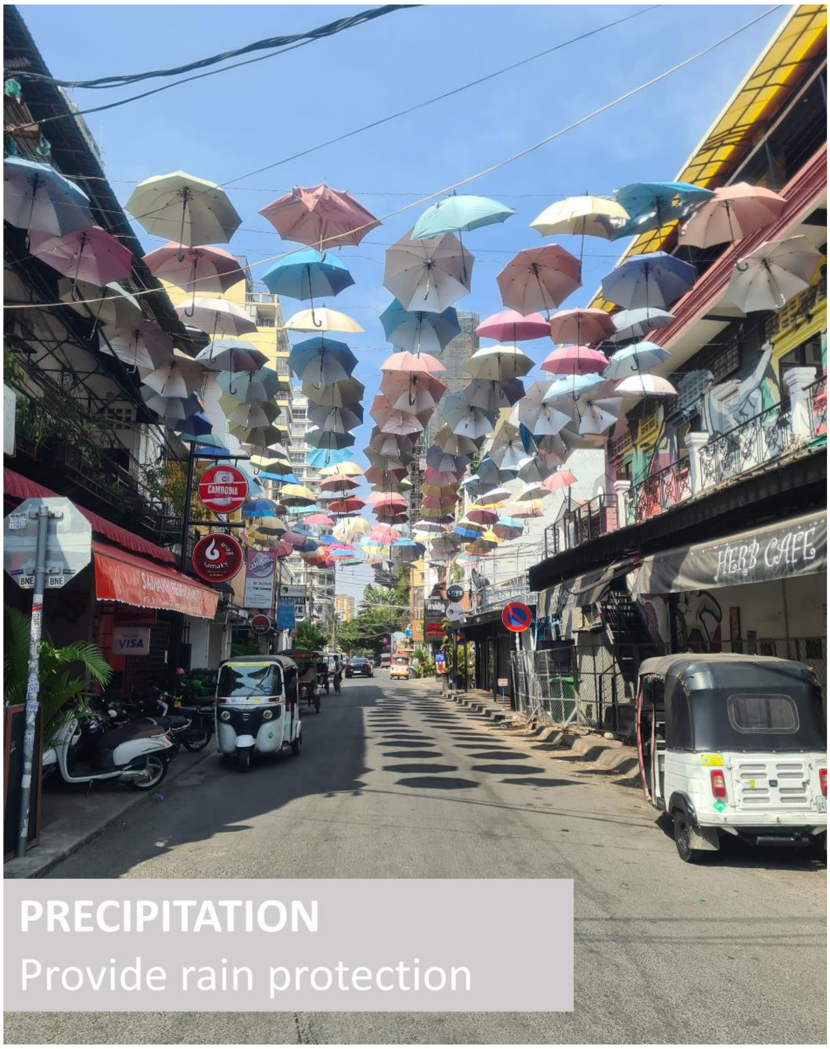
Implementation
For developments facing vegetated slopes, make sure the building does not obstruct the katabatic wind flow from uphill. Maintain adequate gaps between buildings and increase permeability in podium design to enhance the flow through the site. The wind path through the development must be shaded or vegetated to avoid heating up the air.

- **Reduce thermal mass heat storage of building materials**

Thermal mass is the material property of absorbing and storing heat energy. Building materials such as concrete and bricks typically have high thermal mass. These materials store heat energy under sun exposure during the day and release it to the surrounding area at night. By reducing the thermal storage of the building materials, heat dissipation to the outdoor environment and ambient temperature can be reduced.

Implementation
Reduce solar exposure of building materials with a heavy thermal weight. Shade the building mass from the sun with light-weight external shades, such as aluminum louvres or green walls. Materials with low thermal mass are those with low specific heat capacity and density.

2.4 Precipitation



Provide rain protection

Tropical Phnom Penh sees heavy and frequent rainfall and thunderstorms during the rainy season. Protecting pedestrians from precipitation will improve the microclimate and usability of open spaces.

- **Provide cover for rain protection**

  Relative humidity is close to 100% on rainy days. Covered structures keep pedestrians dry and speed up the heat dissipation process for better thermal comfort.

  Implementation
  Provide rain cover along major pedestrian walkways. The angle of deflection from the driving rain effect should be taken into consideration. The estimated angle of deflection of driving rain under the typical heavy rain condition in Phnom Penh is approximately 10 degrees. This should be taken into account in the design of covered walkways for effective rain protection.

3 Way forward

This guidebook is a beginning for climatic oriented design, which helps to improve the urban climate and microclimate designs. Phnom Penh has the aim to walk a long way down the path towards a healthier and more comfortable city.

There are three areas where advancement must be made to improve the city's microclimate science and technology development, policy, practice and design, and public awareness and education. The potentials in each area are identified, and the suggestions made here are not only attainable but also crucial to the improvement of the city's environment.

Science and technology development

The Royal University of Phnom Penh has record of research on urban climate and the researchers contributed to the development of new methodologies to obtain urban data, implementation of scientific findings in research on urban climate, planning and outdoor thermal comfort.

These efforts to advance knowledge and technology must be encouraged and further deepened for the development of strategies and measurements that take the city's unique context into consideration. Adequate funding is essential. Only in this way can the next step forward be solid and grounded.

Policy, practice and design

For the future, governments should introduce a range of measures and proposals for a variety of studies to improve the urban climate. The urban climatic map is very much appreciated, but these efforts must be continuous and concerted. Departments must work together to create a synergy. Particularly, microclimate related data and information should be readily shared among different governmental parties. Further, policy encouragement may be needed to motivate developers to employ urban microclimate strategies.

Three particular areas have been identified in the development of the guidebook: the installation of covered walkway and canopies, adoption of non-building areas, and setting up of green walls. Developers often find it difficult to adopt strategies in these areas because of commercial or statutory constraints. The Government and developers must come together to look for a way out. It will take some negotiations and the result may be of a carrot-and-stick approach, but the main message here is that communication with the industry is just as important as between different governmental bureaus and departments.

Industry practitioners should take the initiative to learn about urban microclimate and implement the strategies introduced in this Guidebook in their projects. A better outdoor environment is for the benefit of both, the general public and the development itself.

Public awareness and education

The local good practices highlighted in the Guidebook is a testimony to effective promotion and education. However, public and professional awareness can still be further enhanced and the gap in professional education and knowledge transfer must be filled.

The Guidebook attempts to be simple and easy to understand. It speaks to practitioners as well as interested laymen in a language stripped of professional jargon. Future efforts similar to this are essential to the spread of knowledge and increase in awareness. The architectural profession as a whole—not just those focusing on green buildings—and the wider population must be engaged in building a better city.

At the same time, there is a gap in the professional education of urban climatology between brief courses and extremely in-depth knowledge pursuit, such as in the form of a PhD. A better ladder of professional training must be provided to engage a bigger number of practitioners and encourage wider application. Academic institutions are in a good position to take the lead.

Conclusion

Considerations for the urban climate are becoming more important and urgent in the face of climate change, and the above areas are key to Phnom Penh's further development into a sustainable city. The way forward may be a long one, but continuous and concerted efforts will make the walk smoother and easier.

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Enhancing Quality of Life through Sustainable Urban Transformation in Cambodia