DESIGN WITH NATURE

INTEGRATED GUIDELINES FOR SUSTAINABLE NEIGHBOURHOOD DESIGN

United Nations Environment Programme

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CREDITS AND ACKNOWLEDGEMENT

DISCLAIMER

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DESIGN WITH NATURE

INTRODUCTION

In a neighbourhood designed with nature, building walls and windows open up to light and air, capturing ambient daylight and cooling breezes, reducing our energy needs. Shaded outdoor spaces with panoramic views create memorable places to meet and relax. Generous planting grows on our streets, rooftops and walls, embedding green into our city and enriching our urban biodiversity and habitat.

DESIGNING WITH THE LANDSCAPE

Landscape must be the starting point of design. The land should inform a unique site-specific answer to development rather than be subjected to the application of rigid standards. This approach to nature gives an aesthetic value to the context, ameliorates the local climate, and relieves environmental pressures. Nature and landscapes are key in improving the quality of life and make communities sustainable in every sense of the word:

- Ecologically – affecting microclimate, creating wildlife habitats
- Socially – making place more liveable, hence increasing the sense of ownership, improving quality of life
- Economically – increasing value because of a better quality of life

Landscape combines landforms, ecosystems, and open space networks. They shape the neighbourhood and connect it to its environment, from the smallest garden to the vast parks. Within each recess of the neighbourhood, landscape keeps the memory of the site natural form before human occupation. Landscape means a lot: it is the open spaces, water, green and movement corridors and walkways; it is parks, squares
and streets. More important than a list of elements, it is their unfolding in movement, which defines the living experience of the city.

‘The urban landscape, among its many roles, is also something to be seen, to be remembered, and to delight in.’ The landscape forms the basis for creating places. To take just one example of strongly structured large urban landscape, Florence is a city with a powerful character and particularly visible intensity. The city lies in a bowl of hills along the Arno, so that the hills and the city are almost always inter-visible. To the south, the countryside penetrates almost to the heart of the city, which creates a sharp contrast. From one of the last steep hills, a terrace gives an ‘aerial’ view of the city core. To the north, small separate settlements, such as Fiesole and Settignano, are visibly perched on characteristic hills. At the symbolic centre of the city, rises the immense and indisputable dome of the Duomo, flanked by Giotto’s bell tower, a point of orientation visible everywhere in the city and at kilometres of it. This dome is the symbol of Florence.

**DESIGNING WITH NATURAL TIME CHANGES**

Urban designers have generally ignored the rhythmic dimension that nature adds to our perceptions of urban space. Their idea of city space is compositional, complete and static. A spatial conception linking nature’s rhythms to urban structure can give new life to our neighbourhoods. Change over time considerations are also essential to good landscape. Design should plan for the unfolding of years, seasonal changes and the passage of hours. This applies not only to the soft landscape, but also to the condition of the materials exposed to the weather. The key is to design the landscape so that it grows gracefully so that places become more attractive, more interesting and more comfortable as trees, shrubs and other plants mature. It also means ensuring that places stay protected and sunny most of the day, and ideally most of the year, to be well used.

Beyond just making cities and buildings functional energy processors, designers can also look for ways to reveal the energy processes in the city and to give them meaning in the lives and experiences of inhabitants. Every aspect of what we design will have to follow the underlying order of nature. The forms we

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1 Lynch 1960.
2 Lynch 1960.
perceive in nature and in traditional cities are patterns of this complex order. The patterns are configurations of relationships, and the relationships are fluxes involving the exchange, processing and storage of energy, matter and information. Each form then manifests underlying energy flux. The urban designer can, with some experience, create urban forms that guide and shape the energy fluxes of the sun, wind, and light. Through light and shade, through coolness and warmth, along delicate webs of narrow streets, which transformed their light pattern like sundials, responsive to seasons and hours of the day, the traditional city was a rhythmic pattern of forms and light making visible the flows of sun energy through the city. In a time when most of our cities conceal their environmental control systems and segregate occupants from the rhythm of life, designers can use many strategies to reconnect our cities to nature processes. In a simple and beautiful way, the city can serve to heal the relationship between people and the living systems of which we are all a part. This effect, while not quantifiable, may have a far greater indirect impact on ecological health than the direct impact of conserved energy.

Sunlight adds a dimension of time to our perceptions of space, as a consequence of sunlight daily and seasonal rhythms. The sun is an ever-changing source of heat and light, a source that we can tap only if we take account of its dynamic character. Observations over time demonstrate a rhythmic measure of space.

**DESIGNING WITH THE CLIMATE**

Different climatic zones require entirely different approaches for the design of the urban fabric.

Moreover, a mosaic of microclimates exists throughout a city. The effect of city design can make air quality worse and buildings more expensive to operate – or it can help clean the air and make buildings to be more energy efficient. Topography, landscapes, street patterns and design, building volumes, shapes and orientation, and choice of materials can contribute to avoid heat islands. Their layout can change locally summer peak temperatures. It can reduce the energy load of buildings while improving external thermal comfort.

<table>
<thead>
<tr>
<th>Climatic adaptation of house typology: All based on a similar courtyard pattern, traditional Chinese houses vary with the latitudes and climates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernacular urban fabrics and buildings were adapted to their climates. In four regions of China, from north-east to south-east, open spaces decrease in proportion to enclosed spaces so that broad courtyards become amazingly smaller. In the dry, colder areas of North and North-Western China, open spaces are generous portions of the house – courtyard complex, while the walls block cold winter winds and the south orientation increases the solar gains. Throughout central China, where winters are mild and summers hot, transitional spaces, such as verandas and rooms with open-faced lattice door panels, increase in extent, while open spaces decrease in proportion to enclosed spaces. In the hot and different hours. Every morning, light from the east will cast a shadow that moves quickly down the opposite wall. Every afternoon, light from the west will cast a shadow that climbs the opposing wall. To experience the whole cycle takes from before sunrise until after sundown. Where east-west and north-south spaces pierce each other, we can experience both time scales. The common volume intensifies both a seasonal and a daily cycle. It combines them, laying one over the other. The result is a crossing in space that proportions time (Knowles 1998).</td>
</tr>
</tbody>
</table>

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4 Any urban space oriented from east to west strengthens our experience of seasons. One main wall is nearly always dark; on the other side of the space, a shadow line moves gradually up the wall then down again. To experience the whole cycle takes exactly one year. The basic movement is always the same. As the sun’s path drops lower in the sky during late summer and fall, the shadow moves up. As the sun’s path rises in the sky during late winter and spring, the shadow moves down. Changing the orientation of the space will evoke a different cycle and rhythm. Any space that is oriented from north to south sharpens our experience of a day. Both main walls are lit, but at
humid areas of South-Eastern China, open spaces – here usually only sky wells – shrink in size while transitional ‘grey’ spaces increase significantly. Buildings are naturally ventilated and sunlight is blocked from penetrating the urban texture. This adaptation of the courtyard form to textures and climates is an optimization of the urban texture that modulates the interfaces with natural elements.

Planning and designing with nature enhances the resilience of a neighbourhood. Originally, resilience is an ecosystem’s ability to recover from or adjust easily to disturbances or change. On a neighbourhood level, the concept of ‘resilient socio-ecological systems’ represents the idea that man and nature coexist and co-evolve. This co-evolution of the neighbourhood with nature is developed in the following strategies.

DESIGN THE NEIGHBOURHOOD AS A GREEN LANDSCAPE
BIOCLIMATIC DESIGN INTEGRATED STRATEGIES
BIOCLIMATIC DESIGN IN COLD AND TEMPERATE CLIMATES
BIOCLIMATIC DESIGN IN MEDITERRANEAN AND HOT DRY CLIMATES
BIOCLIMATIC DESIGN IN HOT AND HUMID CLIMATES
DESIGN THE NEIGHBOURHOOD AS A GREEN LANDSCAPE

Designing the landscape is not a number game in which the planners provide a certain percentage of green space to meet standards. A standard-led approach often results in bland open spaces. They lack enclosure, intimate scale, succession of promenades and discoveries that make our most beloved urban parks and gardens distinctive quality. There must be enough green and unobstructed space for pleasant walks, and creating habitats for wildlife development, but quality and design matter more than quantity. The landscape is a path to civic pride and endless enjoyment for the neighbourhood dwellers. A variety of open space types should be provided from the smallest scales to the larger ones, from the most intimate to the most public, from the most informal to the most formal.

A key design principle is to treat everything as a landscape; buildings define the edge of space; the landscape occupies the space, be it a park, a street, a fence or a sidewalk. This involves designing the landscape structure before the traffic engineer intervention and avoiding space left after planning. Landscape structure is the pattern of green and open spaces, from green courtyards within blocks to pocket parks, to tree-lined streets and nature trails, to larger district parks and nature areas.

Check list of tasks for designing the neighbourhood landscape

— The planning of any site needs to start with a landscape assessment, including topography and microclimatic conditions of the site. This will inform a unique development response with intrinsic landscape elements embedded within the ‘place’.
— Understand the intrinsic characteristics of the site.
— Plan the open space.
— Locate, size and design parks to maximize access at less than 300 metres of all homes.
— Define a landscaping typology hierarchy, with function and frequency of existing and desirable green spaces.
— Create a connected network of green spaces for the entire site.
— Detail the treatment of green spaces and elements.
— Reserve 5% of the site to allow for free drainage on-site water retention. Sustainable drainage occurs best on the lowest-lying land of the site.
— Consider green roofs and three-dimensional greening to provide additional landscape elements in urban development.

Lessons learned from case studies of Eco neighbourhoods

— The hardscape to landscape ratio is radically different from that of traditional neighbourhoods: 40 to 50% (up to 70% in Vauban) is permeable and green.
— In addition to the green courtyards within the blocks, almost every urban block has direct access to part of a larger urban landscape.
— The urban landscape is expanding in three dimensions: for example, green façades in Vauban, green roofs covering 50% of Vauban buildings.

5 Bo01 Malmö, Hammarby Sjöstad, Kronsberg, and Vauban.
The urban landscape enriches the sensory experience in the neighbourhood public space. When it rains, open swales along the streets that clean and slow storm water runoff come alive, animating the streets and park areas with the sound and flow of water.

THE MULTIPLE BENEFITS OF DESIGNING WITH NATURE

In green neighbourhoods, the urban landscape is a living green three-dimensional framework delivering a full range of eco-services. For example, green corridors can regulate the climate. They replace engineered infrastructure by solutions that work with nature, in which water recycles and supports life at local scale. Green open spaces minimize carbon emissions by absorbing carbon from the atmosphere. They can act as sustainable drainage systems, solar temperature moderator, source of cooling corridors, wind shelter and wildlife habitat. Air pollution reduction and urban cooling have multiple long-term health benefits.

Moreover, by integrating nature with both its eco-services and its aesthetic and sensory presence, into the neighbourhood, the urban landscape creates an enriched urban experience. Urban green spaces meet many community needs, which can further benefit civic life. Trees and greenery help beautify public spaces and make them more attractive for leisure, socializing, relaxation and education activities. Benefits for residents include physical activity, safety from traffic, accessible spaces when using a universal design approach, psychological well-being. For example, a community garden can facilitate education about food systems and provide psychological health benefits for gardeners and access to healthy seasonal food.

Ecological and Bioclimatic Densification Strategy in Sungei Kadut redevelopment project in Singapore. Workshop led by Serge Salat at NUS.

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6 Storm water treatment and retention are major features of Bo01, Hammarby Sjöstad, Kronsberg, and Vauban. The urban landscape displays one of its suppressed functions, that of recovering and absorbing rainwater rather than carrying it away in pipes.
Multiple benefits of integrating nature in the neighbourhood urban fabric are as follows

- **Aesthetics**: enhances design quality and sensory experience
- **Recreation**: creates shared activity in recreational spaces
- **Community**: creates a sense of belonging and enhances community gathering
- **Access**: green streets, sidewalks, boulevards, alleys, and pedestrian and bike paths – greener systems of movement and access
- **Regulation and cooling of the microclimate**: heat island effect mitigation in summer and sheltering in winter
- **Insulate, reduce runoff and regulates climate** with green roofs
- **Retention of rainwater** in a variety of bioswales and retention ponds; treat, detain, and store storm water for possible reuse
- **Wastewater**: treat and store wastewater for possible reuse
- **Habitat**: expansion of flora and fauna urban habitat
- **Air quality**: air quality improvement and absorption of CO₂
- **Food**: provides urban agriculture
- **Energy**: creates biogas fuel

This section considers the following actions.

**WORK WITH THE EXISTING LANDSCAPE**

- CREATE A NETWORK OF LINKED GREEN SPACES
- CREATE WILDLIFE CORRIDORS
- DESIGN AND PROGRAMME HIGH-QUALITY PARKS

They are illustrated by two extended case studies.

**CASE STUDY: A NETWORK OF PARKS AND GARDENS, THE ROYAL BOROUGH OF KENSINGTON AND CHELSEA IN LONDON**

**CASE STUDY: WEAVING GREEN SPACES IN THE URBAN FABRIC IN FRENCH DREAM TOWN IN HANGZHOU**

**WORK WITH THE EXISTING LANDSCAPE**

A principle is to work with and value what is already there. Opportunities exist to use the intrinsic landscape positively in the design of new places. A beautiful tree can provide instant maturity in a new square. A grove of good trees or a beautiful old garden can serve as a base for a local park. Tree hedges can be used to create a new parallel road, and if there is an old alley, use it to access a footpath. Visual links between a hill, a beautiful building, or a historical feature beyond the site can be used to create ‘view corridors’ in which open space uses and pedestrian uses can be performed. Creating a safe and usable open space and maximizing the benefits of adjacent structures should be more important than meeting normative standards for provision. The challenge of urban design is to design a concept that makes a positive contribution to the sense of place, in both general and local terms. In creating the plan, adjust and iterate between considerations of this kind, together with the movement structure and development block.

The neighbourhood design should be integrated with the intrinsic landscape characteristics. These include topography; orientation; aspect and prospect; current landscape assets (trees, water, habitat, etc.) and liabilities; contaminated, and poorly drained land, unsightly structures; overhead lines and utility facilities. As a general principle, it is important to focus on how to repair and reuse previously developed or damaged parts of the site, while retaining and respecting undamaged parts. This requires three key considerations:

1. **Identify landscape assets to preserve.** Many of the most valuable spaces, places and landscape assets are precisely thus because they have been left untouched. Most ecological or landscape assets need respecting, rather than exploiting.
2. **Reuse and repair brownfield land.** Many sites will be deficient in natural or semi-natural assets, such as topographical features, watercourses and planting. Furthermore, decontamination or remediation may cause further impacts on the landscape. On such sites, consider ways of introducing new landscape features and wildlife habitats; restoring damaged parts by, for instance, re-profiling a slope; integrating elements from the site’s past life, such as routes, structures and buildings.

3. **Strengthen the identity and structure of the landscape.** Identify landscape features which contribute to the unique character of a site. Particularly on greenfield sites, every effort should be made to incorporate features of the landscape into a scheme. Reviving historic features provides opportunities to enrich outdoor space and can include natural and man-made elements, from watercourses and streams to ancient field boundaries.

**Working with the topographical and the climatic, hydrological and ecological features of the site, facilitates passive solar design of buildings in cold climates and natural urban cooling in hot and humid climates.** Whenever possible, align building footprints, streets and watercourses with the contours of slopes. This allows building profiles to grow out of the ground, minimizes cuts and fills, and uses natural gravity drainage. The design of the urban fabric creates a local microclimate that affects temperature, sunlight and wind movements. Careful landscaping can significantly improve comfort at exposed sites.

**CREATE A NETWORK OF LINKED GREEN SPACES**

The 400m walkable catchment radii focused on neighbourhood focal points is the starting principle for green network design. Aim for major open spaces to adjoint at least one quadrant of the circle, but never more than two. This avoids isolation between developments and allows linear networks to be provided that are no more than 1.2 km (15-minute walk) away from the majority of people.

**Linking green spaces by pedestrian green routes creates a connected green city in which urban locations are connected by attractive routes.** The reinforcement of connections between green spaces is meant to ensure that the green intensification is not restricted to a few locations. Open green space networks are often more useful for visual amenity, recreational uses and wildlife corridors than isolated and unrelated landscape elements. Green spaces that are connected with other green or open spaces through walking and cycling trails or greenways promote higher levels of physical activity and encourage more visits and longer stays.

Green networks serve to give structure, rhythm, and scale to the neighbourhood, but also to create linkages with existing urban areas, other sites and the broader landscape. Green networks can link linear parks, playgrounds, allotment gardens, private gardens, buffer plantations and surface drainage corridors. Greenways can be created to cross or mix with linear features such as natural streams, forest belts or canals and connect with parks and trails in nearby neighbourhoods. They can plug into neighbourhood streets that have bike lanes, reduced car levels and mature trees, creating a network of what the city of Vancouver calls ‘Greenways’.

**A variety of linked parks within a neighbourhood should be planned as a system, providing the ecological, social, physical, and psychology benefits of green spaces to all residents.** This can enable each park to differ by function and character, while remaining accessible and linked to a larger system of open spaces. This linkage is important for children and the elderly. A well-designed and well-maintained park network serves as venues for physical activity and recreation, increases access to nature, and boosts the value of surrounding properties. This network shapes neighbourhood structure and community identity and serves as the backdrop to social interactions between different ages and groups. From the residents’
perspective, three factors are key to design the landscape structure:

- **Access** (visual and physical) from homes and workplaces to green and water areas. Physical closeness is particularly important for groups who have trouble getting around (the old, very young, less affluent, mobility-impaired). Pocket green spaces should be less than 300 to 400 metres from each home; larger parks should be next to transit to increase their accessibility.

- **Connections between spaces that form a network** so that people have no difficulty navigating continuously through them and make them part of their daily walking or cycling circuits. When physical connectivity cannot be achieved, wayfinding, tree-lined pedestrian and cyclist paths can link green spaces together in a network and encourage people to travel between them. The success of trails linking green spaces depends on accessibility, proper maintenance, and safety, and ongoing funding.

- **Variety in terms of facilities and character** so that people can engage in different types of activities. Spaces should appeal to people across their lifespan and to different groups and generations.

**Natural elements should be woven into parks, playgrounds, and buildings**, in the form of appropriate greenery, natural play materials, and water features—particularly in neighbourhoods where access to nature is limited. Attractive landscaping should be integrated in façades vertical gardens, roofs, terraces, sky gardens of buildings to highlight views of nature.

**Creating a continuous gradient of green spaces sizes fosters general accessibility.** A well-developed network of open green spaces, of all sizes, shapes, and functions should ensure general accessibility to green space and provide for a range of recreational needs within close proximity to homes and workplaces. New York City target is to have 90% of New Yorkers living less than a 10-minute walk from a public park. This policy continues the long story of designing medium size and small public parks in New York. Research has shown that in cities like Paris, Roma, New York, there is no single average size, no characteristic scale for a public park. Instead there is a continuous gradient of sizes from Central Park to a ‘long tail’ of pocket parks, cooling and greening the city and providing places for neighbours’ social activities.

Children’s playgrounds, nature protection and sports areas should be at walking distance. Local parks are conveniently within a 3 to 5-minute walk (250 m to 400 m) from most homes. The best starting point for determining the layout is to assess green spaces at walking distances. This accessibility analysis should consider the location of entrances, severance lines (such as railway lines or busy roads) and steep slopes that impede the elderly and people with reduced mobility, particularly wheelchair users. This analysis can also serve as a basis for extending the catchment area of a park, for example by creating more entry points or pedestrian crossings.

**CREATE WILDLIFE CORRIDORS**

**Weaving narrow strands of continuous green spaces into the urban fabric provides continuous habitat for wildlife.** Landscaping should deliver a continuum, from truly wild areas to engineered bio-systems that recreate the natural system functions. Infrastructure like porous pavements helps restore the ecological health of the city by allowing rainwater to seep into the soil or evaporate instead of flowing into wastewater treatment plants. Replacing asphalt and concrete infrastructure, where it is practical to do so, provides natural cooling, accessible recreation spaces, and a more pleasant pedestrian experience. Similarly, restoring wetlands and providing habitat for birds, fish, and other aquatic life restore the ability of these ecosystems to retain storm water, clean waterways,

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7 Forsyth and al. 2017.
and protect the city from storm surges. Sustainable design balances human access and wildlife shelter.

When creating a network of open spaces, areas with limited access can provide rich habitats for wildlife. Railway embankments, for example, are good corridors for wildlife. They are not disturbed by the population and many animals are not affected by train movement. For public parks, a balance must be found between public access and biodiversity. An open space network would form a necklace of different open spaces. These could include private gardens. It is recommended to configure open spaces in long strips to achieve the highest ecological value. Those are well maintained for the first 10 metres, leaving richer habitats at their ends. All neighbourhood sites should be considered as habitat. It is recommended to identify areas to preserve, such as mature trees, hedgerows or streams. They can be used as the basis for creating a landscape structure. This begins to define the land left over that is potentially developable.

**CASE STUDY: DEVELOPING GREEN CONNECTORS IN MORAVIA, COLOMBIA AND CAMINO REAL, PERU**

Moravia is a Colombian neighbourhood initially developed on a dump site. UNEP and EcoCity Builders proposed biodiversity habitat and mobility corridors. The proposal features a series of corridors or pathways. They solve mobility issues and address the lack of green spaces and biodiversity in Moravia. This set of integrated interventions aims at improving Moravia residents’ quality of life. They implement accessible, safe and universal mobility; increase green spaces; promote biodiversity; and utilize resource efficient solar powered technology for public lighting and irrigation systems.

In Camino Real, a community of Cuzco in Peru, UNEP and EcoCity Builders proposed to restore the green areas and connect them with permeable paths, informative plaques of plants and animal species and geological characteristics. A map will highlight the natural spaces in Camino Real and the linkages to the greater area trekking trail system. The proposal weaves together the community as a whole.

**DESIGN AND PROGRAMME HIGH-QUALITY PARKS**

**Why do neighbourhoods need a park strategy?**

- To understand the role that parks and similar open spaces play in the wider community.
- To provide a clear and motivating picture of what the neighbourhood wants parks to be like now, and in 10 to 20 years’ time.
- To establish a strategic framework for each major park’s site management plan.
- To set out a direction for developing and supervising smaller open spaces.
- To provide guidance to all stakeholders so that they understand their role and are motivated to do their best work.

- To enable to focus resources – money, time and human – to meet the challenges that face the parks and open spaces under financial constraints.
- To secure and guide an ongoing programme of capital investment
- To mitigate climate change and conserve biodiversity.

**Key tasks for providing high-quality parks comprise**

- Ensure that routes leading to parks are safe, well marked, and well lit.
- Create adaptable, multi-use spaces for community gathering, play, and social activity for all ages.

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*Adapted from The Royal Borough of Kensington and Chelsea 2016.*
- Accommodate diverse uses and activities within parks.
- Incorporate exercise equipment for all ages.
- Preserve or create natural terrain to support play. For example, plant trees, grasses, and other greenery; make a hill to climb or cycle around.
- Incorporate simple interventions such as colourful ground markings to inspire more active play among children.
- Install playground equipment that includes movable parts, imaginative playscapes, and opportunities for children of all abilities.
- Respond to the local climate by providing shelters that offer shade and wind protection.
- Install drinking fountains to encourage water consumption and support longer play.
- Provide water features to help children and families stay cool while being active even on the hottest days of summer.

Finally, management and programming should encourage people to gather and interact in green spaces, with for example concerts, festivals, and farmers’ markets.
**Priority themes for parks: a roadmap for action**

<table>
<thead>
<tr>
<th>PRIORITY THEMES</th>
<th>GOALS</th>
<th>ACTIONS: HOW WILL WE GET THERE?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provide a balance of leisure facilities and quiet space, so that all can enjoy parks and green spaces and no park is overwhelmed by activity.</strong></td>
<td>• Identify facilities wanted, but lacking, then match to appropriate park, and build facility • Get more people into the parks and enjoying facilities available. Ensure parks are accessible as well as welcoming • Ensure residents benefit from contact with nature • Develop policies for personal trainers and events</td>
<td>• Improve sports facilities • Review the management of kiosks in parks • Promote healthy living and well-being • Infrastructure improvements</td>
</tr>
<tr>
<td><strong>Ensure the parks are safe places to visit and enjoy, demonstrate best practice in tackling crime and disorder, and ensure that parks are acknowledged to be safe</strong></td>
<td>• Identify current and future safety issues • Focus resources in problem areas • Promote partnership and community involvement • Communicate action and success</td>
<td>• Review byelaws where appropriate • Utilize current and emerging media and technology to improve internal and external communication • Maintain an on-site presence at key sites, and utilize CCTV where appropriate</td>
</tr>
<tr>
<td><strong>Manage the long – term resilience of the parks in relation to usage, biodiversity and climate change</strong></td>
<td>• Create and start implementing a long-term tree strategy and a biodiversity action plan • Identify and manage pressure points in parks in terms of general usage and events • Raise the quality, quantity and sustainability of green spaces to ensure their protection as a show of best practice for other landowners • Improve sustainability of parks, including bettering existing buildings, and pioneering Sustainable Urban Drainage Systems (SUDS) and sustainable/resilient planting where appropriate</td>
<td>• Review vegetation cover to improve resilience • Explore options for the proactive management of pests and diseases using natural solutions, and pilot a proactive health plan for notable trees with external funding • Refurbish play areas for resilience under heavy usage and replace when they are at the end of their life cycle • Raise public awareness of biodiversity • Review of facilities and infrastructure to ensure it is fit for purpose/achieving its full potential</td>
</tr>
</tbody>
</table>

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9 Adapted from The Royal Borough of Kensington and Chelsea 2016.
| Maximize funds by harnessing external resource (where this fits park interests) | • Identify where a funding shortfall will have a negative effect on the plan  
• Identify external sources of funds/grants/donations and apply for funds  
• Expand managed volunteer programme  
• Develop partnerships in order to access external funding.  
• Increase commercial activity (as appropriate) | • Ensure that income-generating activity in parks directly benefits the parks in which it takes place  
• Involve stakeholders in the strategic management plan for their parks  
• Explore match-funded crowdfunding opportunities  
• Develop further a volunteer programme where citizens do more |

**Kensington Gardens, London. Photo: © Serge Salat.**

### CASE STUDY: A NETWORK OF PARKS AND GARDENS, THE ROYAL BOROUGH OF KENSINGTON AND CHELSEA IN LONDON

With an area of 12.13 km² and a population of 156,129, the borough of Kensington and Chelsea has a density of 12,871 people/km². Thirty percent of the land is streets. Altogether, 46.4% of the land is public or semi-public open space. All residents have easy access to a green, open space for relaxation, a variety of leisure pursuits and quiet reflection in an area of London with a dense population and competing demands on space. These green spaces are safe and pleasant for people to use.
Seventy-eight ha of public green space include 28 parks, two cemeteries and a further 60 green spaces. They comprise over 3,200 trees of 180 species. To these should be added 235 private open spaces comprising 88 private squares with gardens accessible to surrounding residents only (most often of half ha to 1 ha area) totalling 88 ha. Each park has its individual history, landscape, features, user group profile and local community, all of which contribute to creating its feel or essence.

10 The Royal Borough of Kensington and Chelsea 2004 and 2016.
The borough totals 166 ha of green space, that is 14% of the land area and 10.6 m²/inhabitant. Three nearby parks of metropolitan size need to be included in the calculation of green space accessible to the borough residents. They comprise: Battersea Park (81ha) in the London Borough of Wandsworth beyond the southern boundary of the borough; Kensington Gardens/Hyde Park (249ha), partly within the City of Westminster, to the east of the borough boundary; and Wormwood Scrubs (65.5ha) in the London borough of Hammersmith and Fulham. Altogether 570 ha of green spaces are accessible, that is 36.5 m² per resident.
If we add civic non-green space, 197 hectares of public and private open space in the borough cover 16.4% of its area. They are distributed in 339 open spaces (on average one every 100 m from each residence)\textsuperscript{11}. The borough parks are places of social activity with:
- 26 playgrounds
- One café and three kiosks
- More than 20 sports facilities (including tennis courts, grass pitches, multi-use games areas, golf and cricket wickets)
- Three outdoor gyms\textsuperscript{12}

\textbf{Pembridge Square in Kensington and Chelsea, London}

An example of the many gardens of Kensington and Chelsea is Pembridge Square. The central garden was laid out rapidly and was fully planted by 1865 and surrounded by heavy iron railings; a Garden Trust was set up in the same year to look after it. At his death in 1978, at the age of 97, William Irving (1881–1978) was the last of the seven trustees of the Garden who had been appointed in 1953. He had sent a sealed letter to the Pembridge Association in 1976 with instructions that it was not to be opened until after his death: ‘The garden should continue to be maintained as an ornamental “oasis” for the relaxation of authorized users, considered now to be more important than ever, having regard to the increasing speed, noise and stress of London life’. He asked the Pembridge Association and the Kensington Society to give ‘what assistance and support may be necessary’ for the Trust Deed to be amended by the High Court to make it workable in present-day conditions. Ultimately, with the support of the Council, the Garden Square was brought under the control of the Kensington Improvement Act which allowed the raising of a ‘garden rate’ to pay for the maintenance.

\textsuperscript{11} The Royal Borough of Kensington and Chelsea 2004.
\textsuperscript{12} The Royal Borough of Kensington and Chelsea 2016.
CASE STUDY: WEAVING GREEN SPACES IN THE URBAN FABRIC IN FRENCH DREAM TOWN IN HANGZHOU

The design of the neighbourhood creates three attractive centres: two squares at the entrances to the neighbourhood, at the level of the two bridges, and a large central square by the water. These three squares open onto the river and nature as privileged spaces for social life. From one square to another, people can cross the heart of the blocks by semi-covered passages, to find the traditional scale of Chinese villages and the rediscovered nature that slips between constructions. French Dream Town is a natural new space, taking advantage of the tremendous skills of Chinese gardeners. In this new conception of town planning, nature becomes the common thread of the city of tomorrow. The presence of water, plants, the work on shade and natural ventilation of buildings, will effectively fight against the heat island without spending energy.

French Dream Town, Hangzhou, developed by Optiva Darna, southern part. Design: Anouk Legendre, XTU
Cities are mosaics of microclimates locally modified by the site topography and by the form of the urban fabric. Development supplants vegetation with asphalt and buildings. Cool, transpiring green surfaces are replaced with heat-absorbing dark surfaces, such as dark roofs and heat-storing massive surfaces, such as concrete. Taller buildings in the inner city block the wind. They create more friction, and reduce the ability of other buildings to lose heat to the night sky. This induces the urban heat island effect in which central city temperatures are significantly hotter than the surrounding countryside. The combined impacts of solar radiation, convection, thermal capacity, albedo (degree of reflection of light by an object) and wind can cause differences in microclimates up to 15 °C in distinct parts of a city. High summer temperatures increase energy costs and health risks. The effect of city design on microclimate can make air quality worse and buildings more expensive to operate – or it can clean the air and help buildings to be more energy efficient.

Neighbourhood morphology can by itself reduce energy demand for thermal comfort by 60% or more. Urban form impacts on wind, thermal radiation, and temperature. These parameters affect both the energy consumption and the outdoor comfort. Designers should adapt layouts of buildings, green spaces, squares and streets to local climates. The scheme should optimize natural lighting and shading, natural ventilation and cooling in summer, solar gains in winter and solar energy collection for photovoltaics. Bioclimatic strategies for the urban fabric are crucial to passive design at building scale. They control access to the site resources of the sun, wind, and light. They have a major impact on reducing or magnifying the buildings’ heating, cooling, and lighting loads. Urban patterns are critical for access to renewable site energy, and for natural lighting, solar heating, and ventilation in buildings. Urban bioclimatic design re-establishes the architectural link between man and climate.

An integrated approach, with passive and non-mechanical cooling solutions to moderate air temperatures and increase the adaptability of cities to cope with thermal stress and climate change, includes:

- Designing urban spaces to minimize heat build-up and retention (Urban design).
- Designing bioclimatic buildings (building design).
- Increasing the green and permeable cover (permeable infrastructure).
- Increasing tree canopy (permeable infrastructure and shade).
- Increasing the number of and accessibility to natural and man-made water features (water infrastructure).
- Increasing the ability of urban roofs, walls, and pavements to reflect, rather than absorb, solar radiation (reflective infrastructure).
- Enhancing thermal insulation of buildings (thermal insulation).

This section considers the following actions.

DESIGNING THE URBAN FABRIC FOR NATURAL COOLING
BIOCLIMATIC BUILDING FORMS
COOLING WITH GREEN SPACES
COOLING WITH WATER SPACES
SHADING
GLAZING, MATERIALS AND SURFACES

They are illustrated by an extended case study.

CASE STUDY: FRENCH DREAM TOWN IN HANGZHOU
INTEGRATED BIOCLIMATIC ZERO-ENERGY STRATEGY

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DESIGNING THE URBAN FABRIC FOR NATURAL COOLING

Design offers an enormous potential for establishing sunnier, warmer spaces in winter, and cooler, shaded ones in summer. Considering topography, landscape, street pattern and section, construction volumes, shapes and orientation, and choice of materials can avoid heat islands, change locally summer peak temperatures, and diminish the energy load of buildings while improving external thermal comfort. Urban design can significantly reduce the energy consumption of buildings through shading, natural cooling, wind movement, and passive solar gains, while creating a comfortable public space. It must simultaneously address access to daylight, solar radiation and wind for as many buildings as possible. Modifications to cool the city by adding shade, channelling winds to bring ventilation to more edifices, and working with the topography can result in an urban cooling plan.

Even for projects of single buildings, the architect should consider building group approaches because each building contributes incrementally over time to define a larger pattern. The form and placement of one single building introduce a set of relationships with the street and with nearby buildings. It configures open space and creates distinct microclimates around the constructions.

Design is key to take advantage of the wind flows, develop air paths that enter the urban fabric and remove the accumulated heat. The arrangement of built form and voids, the construction heights and their geometry, all have an impact on urban temperature. The form of the urban fabric affects shadowing and wind. Design should enhance air movement through shaping of street canyons and building geometry. Cost-effective integrated methods are the orientation and layout of buildings and greenery, water bodies and reflective coverings, and the use and combination of open and semi-open spaces at different heights enhancing cross-ventilation.

Designers can act on the surface coverage and on the orientation and geometry of streets.

Surface coverage

- Topography, solar radiation, and wind combine to accentuate certain characteristics of the neighbourhood’s microclimate. The slightly cooler and denser air, on the green slopes, flows down towards the urban area. Principles for predicting the microclimate on a site are as follows:
  - Density drives air movement.
  - Temperature varies with elevation.
  - Solar radiation varies with terrain aspect.
  - Large water bodies moderate the daily and annual temperature range.
  - High mountains form wet windward slopes while low hills create wet leeward slopes.

In regions with significant topographic variations, it is recommended to
  - Locate undeveloped green areas on higher slopes to provide a cool air source.
  - Connect them with downhill corridors leading to urban areas.

15 Using appropriate building forms can make passive ventilation of buildings an option and avoid mechanical air conditioning.

16 The temperature difference between the city fabric and vegetated slopes induces local airflow. The airflow temperature under tree canopies is approximately 1–2°C lower than the ambient air (ETH Zurich 2017).
o For projects facing green slopes, make sure constructions don’t block the wind flow from uphill.

o Maintain adequate gaps between buildings and increase permeability in podium design to enhance the flow.

o Shade and vegetate the wind path to avoid heating up the air17.

▪ Lowering the Coverage Ratio18 provides more open space around the constructions, avoiding heat accumulation during the day, and decreases the air temperature. However, to prevent solar radiation entering the urban fabric, buildings should not be too spaced (See Sky View Factor below). Building developments with large ground coverage, such as those with podium design, restrict wind flow at near-ground levels19. In contrast, podium-free designs increase the air volume at the ground level and contribute to a more comfortable environment.

Minimize ground coverage and avoid large podium designs to enhance wind penetration. Source: HKGBC 2017.

Orientation of streets

▪ The orientation of streets controls the solar access inside and outside buildings, the permeability to airflow, and thus the passive cooling potential. It is crucial to explore the urban breeze pattern to optimize street networks. Streets aligned to breezeways promote air movement20. An array of main streets, wide main avenues and breezeways aligned up to 30° to the prevailing wind direction maximizes the penetration of winds. Shortening the length of the street grid perpendicular to the prevailing wind direction minimizes air stagnation.

Geometry of streets

▪ The street aspect ratio (H/W) determines the incoming and outgoing radiation and thus the heat flux and building energy consumption. It is the ratio of the street height (H) to its width (W)21. The aspect ratio It is crucial to evaluate the best options that both provide shading and increase wind flows. The combination of low buildings and wide streets (or lower aspect ratio) enhances the entrance of wind and thus removes urban accumulated heat. Such canyons improve nocturnal cooling. On the other hand, streets with a high aspect ratio offer more shade during the daytime and thus improve thermal comfort and diminish energy consumption22.

24 HKGBC 2017.

17 HKGBC 2017.

18 The Coverage Ratio is the ratio between the building footprint and the land area.

19 The space between any two podiums should measure at least 15 m and align with the prevailing wind direction (HKGBC 2017).

20 An urban heat island (UHI) is an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The temperature difference is usually larger at night than during the day, and is most apparent when winds are weak.

21 It is calculated by dividing the mean height of buildings by the width of the street.

22 ETH Zurich 2017.
• The sky view factor (SVF), the fraction of sky visible from the ground\textsuperscript{23}, determines the radiation received at ground level during the daytime (solar radiation) and the release of accumulated urban heat during the night (nocturnal cooling). Lower SVF provides more shadow inside the street canyon during daytime and thus curtails the rise of ground temperature. However, trapping of the outgoing radiation during night-time can occur and thus the decrease of ground temperature will be lower at night\textsuperscript{24}.

BIOSCLIMATIC BUILDING FORMS

For bioclimatic efficiency, buildings must be neither too big nor too small. This comes from two imperatives: one is concerned with bioclimatic architectural design; the other, with solar access and density.

• Energy conservation and life quality in buildings depend on access to sunshine and cross-ventilation.
• Higher density of development should be combined with solar access.

Depending on climates, designers can act on the Surface to Volume Ratio ($S/V$) and on the Passive Volume Ratio of buildings.

• Surface to Volume Ratio influences thermal losses through a building envelope but also the potential of a building to benefit from natural lighting, ventilation and from solar gains. With a high $S/V$, comparatively more building skin is exposed to heat losses through the envelope. However, a high $S/V$ provides a higher exposure and capability to harness the natural energies of the sun, wind and light for thermal comfort and natural lighting.

• Passive Volume Ratio is the percentage of a building volume that benefits from passive techniques such as solar gains, solar heat storage and heat inertia, cross and stack ventilation, and natural light. It is the percentage of the total building volume less than 6 m from the building’s envelope. The low Passive Volume Ratio of a large building means spending more energy handling the internal stresses of overheating in commercial buildings in summer. It also means less potential for the architect to ‘design with nature’ and to use natural energies for natural lighting, heating and cooling.

The right size for a building section. High passive volume depends on the right size of the building section. It is recommended that designers breakdown programmes into compositions of thin buildings interwoven with green and water spaces to benefit from natural lighting and ventilation. The size of building sections depends on orientation. A building depth of 12–13 m is about right for N-S exposures whereas the depth for an E-W exposure averages 3 m greater. Useful sunlight, especially in winter, can enter from only one side of a N-S section. But it enters from that the sky is completely visible with no obstacles around.

\textsuperscript{23} It is the ratio of the radiation received by a planar surface to the radiation emitted by the entire hemispheric environment. SVF is a dimensionless value that ranges from 0 to 1. For instance, an SVF of 1 means that the sky is completely visible with no obstacles around.

\textsuperscript{24} Lower SVF can worsen the UHI during night-time but improve outdoor thermal comfort during daytime due to shade provided by urban elements.
two sides of an E-W section. This provides 2–3 hours of
sun from the east in morning, another 2–3 hours from
the west in the afternoon, enlivening most of the space
in the deeper unit.

Finding the right balance between S/V and density. A
critical cut-off value of S/V = 0.1 provides for good
solar access and cross-ventilation in a dense, compact
and continuous urban fabric. The cut-off value of S/V =
0.1 provides a simple but powerful design tool.

Architects or urban designers don’t have to wait until a
project is far advanced to evaluate its passive-design
potential. Even at very early stages of planning, a simple
calculation, performed on alternative massing
schemes, provides a basis for comparing the eventual
character of their energy usage. If S/V is more than 0.1,
designing with nature is a good option. On the other
hand, if S/V drops below 0.1, reliance on energy-
intensive systems is inevitable.

COOLING WITH GREEN SPACES

Greening the urban fabric encourages biodiversity,
reduces the urban heat island effect, provides shade
and cooling, improves air quality, soften the harshness
of the cityscape, restores wildlife habitats, and
reconnects people with nature. Planted areas can be
as much as 6–8°C lower than built-up areas due to a
combination of evapotranspiration, reflection, shading,
and storage of cold. When creating parks in dense
areas, cool air from the green areas replaces heated air
rising over heat island peaks. Properties of vegetation
include high albedo and low heat admittance. They
diminish accumulation of incoming solar energy.
Additionally, trees provide shade and minimize the
heat gain from solar radiation, which improves thermal
comfort. Also, the decrease in ambient air temperature
and the shading lower building energy demand for
indoor cooling. Vegetation provides seasonal shade for
buildings, screens them from the wind, cools the air
through water loss and filters dust in the atmosphere.
The exterior surfaces of buildings offer vast
opportunities for the insertion of greenery into urban
landscapes.

Detailed Strategies for Bioclimatic Green and Blue Urban Fabric in Sungei Kadut redevelopment project. Workshop at
NUS led by Serge Salat.

25 Knowles 1981.
26 Latitude affects the cut-off for S/V. Los Angeles,
where this study was sited, is at 34 N. At higher
latitudes, where the sun is lower in the winter sky,
bUILDINGS must be either shorter or spaced further apart
for solar access; the result is a higher cut-off value for
S/V. Lower latitudes produce the opposite effect, in
which buildings can be either taller or placed closer
together without losing solar access. The result is a
lower S/V cut-off.
Green Plot Ratio measures the quantity of landscaped surfaces compared to a development’s site area.

The Green Plot Ratio is a three-dimensional ratio between the greenery and the land area. It includes vertical and horizontal landscaping, green façades, sky gardens, lawns and trees, raised planters and urban farms. Integrating green spaces into constructions at multiple levels can achieve a green plot ratio over 100% as requested in new developments in Singapore. It provides cooling to the environment and diminishes surface temperature.

Bo01, Malmö, Sweden, Green Points and Greenspace Factor

Bo01 is part of the residential district Västra Hamnen in Malmö. Despite the densely built-up urban character, much attention was paid to the diversity of green spaces and to biodiversity. During the development, two methods were used to turn Bo01 into a green neighbourhood: the ‘green points system’ and the ‘green space factor’. The basis for the green points system was a long list of measures from which developers had to choose ten to use in the future inner courts. The green space factor describes the ecological value of a lot as an average of its parts qualities. Depending on whether the part lot provides room for green, ecological measures and rainwater management, it is given a value between 0.0 and 1.0. The rule was that each plot as a whole had to score an average of at least 0.5. Most developers and architects were enthusiastic about these clear guidelines. It enabled them to discuss sustainability with the future residents.

Designers can act on city scale urban greening, transport corridors, urban fabric greening, urban farming, water spaces, permeable paving, and three-dimensional building greening.

Large urban parks, forests and natural reservoirs can be at the edge or in central parts of the city. They are called ‘cold islands.’ Green belts supply coolness to nearby areas. Implementation should consider the general climate patterns (such as wind flows) to maximize the cooling benefits.

Transport corridors can be used both as wind corridors and green connectors. Arranging vegetation along
them shades the infrastructure surface. Design should lessen incoming solar radiation while increasing natural ventilation. A combination of different greenery heights together with their location enhances airflow.

**Organizations of interwoven buildings and green spaces can cool the ambient air temperature.** Plantations, lakes and ponds will increase humidity while evaporation will reduce temperatures. Vegetation will moderate and stabilize microclimate. Midsize parks and pocket parks provide areas of thermal comfort for leisure and recreation and should be 300 m to all homes. Greenery around buildings and green courtyards ameliorates the thermal comfort along pedestrian paths and creates continuous thermal comfort pathways. It shades pedestrians, building and ground surfaces. Vegetation absorbs the incoming solar radiation and reduces heat. Trees provide shadowing. Many small open spaces evenly distributed have a great cooling effect. Streets should be oriented to carry cooler air away from parks.

![Chattanooga interwoven organization. Left: Interwoven buildings and planting. Right: Landscaping. Source: Mark DeKay.](image)

In Chattanooga plan by Mark DeKay, green spaces use existing vacant land lots and connect them to form a pedestrian green network. Chattanooga urban cooling plan is based on three key ideas: cool the city by increasing dispersed vegetation; disperse wind throughout the urban fabric by creating passages in the middle of blocks and between buildings; disperse wind throughout the urban fabric by using landscaping and open space patterns to direct wind.

*Chattanooga urban cooling plan. Source: Mark DeKay.*

**Urban farms can serve as green islands.** Growing food within urban areas can be installed in underutilized spaces including rooftops, abandoned buildings and vacant lots. Urban farms also increase the food made locally, thus preventing CO₂ emissions in transport from distant producers, improving food security, and improving community health by providing fresh food.
Green pavements replace artificial material on urban pavements with natural soil elements and grass. They can use permeable pavers, pervious concrete or porous asphalt. They diminish the heat accumulation, decrease surface temperature and influence thermal comfort and the UHI. Porous pavement systems include additional voids compared to conventional ones. They allow water to flow into the ground or into water holding fillers. This contributes to store runoff. These pavements enhance water evaporation and stay cooler than conventional ones. The greatest value occurs when multiple benefits, such as the improved stormwater management and outdoor thermal comfort, are factored in.


COOLING WITH WATER SPACES

It is recommended to replace engineered infrastructure by solutions that work with nature, in which water recycles and supports life at local scale. Nature-based solutions for the water cycle soften the built environment, naturally absorbing storm water and diverting it from the sewers and wastewater treatment plants. Green infrastructure assets include among other features rain gardens and permeable pavers. In Malmö Bo01’s urban landscape, for example, rainwater is led from the roofs to become a feature in a private garden court or to be displayed as open features inside the blocks. It is then channelled to streets, to landscape filtering areas, and to the saltwater canal or the sea. When it rains, the place becomes alive with water sounds and flows. People can locate their position in relation to storm water, enriching sensory awareness. Rather than being buried in pipes, storm water becomes an active spatial reference in the neighbourhood.
SHADING

Shading reduces air and surface temperature. It also improves the pedestrians’ thermal sensation, mitigating heat stress. Urban geometry (aspect ratio) and building/street orientation can shade streets. If it is necessary to have shade in summer and solar gains in winter, deciduous trees can provide it better because of their summer foliage, while allowing sunlight to filter through their branches in winter.

Designers can act through providing tree canopies, shading pedestrian spaces and bicycle lanes.

- Providing tree canopies. A way to reduce pedestrians’ direct exposure to solar radiation is to shade them with tree canopies. The relation between building and tree height will determine the proportion of the façade shaded by trees. It is recommended to
  - Plant trees with large canopies in frequently used open spaces.
  - Select plant species with high leaf density to maximize the shading effect.
  - For large sites, provide tree coverage for over 25% of the total site area.


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29 HKGBC 2017.
Shading pedestrian spaces. Buildings, canopies or trees can protect pedestrian spaces against direct sunlight. The design of shaded pedestrian spaces should consider the relationship between the year-long sun path and the users. Awnings and colonnades transform public footpaths, verandas and terraces into habitable edges. They provide protection from the summer sun and seasonal storms, allowing to create breathable, outdoor spaces and maintain activity on streets all day long. Planted trellises, sheltered walkways, freestanding shade structures and trees create outdoor spaces that are welcoming all year. They embrace indoor-outdoor lifestyle while protecting from the hot summer sun and rain. They allow to cross bridges, occupy parks and enjoy rooftop views while appreciating the fresh air, natural light and openness.

Shading bicycle lanes. They shield cyclists from direct sunlight and high air temperatures, and help them have a comfortable ride, thus promoting active mobility.

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30 Brisbane City Council 2014.
GLAZING, MATERIALS AND SURFACES

Glazing

The choice of glazing should minimize solar gain and heat transmission through the façades.

Materials and surfaces

The nature of surfaces also influences the microclimate. When a material absorbs solar radiation, some of the light energy is converted into heat energy, and the material warms up. Darker materials feel hotter than lighter ones when both are exposed to sunlight. The lighter-coloured materials reflect more sunlight than darker colours and have what is called a higher albedo. In urban areas, the effect of low albedo, notably of asphalt, contributes to the urban heat island. Increasing urban albedo can diminish summertime temperatures, resulting in better air quality and savings from less air conditioning costs.

Reflective materials can increase roof and pavement albedos of urban roofs and paved surfaces will induce a negative radiative forcing on the earth equivalent to offsetting about 44 Gt of CO₂ emissions. At ~$25/tonne of CO₂, a 44 Gt CO₂ emission offset from changing the albedo of roofs and paved surfaces is worth about $1,100 billion. Furthermore, many studies have demonstrated reductions of more than 20% in cooling costs for buildings whose rooftop albedo has been increased from 10–20% to about 60% (in the US, potential savings exceed $1 billion per year) (Akbari et al. 2008).

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 diminish the ground surface temperature. They reduce their surface temperature by reflecting a significant percentage of solar radiation. These surfaces present a light colour, or white. They have a high albedo (high solar reflectance) and high thermal emittance. They are obtained by implementing lighter coloured asphalt on streets and roads and by cool tiles or special coatings on urban pavements. Use cool materials with an albedo index of at least 0.4, such as those of lighter colours, for outdoor ground surfaces. Cool roofs have high solar reflectance and high thermal emittance. Their white or lightly coloured reflecting surfaces decrease their surface temperature and heat transferred into the buildings below. They reduce cooling energy consumption and energy costs in buildings. They heighten the urban environment albedo if broadly applied. They present a high mitigation potential for UHI. The wide implementation of cool roofs is financially and technically viable. They provide a cost-effective solution to increase building energy efficiency.

Cool façades present covering layers that limit the absorption of solar radiation. They cut the heat transferred into the building and the energy consumption for interior cooling.

Thermal mass is the property of absorbing and storing heat energy. Materials such as concrete and bricks typically have high thermal mass. Reducing the thermal storage of materials, diminishes heat dissipation to the outdoor environment and ambient temperature. 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 aluminium louvres or green walls (HKGBC 2017).

Water cooling façade systems transfer heat by evapotranspiration outside the buildings. They use water integrated within the building façades. Implementation should be focused on south-facing façades. Recent research proposes a double skin façade with cooling pipes integrated within a shading device, such as a Venetian blind. Cooling water produced by a cooling tower circulates in the pipes and takes away the radiant heat.

Designers must consider the following options.

- Increase the albedo and reflectance of all surfaces with light colours.
- Use cool pavements, roofs and building envelope.
- Use porous pavements.
- Reduce thermal mass heat storage of building material.
- Use water.
• Use advanced technologies such as photocatalytic envelopes, phase change and thermochromic materials.

• Use dynamic and active roofs and façades.

**CASE STUDY: FRENCH DREAM TOWN IN HANGZHOU INTEGRATED BIOCLIMATIC ZERO-ENERGY STRATEGY**

This case study presents how the bioclimatic design strategies presented in this chapter are applied to French Dream Town in Hangzhou, designed by Anouk Legendre, XTU, for the Southern Part and by Serge Salat, architect for the Northern Part. Integrated with smart systems and renewables, these bioclimatic strategies allow to achieve zero energy for the entire development.


**Green Design Concept**

The green design concept shapes the urban fabric to enhance shading, natural ventilation, accumulation of rainwater, three-dimensional greening, and collection of solar energy. Hangzhou climate has very hot summers, mild winters, and is humid all year. Different sustainable systems both passive and active are proposed

- **Shading of the façades by large overhanging solar canopies.**
- **Natural ventilation:** In the months of mild temperatures the buildings will work with natural ventilation. A practicable stripe on each window will allow the air in rooms using the central (hotel, apartments, AI West Wing) and perimeter (AI East Wing) atria as a ventilation shaft. This passive system permits cooling without energy expenditure.
- **Accumulation of rainwater.** The rainwater will be collected cooling and for watering plants on the green roofs and green façades.
Three-dimensional greening extends on all building and urban surfaces achieving a high green coverage ratio with green roofs, green terraces, green façades, green patios and green pavement.

Collection of solar energy. On the curved solar canopies, a series of photovoltaic panels will capture energy for the energy of the buildings.

The design crafts simple forms to achieve maximum energy efficiency with passive bioclimatic techniques.


Shaft Ventilation and Natural Lighting

Full height skylight atria achieve natural lighting and ventilation through chimney effect and ensure a distribution without corridors. By giving the atria multiple roles, the project optimizes the surfaces due to the compact shape of the buildings.

Dream Town Northern Part. Atria. The buildings don’t comprise closed corridors which would require artificial lighting and ventilation. The central atria naturally lit with gangways to access rooms distribute the hotel and apartment building. The AI Experience Centre open plan with movable partitions structures open spaces 8.4 m side allowing the free flow of air across the entire floor plate of the 2 wings.
The project skylight atria have extensive roles and are key for the energy performance of the buildings. They are all lit in overhead light and can open in their upper part. The multiple roles of the atria are:
- Contain the vertical public circulation (helical staircases) of the different buildings; This role is particularly important in the Al Experience Centre which aims to accommodate a large audience by offering varied routes and experiences.
- Maximize the natural light and contribute to reducing the energy consumption for lighting by 50%.
- Enhance natural ventilation in summer to reduce cooling energy consumption by about 20%.
- Use passive solar gain in winter (for the atrium at the south-east corner of the Al Experience Centre) and help reduce energy consumption for heating.

**Flexibility**

Vertical cores at the periphery of the buildings provide flexibility for the floor plates.
Greening

French Dream Town patio greening and permeable green paving, Hangzhou, developed by Optiva Darna, Southern Part. Design: Anouk Legendre, XTU.

Green roofs, vertical greening and green terraces achieve an above 100% Green Plot Ratio. The green plot ratio calculated on the building footprint for each building is as follows (without the green terraces): hotel: 109%; apartments: 158%; AI Experience: 96%. The average green plot ratio is 116%.

Overall, green roofs in French Dream Town northern part comprise 1,814 m² and green facades comprise altogether 1,188 m². As a result, architecture greening totals more than 2,735 m². To these, should be added the green terraces.
**Shading and positive energy**

French Dream Town Northern Part is positive energy through 5000 m$^2$ of solar PV canopies. It produces 220% of its energy consumption, making the whole 2-ha French Dream Town site a zero-energy development.

*French Dream Town, Hangzhou. Southern Part design: Anouk Legendre XTU. Northern Part design: Serge Salat.*

*Dream Town Northern Part. Photovoltaic canopies. Design: Serge Salat.*

*Dream Town Northern Part. Photovoltaic canopies. Design: Serge Salat.*
The positive-energy strategy comprises two levers
1/ Reducing the demand by about 30% through energy-efficient architectural forms and through green integrated systems for energy and water
2/ Supplying the remaining energy loads by renewable energy.

- **Reducing the demand through energy-efficient forms.** The cooling loads in a climate like that of Hangzhou are typically 2.75 to 3 times higher than the heating loads. Thus, the design minimizes primarily cooling energy loads. The project atria with skylights, the positioning of the safety circulation at the buildings’ periphery and the green roofs and terraces are all part of the green strategy. They make it possible to obtain positive energy buildings using photovoltaics. All areas within the buildings are less than 6 m from a natural light source achieving a 100% Passive Volume Ratio. The atria with skylights ensure that no corridors occupy a significant part of the floor areas with long luminous operation hours. Therefore, during the daytime, the buildings will be mostly lit by natural lighting, ensuring significant lighting savings.

- **Reducing the demand through energy-efficient systems.** Through holistic integrated planning of multiple energy saving measures, the most feasible ones were combined into one proposal.

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41 While being energy efficient by design, the project also maximizes saleable floor-plates. For the AI Experience Centre the project achieves a ratio of saleable surfaces compared to circulation surfaces of 73% and for the hotel and apartments buildings it achieves a ratio of 78%, which is much higher than the commonly acceptable 60% ratios.

42 Previous studies of similar buildings in similar climatic conditions (Ningbo campus GEF-World Bank project) suggest that the bundled implementation of the above measures as well as the atrium building shape can have a significant effect on reducing the energy demand. In the similar Ningbo campus building, the implementation of these measures resulted in an overall decrease of 28.5 % of the energy loads compared to the baseline scenario. This overall decrease results from
- 60% decrease in heating energy
- 17% decrease in cooling energy
- 48% decrease in lighting energy.
- Reduced U-value\textsuperscript{43} of glazing\textsuperscript{44}
- LED panels and daylight control\textsuperscript{45}
- Solar power generation

- **Supplying the remaining energy loads with renewable energy.** The implementation of PV modules will generate renewable energy generation on-site, will make the development energy positive and carbon neutral\textsuperscript{46}.

The energy self-sufficiency Index of French Dream Town depends on two technical variables: 1. The implementation of energy efficiency measures for systems; 2. The type of PV cells (monocrystalline or polycrystalline)

<table>
<thead>
<tr>
<th>Energy self-sufficiency Index</th>
<th>Northern Part of French Dream Town</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without system’s energy efficiency and with polycrystalline cells</td>
<td>137%</td>
</tr>
<tr>
<td>With system’s energy efficiency and with monocrystalline cells</td>
<td>221%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy self-sufficiency Index</th>
<th>All French Dream Town</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without system’s energy efficiency and with polycrystalline cells</td>
<td>61%</td>
</tr>
<tr>
<td>With system’s energy efficiency and with monocrystalline cells</td>
<td>99%</td>
</tr>
</tbody>
</table>

The tables above show the importance of obtaining a good balance between energy efficiency measures to diminish the demand (bioclimatic architectural forms and energy efficient systems) and PV supply. Depending on the energy efficiency, the solar supply achieves different levels of self-sufficiency. In all scenarios, the Northern Part is energy positive but the investment in PV panels proves much more efficient when architectural forms and systems are optimized. The effectiveness of PV investment increases by 60% in the Northern Part when demand reduction by design is made first. Similarly, if bioclimatic design is not implemented first the PV panels cover only 61% of French Dream Town needs. With bioclimatic design and energy efficient systems, all French Dream Town can be made zero energy with the Northern Part PV panels.

\textsuperscript{43} The U Value is the measure of air to air heat transfer through glass due to the thermal conductance of the glazing and the difference between indoor and outdoor temperatures. It is expressed as W/m$^2$K (Watts per m$^2$ per 1° Kelvin) or W/m$^2$ °C (1 Kelvin equals 1°C). The U value is a measure of the rate of heat gain or heat loss through the glazing due to environmental differences between outdoor and indoor air. The lower the U Value the lower the heat transfer, the better the insulation.

\textsuperscript{44} In a climate combining hot weather in summer and cold weather in winter, solar gain should be balanced across seasons. In a climate like that of Hangzhou, cooling loads are about 2.75 times higher than heating loads. It is thus recommended to focus on reducing solar gains in summer and heat transfers through the envelope in winter. This is achieved by reducing the windows transmittance, and the U values of glazing compared to baseline.

\textsuperscript{45} From the analysis of similar projects (Ningbo campus GEF-World Bank project), the implementation of LED panels and daylight controls is recommended. This could reduce the energy required for lighting by up to 30%. The implementation of daylight light sensors, to operate the LEDs according to the availability of natural lighting, is recommended.

\textsuperscript{46} The solar canopies above the Northern part have a total area of 4,923 m$^2$. They can currently hold an area of PV of about 4,675 m$^2$ once deducted edges. This will generate 940,000 kWh/a with monocrystalline cells and 815,000 kWh/a with polycrystalline cells. The Northern part of French Dream Town is largely energy positive both though reducing the demand with energy efficiency and through supplying solar energy.
BIOCLIMACTIC DESIGN IN COLD AND TEMPERATE CLIMATES

IMPACTS OF URBAN FORM ON ENERGY USE

Over the past decades, many cities have developed urban structures where buildings stand far apart from each other, creating a broken urban ‘fabric’. In cold climate zones, this dysfunctional pattern leads to high energy demands for heating. An uninterrupted urban fabric with buildings clustered together along the street at the block perimeter is much more energy efficient.

A comparative analysis done in Europe has found the following impacts of urban fabric on energy demand. In a temperate climate, a compact continuous urban fabric, with 21-metre-high perimeter blocks, requires four times less heating energy than a broken urban fabric, with 60-meter-high, freestanding tower\textsuperscript{47}. In cold climates, more compact forms reduce heat losses. They expose less surface area for the volume enclosed and share more wall space. As density increases, design should ensure natural ventilation and lighting with narrow floor plans—less than 12–14 m deep floor space—while not heightening the need for cooling in summer. Denser development will be less able to use passive solar gains and on site generated solar energy under the form of solar thermal or PVs. However, the urban form design may partially overcome these limitations.

KEY DESIGN RECOMMENDATIONS

Key design recommendations in cold climates are as follows

- **Design compact urban forms with buildings aligned along the perimeter of the block and inner courtyards.**

- **Maximize the warming effects of solar radiation through orientation.** In cold climates, let the light in. The key to optimizing the solar potential of the site is to orient buildings largely to the south. This tends to create an east-west street model. It is feasible to move up to 30° away from south and yet have 90–95 % of a PV module or solar collector maximum output. In a cold climate, the more sun, the better (potential problems of overheating and glare can be dealt with during the design phase). Contrary to common beliefs, it is possible to achieve high levels of natural light with a tight urban form. Careful design can provide sufficient solar access to all floors in tighter settings and to solar energy systems installed on roofs. For natural lighting, larger windows can compensate lower solar access on the ground floor\textsuperscript{48}.

- **Reduce the impact of winter wind with gradual height transitions.** In cold climates, urban geometry may exacerbate the adverse effects of the wind. Abrupt changes in building height significantly increase wind velocity in streets and open spaces. Therefore, gradual height transitions of building groups, sloped toward prevailing winds, minimize wind movement in streets\textsuperscript{49}. Gradual height transitions allow most of the cold wind to pass over the top of buildings. Height transitions from one building to another, or from one neighbourhood to another, should not exceed 100%. Decreasing wind speed will improve

\textsuperscript{47} Salat et al. 2011.

\textsuperscript{48} However, a balance needs to be found between new developments and constraints imposed by the local environment, particularly with regard to land use and street configuration in adjacent areas, as well as the height and rooftopscape of adjacent buildings.

\textsuperscript{49} Reducing the effect of the sea wind coming from the Öresund is one of the reasons for the irregular street patterns in Malmö.
pedestrian comfort in outdoor spaces, and reduce heat loss from buildings.

- **Orient and size streets and blocks to integrate concerns for light, sun, and shade.** Wider east-west streets give better winter solar access while wider streets towards prevailing wind flows improve wind movement through the city. Narrow north-south streets create shade from one building to the next.

An example of urban design that reduces the wind impacts in cold climates while providing unique urban forms and dramatic contrasts between inside and outside is Bo01, Malmö, in Sweden. The buildings facing the Öresund are five- to seven-story slabs, approximately 50 to 60 metres long, with small gaps between them. Their position at slight angles to one another deflects the wind. Buildings inside the blocks plug the gaps between the edge buildings. Together the outside edge buildings and the inside buildings create an effective windbreak while creating an enjoyable pedestrian experience.

CASE STUDY: WATER URBANISM AND GREEN BOCKS IN AMSTERDAM AND HAARLEM, NETHERLANDS

Amsterdam grew out of a 13th-century fishing village and acquired the status of a city at the beginning of the 14th century. Amsterdam is representative of a distinctive regional city type. Its construction is on land reclaimed from the sea and is expansion guided by the extensive presence of canals. In the older sectors of the city, the distribution and type of buildings are specific to this city and to the architecture of the Netherlands. Amsterdam’s expansion in the Golden Age took the form of rows of plots constituting large blocks around big gardens, all of which was integrated into a connected network of canals, streets, and bridges.
Amsterdam in 1652. Canvas, 100 cm × 137 cm. Amsterdam Historical Museum.

Amsterdam. The sequence and diversity of doors supply rhythm to the urban path. Photo: © Françoise Labbé.
Amsterdam. The architectural work along the streets, especially those facing the canals, is complemented by the treatment of the corner and the closures that block the perspectives. Photo: © Françoise Labbé.

Amsterdam. The spaciousness and shape of the gardens inside the blocks provide residents with an interior space they can readily appropriate. In this case, they created an intimate, sociable setting in a French-style garden, bounded by plantings on a human scale. Photo: © Françoise Labbé.
Amsterdam canal. Photo: © Françoise Labbé.
Inner green blocks in Haarlem, Netherlands. Top: Progression from the street door to the inner block green core. Bottom: The green courtyard is layered with more public and more private green spaces with subtle differences in permeable paving. Photos: © Françoise Labbé.
BIOCLIMATIC DESIGN IN MEDITERRANEAN AND HOT DRY CLIMATES

Urban fabrics in hot dry climates are usually compact and dense with narrow streets and small squares and with tall vegetation for shading. Traditional urban fabric is made of a multiplicity of courtyard houses. This layout provides optimal protection against solar radiation.50

COMPACT TRADITIONAL URBAN BLOCK ORGANIZATION IN HOT AND DRY CLIMATES

The houses forming a block mostly develop in groups around the mosque. The blocks are very dense and compact, leaving little room for open-air streets. In Fez, wooden lattices cover many streets. They filter light and give it an architectural dimension. The houses are not visible from the outside. Only the inside reveals all their beauty.

50 Salat et al. 2011.
Fez medina urban block organization around the mosque. Drawing by Adrien Cuau. École Spéciale d'Architecture, Paris.
HOW TO DESIGN STREETS FOR HOT AND DRY CLIMATES

In hot arid climates, night temperatures are significantly lower than day temperatures, and a rise in nocturnal temperature is welcome if it is accompanied by a decrease in diurnal temperatures. This is why narrow and tall streets with a low sky view factor\(^{51}\) and a high aspect ratio (H/W) is the optimal street form. They prevent heat for entering within the urban fabric during the day and the limitation of heat release towards the night sky is not so much an issue as nights are cold. Besides, comfort is not only based on temperature but also on radiative exchanges. In the daytime, a low sky view factor increases direct shading and reduces reflected radiation.

\(^{51}\) The sky view factor (SVF) is the fraction of sky visible from the ground. SVF determines the radiation received at ground level during the daytime (solar radiation) and the release of accumulated urban heat during the night (nocturnal cooling). Lower SVF provides more shadow inside the streets during daytime and thus curtails the rise of ground temperature.
Narrow streets with tall buildings are characteristic of vernacular layouts in hot climates. They create more shade than wide streets and shade east and west façades on north-south oriented streets. Since the midday sun has a high-altitude angle, it is difficult to use one building to shade another except for very high building height to street width (H/W) proportions of 4/1 or greater. In hot and arid climates, buildings are very close together to increase shade.

Key recommendations are as follows

- **Maximize shade.**
- **Minimize hot, dust-laden winds.**

**Street design should ensure that buildings shade each other and adjacent exterior spaces.** When façades are shaded, their surface temperatures are lower. Thus, the buildings gain less heat and use less energy for cooling. When streets and sidewalks are shaded in summer, daytime mean radiant temperatures are lower, creating more comfort for pedestrians.

CASE STUDY: SHADED NARROW STREETS WITH A HIGH SHAPE FACTOR, FEZ MEDINA, MOROCCO
The plan of Fez medina is star-shaped. The centre is the Mosque University El-Quaraouyyine and its close surroundings such as the sanctuary of Moulay Idriss and the souks. All the streets gather towards this central point. The city topography complicates this convergence. First, gentle gradients ascend on the outskirts of the medina to the west. Then the slopes steepen, the walls are taller, the streets narrower. The streets block light penetration.

*Fez medina, Morocco. Contrast between built and void spaces: in white, the network of streets and interiors of the most remarkable edifices; in black, the built volumes. The streets branch out into several smaller and smaller streets, moving from more public to more internal. Each colour corresponds to a progressive level of intimacy and depth within the pattern: purple, the busiest street; red, the distribution area for the smaller streets; then the inner alleys in blue and finally the green cul-de-sac serving a single-family house. Drawing by Adrien Cuau. École Spéciale d’Architecture, Paris.*

Examples of aspect ratio (H/W) of typical streets in Fez medina.

<table>
<thead>
<tr>
<th>Street</th>
<th>H/W</th>
<th>L</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulevard</td>
<td>1.28</td>
<td>7m</td>
<td>8-9m</td>
</tr>
<tr>
<td>Derb Jama’ Zellij</td>
<td>4</td>
<td>2m</td>
<td>8m</td>
</tr>
<tr>
<td>Derb Nekhaline</td>
<td>3.2</td>
<td>2.5m</td>
<td>8m</td>
</tr>
<tr>
<td>Derb Sid L’Aouad</td>
<td>7</td>
<td>1m</td>
<td>7m</td>
</tr>
</tbody>
</table>
Fez medina presents a ‘fractal’ pattern. From the boulevard to the many narrow cul-de-sacs, the medina is a labyrinth of more than 9,454 alleys. Its structure is ‘fractal’: like the roots of a tree, the streets spread, becoming smaller and more intimate. The alleys vary in size, ranging from 1 to 4 metres wide, for an average of 9 metres high as in most Moroccan medinas. Their typical aspect ratio (H/W) is 3.6. The streets may appear all narrow but they present a threefold clear hierarchy. First, large continuous ones bust with a lot of activity and cross the medina. Second, residential ones are quieter. They lead to alleys, many of them dead ends.

Visual effects in Fez medina streets. From left to right and from top to bottom: discovery, framing, inflection, closure. Drawings by Adrien Cuau. École Spéciale d’Architecture, Paris
Street definition and light colour (high albedo) patterns in Fez medina

Derb Attarine, Fez, Morocco.

The street which allows to distribute towards the alleys. Second link in the fractal street chain.


The façades on the streets of Fez Medina have similar heights, which accentuates the labyrinthine aspect. The great heights, the narrowness of the passages, everything prevents heat from penetrating the urban fabric. The lack of buildings’ alignment, their few centimetres offsets, make the street space dynamic and accelerate air movement.

To reinforce thermal inertia, the façades have few openings. The elements that punctuate them are the doors and windows in mashrabiyya (wooden lattice screens). Each window performs a ventilation function while filtering light.
Trees and adjacent buildings shade the streets. Their white façades and light ochre paving present a high albedo. Their winding and irregular shapes accelerate the breezes coming from the nearby sea.

Streets in Sidi Bou Said, Tunisia. The albedo of clear surfaces on walls and paving avoids trapping the heat. Narrow streets are naturally shaded. Lush vegetation in the courtyards and streets provides additional shade and cools the air by evapotranspiration. Photos: © Françoise Labbé.
Mashrabiyya windows (wooden lattice screens) let the air in the house while filtering light and preventing heat penetration.
Ratti et al. (2003) summarize the advantages of continuous courtyard textures for hot arid climates:

- A greater envelope surface area and thermal mass.
- Access to daylight through the courtyard and shallow plans.
- Narrow spaces providing shade and enhanced thermal comfort.

The combination of these three characteristics establishes a context in which low-energy strategies limiting use of air conditioning are possible. An essential feature of courtyards is that they create a microclimate. Their intermediary interior environment is quieter, cleaner, and more private than the street. When we consider all the effects taken together, traditional continuous courtyard textures are superior to freestanding pavilions in hot dry climates.

The lower sky view factor of the courtyard textures is beneficial in hot and arid climates. It offers shading during hot diurnal periods. As nights are cold, the lower potential of night cooling is not an issue. When
considering the temperature differences between day and night in arid climates and the thermal inertia phenomenon, these urban textures with courtyards perform very well in these climates.

Tunis medina courtyard. Photos: ©Françoise Labbé.

The urban fabric in the central area of Tunis medina illustrates the climatic optimization of courtyard textures. They comprise three hierarchical levels: the main large central courtyard of the mosque, the medium-size courtyards of the Koranic schools, and the myriad of private houses small courtyards. Source: ASM Tunis.
In medinas, voids divide areas of activity and of residence and structure around them the private and public space. An intricate set of solids and voids organizes the urban fabric. It follows a clear hierarchy.

Fez medina, for instance, presents three types of voids: private voids (the interior courtyard of a house), semi-public voids (the courtyard of the mosque forbidden to non-Muslims) and finally public spaces.

Empty spaces in Fez medina. On the diagram: in green, the private spaces; in blue, the semi-public spaces; and, in purple and red, the public spaces. These voids vary in size depending on their importance, as is the case with the mosque, for example. Drawing by Adrien Cuau. École Spéciale d’Architecture, Paris.

Aspect ratio of the mosque courtyard.

Aspect ratio of semi-public (left) and private courtyards (right).

A square central courtyard organizes this Marinid house of Hispanic influence. It is refreshed by a fountain and shaded by fruit trees. The ambulatory galleries around are typical of Hispano-Moorish architecture. The building is divided into three parts, two floors and a mezzanine. The large vertical posts marking the structure of the patio rise to unhook in superb narrow arches which do not weigh down the façade. The composition of the balconies and mashrabiyya windows are also of Hispano-Moorish influence. The geometry, made up of numerous vertical and horizontal lines enrich the beauty of this interior courtyard. In the Arab world generally, the façades, which we see adorned on the street side in the West, are inside buildings.

Sa’did period house in Fez medina. Left: Plan. Right: Section and elevation on the courtyard interior. Drawings by Adrien Cuau.
DESIGNING CONTEMPORARY BUILDINGS IN HOT AND ARID CLIMATES\textsuperscript{52}

Open buildings without air conditioning

Hot and dry climate zones experience very hot daytime temperatures and, depending on the altitude and latitude, huge temperature differences between day and night. Therefore, massive and heavy exterior walls and roofs are highly important to keep the temperature constant for a longer time and to create a natural barrier between the interior and exterior temperatures. Massive walls and roofs absorb the heat slowly during the day and slowly release it during the cooler nights, thus reducing the amplitude of temperature variations between day and night. Natural ventilation during night-time allows fresh air inside the building to cool the inner structure which can in turn absorb internal gains during the daytime, thus maintaining a comfortable indoor temperature throughout the day.

![Open building type in hot dry climate. Source: PEEB 2020.](image)

- **Shape** – Buildings are compact and close to each other shadowing each other’s façades.
- **Walls** – The walls are massive for blocking the heat during day peaks.
- **Roofs** – The roofs have thermal insulation, reducing the heat flow to the interior, are light-coloured with a reflective coating and are naturally ventilated below.
- **Shading** – Generous awnings and roof overhangs and external shading elements minimize solar radiation on façades and windows.
- **Windows** – Small louvre windows or shutter windows allow for improved air circulation.
- **Windows to wall ratios** should be optimized to avoid excessive solar gains.

Closed buildings with air conditioning

In very hot dry climate zones, mechanical cooling might be needed for comfortable interior conditions. A closed, well-insulated and airtight building design, based on the Passive House principles\textsuperscript{53}, can be an adequate solution.

- **Shape** – Buildings are compact and close to each other shading each other’s façades.
- **Walls** – The walls are massive or with high thermal insulation and airtight.
- **Roofs** – The roofs are heavy with thermal insulation and light-coloured with a reflective coating.

\textsuperscript{52} Based on Gruner and Zinecker 2020.
\textsuperscript{53} Passive House principles according to the Passive House Institute: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction.
- **Shading**—Generous awnings, roof overhangs and external shading elements minimize solar radiation on façades and windows.

- **Windows**—Optimized window-to-wall ratios and high performance and airtight windows with solar films or double glazing.

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**BIOCLIMATIC DESIGN IN HOT AND HUMID CLIMATES**

Tropical architecture has always relied upon shading and the perforation of a building’s exterior, allowing light and air to penetrate in the internal spaces. Applying this principle at every scale consists in opening out a room, an apartment, a building, a cluster of buildings, a neighbourhood, so that they can ‘breathe’ and be cooled without the aid of artificial ventilation. Passive cooling strategies first prevent by design heat from entering the streets and edifices. They also remove heat from the building envelope and outdoor areas through natural cooling. Cost-effective methods are the orientation and layout of buildings and greenery, water bodies and reflective coverings, and the use and combination of open and semi-open spaces at different heights enhancing cross-ventilation. Design should include passive techniques such as urban fabric arrangement, porosity, greening and coatings to reduce heat accumulation.

This section considers the following actions.

- **MAXIMIZE WIND VENTILATION WITHIN THE SITE:**
  - Breathing Urban Fabric
- **MINIMIZE SOLAR RADIATION AND MAXIMIZE SHADOW**
- **COOL THE SITE WITH VEGETATION:**
  - Three-Dimensional Greening
- **COOL THE SITE WITH WATER**
- **DESIGNING CONTEMPORARY BUILDINGS IN HOT AND HUMID CLIMATES**

They are illustrated by three extended case studies.

- **CASE STUDY:** Green Spaces Interwoven in the Urban Fabric at All Scales in Singapore
- **CASE STUDY:** A 3D Green Matrix in Kampung Admiralty, Singapore
- **CASE STUDY:** The First Integrated Zero-Energy Building for the Tropics in NUS, Singapore
In hot and humid climates, good ventilation is necessary to remove excess heat from streets and open spaces and to provide cross-ventilation in buildings. In the tropics, design should strengthen the wind flows, develop air paths that enter the urban fabric and remove the accumulated heat. The arrangement of built form and voids, the constructions' heights and their geometry affect wind. Design should enhance air movement through shaping of street canyons and building geometry. Singapore and Sao Paulo, for instance, very thin high buildings have been successfully implemented for their benefits on local thermal comfort due to both shading and wind acceleration.

Schematics summarizing key urban form strategies for maximizing wind flows in the tropics. Source: Sungei Kadut workshop in Singapore NUS led by Serge Salat.

In the tropics, a decrease in wind speed from 1.0 m/s to 0.3 m/s is equal to 1.9 °C temperature increase, and outdoor thermal comfort under typical summer conditions requires 1.6 m/s wind speed. (ETH Zurich 2017).
Design recommendations are as follows.

**Create major and minor breezeways.** Breezy streets oriented to the prevailing wind maximize air movement and increase the access of buildings to cross-ventilation. Linear streets and open spaces, where the prevailing wind flows, establish major breezeways. Building separation that allows wind to enter forms minor breezeways. During site planning, careful consideration of the building layout should maintain major breezeways and leave sufficient gaps between buildings to facilitate wind penetration.\(^{55}\)

**Orientate streets to facilitate airflow.** The direction of streets controls the solar access inside and outside buildings, the permeability to airflow, and thus the passive cooling capacity. Streets aligned to breezeways support air movement and reduce Urban Heat Island (UHI). The street orientation oblique to prevailing winds creates two sides of buildings with positive pressure and two sides with negative pressure. This optimizes cross-ventilation potential. To maximize cross-ventilation access and airflow in streets, it is recommended to orient primary avenues at an angle of approximately 20–30° either direction from the line of the prevailing summer breeze.\(^{56}\)

**Design well-ventilated walkways.** Urban designers should consider people lines of movement across the urban area. They should align well-ventilated pedestrian walkways parallel to the prevailing wind. A walkway network should have five essential characteristics: continuity, safety, comfort, convenience and delight. Multilevel links and skywalks are a walkway system that provides these benefits.\(^{57}\)

**Link open spaces into ventilation corridors.** Connecting open spaces into ventilation corridors reduces temperatures and improves outdoor thermal comfort. The linkage of open spaces allows the prevailing wind along breezeways and major streets to penetrate deep into the city fabric.\(^{58}\) Radial ventilation corridors of streets or open spaces Examples in Hong Kong and Singapore, for instance, follow the concept of a ‘city in a garden’. It has many green spaces embedded at all scales into the urban fabric, including connectors that serve as green linkages between parks.

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55 HKGBC 2017.
56 ETH Zurich 2017.
57 ETH Zurich 2017.
space take advantage of cool air drainage and night thermal currents. It is recommended to use wide linear parks of 100 m or more in width to enhance urban cooling on calm nights. Designers should orient some of these wind corridors parallel to the prevailing breezes to bring wind deep into built-up areas. Wind corridors should connect greenbelts with centres of built-up density. The area of the greenbelt should be 40–60% of the size of the urban area to be cooled.  

![Linkage of open spaces. Source: HKGBC 2017.](image)

- **Arrange buildings to avoid obstruction.** Impeding the breezeway can block most of the wind and lower comfort and air quality. When a development site covers a breezeway or wind corridor, prevent placing any building massing there, so the prevailing wind can flow through the urban district. The axis of the buildings should be parallel to the prevailing wind to avoid breeze obstruction. An effective layout is to stagger the blocks such that the rear blocks receive the wind penetrating through the space between the blocks in the front row. Thin buildings with smaller footprints also improve ventilation.

- **Guide wind flows.** Wind velocity is often low on the leeward side of a building, forming a wake zone. It is recommended to orientate building blocks so that the longitudinal axis is parallel to the prevailing wind direction to channel or direct wind across the site. A building separation for wind flow should measure at least 15 m to be effective. Guiding and increasing the wind flow through voids enhances the wind volume and the urban air ventilation. Singapore Housing Development Board (HDB) for instance designed void decks in buildings to improve wind flows.

![Left: Arrange buildings to channel wind. Right: Wind corridor aligned with prevailing wind. Source: HKGBC 2017.](image)

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59 ETH Zurich 2017.  
60 HKGBC 2017.  
61 ETH Zurich 2017.
• **Accelerate wind flows with variation between building heights.** Altitude increases wind speed exponentially. The difference between low- and high-rise buildings enhances wind velocity due to the air dynamics between buildings. Urban design should arrange buildings according to ascending heights regarding wind direction to allow wind to reach the rear blocks. An option is to stagger building heights and to add void decks. For a multi-building scheme, it is recommended to adopt a stepped building height profile by placing lower buildings on the windward side. For a single-building development, designers should consider the heights of the adjacent buildings in the design. The taller building should at least double the height of the shorter one\(^6\).

Stepped building height profile. Various height buildings can capture prevailing wind and divert it to downwards to pedestrian area by the downwash effect. Project and drawings by Qin Shuxu.

• **Reduce building frontage.** A large building façade facing the prevailing wind direction diminishes wind penetration and affects the wind environment at downwind locations. Reducing the building frontage enhances wind penetration. The adoption of aerodynamically shaped façade also facilitates wind flows around the building structure.

\(^6\) ETH Zurich 2017.
Create voids between and in buildings. Gaps between buildings enable airflow towards the downwind areas. Buildings should be separated by at least 15 m to create minor breezeways. Void decks at the ground floor of buildings or at different levels such as sky gardens are a better option than excessive widening of streets and outdoor spaces. They increase permeability and encourage the airflow through and around the buildings while introducing additional shaded spaces. Mid-level voids are especially relevant for deep canyons or tall building blocks. Designers should align these features with breezeways and air paths to maintain good ventilation. They should be parallel to the incoming wind, or their angle should be no more than 30° to the prevailing wind direction. There should not be more than one turning point. Sky gardens should contain as few building structures as possible to facilitate wind penetration. They should be of at least 3 m tall. Apart from their ventilation benefits, sky gardens are communal spaces enhancing social life in a thermally comfortable environment.

The continuous length of a particular façade should be less than five times the width of the street canyon along it to avoid wall building effect.

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63 The continuous length of a particular façade should be less than five times the width of the street canyon along it to avoid wall building effect.

64 HKGBC 2017.

65 ETH Zurich 2017.

**Design permeable ground Level.** Ventilation bay at the ground level enables wind to flow through and provides thermally comfortable shaded open spaces for communal use. It is recommended to place semi-outdoor shaded spaces with great permeability at the ground level and locate enclosed spaces higher up. The elevated building structure will increase air volume at the ground zone.
MINIMIZE SOLAR RADIATION AND MAXIMIZE SHADOW

Shading reduces air and surface temperature. It is crucial around noon when the sun angles are at the highest. Urban geometry (aspect ratio) and building/street orientation can shade streets.

Additional physical control to solar access is achieved through horizontal and vertical shading structures or devices.

**Design recommendations are as follows.**
- **Orientate buildings to maximize shade.** Buildings’ position should consider the sun’s path and prevailing wind patterns. Their orientation can increase their performance and provide shade on nearby outdoor structures such as sidewalks, public spaces and streets. Optimized building orientation can lower the sun exposure and therefore minimize solar heat gains through the façades. Urban shading at street level can be achieved through two approaches:
  o creating deeper street canyons.
  o avoiding east-west direction of outdoor spaces.

- **Fix shading devices on buildings.** Shading devices can be fixed components, such as canopies, brise-soleils, horizontal or vertical louvres, blinds, roof overhangs; or movable elements. They control direct solar radiation and diffuse the reflective radiation of building envelopes. They limit the heat gains and improve the thermal comfort of both indoor and outdoor environments. They also increase the building energy performance by reducing the peak cooling load. The most common shading elements used in the tropics are horizontal overhangs to block high-angle sunshine during midday and vertical fins to protect from low-angle sunshine during the morning and afternoon.

  ![Newton Suites, Singapore. Sunshade detail. WOHA Architects. Photo © Patrick Bingham-Hall.](image)

  The exterior of the tower uses sun shading elements, patterned planes of textured panels and protruding balconies to create a façade that is functional yet expressive. The horizontal, metal expanded mesh sun shading screens the strong tropical sunlight. The angled mesh prevents insolation while permitting visual connection to the ground. The angled expanded mesh changes appearance with viewpoint, seeming anywhere between solid and transparent. This, combined with the cast shadows and interference patterns between the shadows and the mesh, gives the building a constantly shifting, blurred character depending on the angle and time.

- **Use permanent and movable shading devices.** These are horizontal or vertical systems that shield people from harsh sunlight all day such as urban pergolas, shade sails, framed canopies, shelters, or even solar cells applied on façades. They should control the intensity of solar radiation but should not obstruct the breezeway. Their effect depends on their material, geometry, dimension and location. It is imperative to study the sun path to define the type and properties of the shading
device. Movable shading devices permit users to adjust the spatial properties according to personal requirements. Mobile devices are commonly light and simple to install. They can offer additional shading during the daytime, for example in parks, sports fields, or temporary public spaces.

Removing them during night-time allows flexibility and variety of shaded and sunlit areas all-day round. Movable shading systems can adapt to different solar angles, providing shading where needed.

COOL THE SITE WITH VEGETATION: THREE-DIMENSIONAL GREENING

The benefits of urban greenery, vertical greening, green roofs and elevated sky gardens are extensive. Vegetation provides shade, reducing the urban heat-island effect and cooling public spaces. It offers visual amenity and interaction with the natural environment. It calms anxiety and supports health. Usable green spaces promote opportunities for physical practice and active lifestyles while fostering community interaction.

Buildings and groups of buildings offer multiple opportunities for three-dimensional greening from enriching and connecting the urban fabric with laneways, cross-block linkages and city rooms to creating sky terraces and elevated gardens, to green roofs and green façades.

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68 ETH Zurich 2017.

69 Brisbane City Council 2014.
Incorporating laneways, arcades, and new cross-block links into the design of ground floor public spaces contributes to the porosity and vibrancy of cities. These spaces increase opportunities for pedestrian movement, business activity and urban vibrancy at the street level. The provision of generous semi-outdoor spaces within the lower levels of buildings creates an open and permeable ground plane where people can meet for work, lunch and to relax. Strategically located along building frontages, these city rooms create visual and physical connections between indoor and outdoor spaces, drawing landscape and natural air into buildings. Varied in shape and size, they are united by the intent to open buildings up to the street and encourage occupation. Elevated spaces for recreation support active lifestyles and offer breathing room. Green and shaded, they are places to relax and enjoy spectacular city views. While allowing for active recreation and passive occupation they can also supply multiple benefits including absorption of rainwater.
insulation, creating a habitat for wildlife, a more aesthetically pleasing roofscape, and mitigating the urban heat-island effect\textsuperscript{70}. Green roofs decrease the temperature of roof surfaces and diminish the urban heat\textsuperscript{71}.

\textit{Newton Suites, Singapore. Sky garden. WOHA Architects.} Protruding sky gardens and balconies combined with sun shading screens establish outdoor living places that are sheltered with ample cross-ventilation due to elevated location and are particularly suited for the hot tropical climate. Landscape is used as a material – rooftop planting, sky gardens and green walls were incorporated into the design from the very beginning. Creeper screens are applied to otherwise blank walls to introduce visual delight, absorb sunlight and carbon and add oxygen in the dense environment. Most available horizontal and vertical surfaces are landscaped; creating an area of landscaping that is 130\% (110\% planted) of the total site. Photo © Patrick Bingham-Hall.

\textsuperscript{70} Brisbane City Council 2014.
\textsuperscript{71} Evapotranspiration influences nearby air temperature. It produces benefits in terms of UHI mitigation and lowering of building energy consumption. A green roof provides a rainwater buffer, purifies the air, reduces the ambient temperature, regulates the indoor temperature, saves energy and encourages biodiversity in the city.
Design recommendations are as follows.

- **Design blocks with a three-dimensional micro urbanism approach.** Rethinking urban blocks with porosity for wind flows and vertical landscaping leads to innovative 3D green matrices. High-density/high-amenity 3D green blocks minimize the need for artificial cooling while creating multiple community spaces. A three-dimensional green city replaces the two-dimensional segregated city. Urban blocks designed with a three-dimensional permeable green micro-urbanism move from the conventional model of enclosed buildings where floors are arrayed around a central core\(^2\). This approach allows integrating solar energy, urban agriculture, layers of commercial and recreational, of offices, and of housing in stacked structures rather than segregating them in separate buildings.

- **Green the site with a green plot ratio above 100%.** Regreening blocks mitigates the urban heat island effect and saves cooling energy, while providing sheltering and shading for communal spaces. Singapore’s Urban Redevelopment Authority stipulates that 100% Green plot Ratio\(^3\) should be

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\(^2\) WOHA et al. 2016.

\(^3\) The Green Plot Ratio – the measure of regreening – compares the total landscaped area of an urban
the minimum requirement in the city’s new developments. Greening in three dimensions with green façades, green roofs and sky gardens allows achieving 100% Green Plot Ratio—or more—and minimize the need for artificial cooling. Screens of vegetation on building walls transform the cityscape’s appearance from hard, engineered surfaces to green landscapes with buildings as gardens replacing buildings as mass. Interweaving fine grain gardens at multiple levels ventilates and cools the urban fabric. The gardens perform as environmental filters to absorb carbon and reduce heat gain while creating large-scale communal space at various levels. Designers should place these sky gardens at strategic levels, responding to the building context, orientation, structure, and circulation zones. Elevated gardens—often cantilevered from the mass of a building—can thrive in tropical cities, taking advantage of the climate and the sunlight high degree. Tropical cities have a year-round vertical sun path, which can be utilized to encourage tropical rainforest type growth, with a high density of trees and plants at every level. Sky gardens should be fully self-sustaining, irrigated with collected rainwater, and functioning as part of a building’s recycling and energy-saving program. Photovoltaic panels can power the watering and lighting systems for each garden. 3D greening can be extended to towers by subdividing them with horizontal layers of sky terraces and sky gardens, spaced no further than 25 metres apart74.

View of Sky Terraces from Sky Lounge in Park Royal on Pickering Hotel in Singapore. Singapore-based WOHA Architects have long been advocates of the ultimate ‘green city’—one that would comprise more vegetation than if the site were left as wilderness. The PARKROYAL on Pickering was designed as a hotel-as-garden that would double the green-growing potential of its plot. Adorned by frangipani and palm trees and draped with tropical plants, curvaceous sky gardens are cantilevered at every fourth level between the blocks of guest rooms. Greenery flourishes throughout the entire complex, and the trees and gardens of the hotel appears to merge with those of the adjoining park as one continuous sweep of urban parkland. Photo: © Patrick Bingham-Hall.

development with the size of its plot. If newly planted vegetation equals the size of its natural (untouched by humans) condition, the Green Plot Ratio would be 100%. Three-dimensional greening of the urban block allows reaching even higher ratios. For example, WOHA, a Singaporean architecture firm, designed as early as 2003 a development, the Newton Suites apartment tower, where the Green Plot Ratio was 130%—the first time a development had ‘overplanted’ its site. The Parkroyal on Pickering Hotel (2007–2013) attains a Green Plot Ratio of 240%.

74 WOHA et al. 2016.
School of the Arts, Singapore. WOHA Architects. Sky bridges and roof suspended above garden terraces between academic blocks. Photo: © Patrick Bingham-Hall

- **Multiply green linkages and green community spaces at many levels.** Designers should layer and hollow urban blocks. This will recreate street life and community space with gardens and parks in the sky. Open-air precincts at various floors offer new street levels as part of a three–dimensional matrix. These layers of space become naturally ventilated clusters of occupation.
To improve the accessibility and connectivity, sustainable design suggests many elevated linkages between buildings.

Project and drawings: Shin Shuxu Architect.

- **Develop vertical greenery and green façades.**
  Vertical greening refers to vegetation expanding directly onto a building’s façade or growing on a separate structural system\(^{75}\). Vertical deciduous climbing plant canopies strategically integrated on façades can act as dynamic solar shading devices responsive to the seasonal climatic change. The green wall typology is diverse and includes green façades, living walls, vertical gardens, hanging gardens, bio-shaders and bio-façades. Green walls can be internal and external, providing shade, insulation and visual relief\(^{76}\). The thermal performance of a green wall depends significantly on leaf coverage which is measured by the Leaf Area Index\(^{77}\). With a 100% leaf coverage, a green wall can reduce the façade’s surface temperature by 3–6°C\(^{78}\). The temperature inside the building remains more stable. Green façades lower the building energy consumption for cooling and improve the pedestrians’ thermal comfort. The advantage of vertical greening is that the dense foliage can block the high angle sun during summer while allowing low angle solar radiation entering the building during winter when the leaves shed off. The maximum efficiency is achieved when vertical greening is combined with advanced glazing. Maximum shading occurs in summer when the plant is at its peak growth. The shedding of leaves in winter reduces the shading and allows beneficial solar radiation to penetrate through the windows to the building interior. Multiple benefits of vertical greenery can be divided into three categories: Aesthetic, Environment, and Economic.

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\(^{75}\) The latter can be freestanding and adjacent or attached to the wall.

\(^{76}\) Brisbane City Council 2014.

\(^{77}\) Leaf Area Index (LAI) is a dimensionless quantity that characterizes plant coverage. It is defined as the one-sided green leaf area per unit surface area. Different LAI variants can be investigated to determine the best combination percentage of leaf area for both summer and winter. Landscape architects can choose the appropriate type of plants for the vertical greening at a later stage. Literature analysis suggests that from the perspective of daylighting and incident solar radiation, the combination of LAI 0.9 during summer and LAI 0.3 during winter is the most efficient.

\(^{78}\) HKGBC 2017.
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<tr>
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<td>- Visual relief from urban environments</td>
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<td>- Enhance architectural designs, create iconic landmarks in the city</td>
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<td>- Enhancement of biodiversity through addition of natural habitats within the city – Attraction of wildlife and insects</td>
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<td>Economic</td>
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Sky Green, Taichung. WOHA Architects. Sky Green is a mixed-use development at the heart of Taichung, in Taiwan, in a densely developed and vibrant neighbourhood. The development consists of two 26-storey residential towers with apartment units from level 4 onwards, and retail spaces. Away from the busy street life an intimate, serene landscaped courtyard greets the residents as they return to their homes. Above the retail shops rise the two residential towers and generous recreation facilities for indoor and outdoor activities. Both towers have deeply recessed windows. Protruding green balconies envelop the façades. Trees, sky gardens and mesh screens serve as a trellis for green creeper plants.

Photo: © Koumin Lee.
COOL THE SITE WITH WATER

Water bodies and features improve overheated building environments. Their effect comes from water surface temperature that does not increase as much as the rest of the urban area. Thus, water acts as a cool sink. If the water body size is sufficient, wind circulation patterns develop.

*Schematics summarizing key urban form strategies for maximizing wind flows in the tropics. Source: Sungei Kadut workshop in Singapore NUS led by Serge Salat.*
Water bodies

- **Associate blue and green spaces.** Associating blue and green strategies in urban areas brings integrated solutions. Water (blue) and vegetation (green) affect climate differently. Knowing the benefit of combining them is crucial.

- **Take advantage of open spaces along the seashore.** The waterfront sites are the gateways of sea breezes. The different heat capacities of the land and sea induce contrasts in air pressure and sea breezes. The fresh air from the sea can be 2–4°C cooler than the ambient air temperature in an urban area.\(^79\) The cool sea breezes can ventilate hot air trapped in the city fabric effectively at night. For project sites near the waterfront, it is recommended to facilitate sea breezes by placing low-rise and permeable building blocks on the shore and by providing wind corridors perpendicular to it. The wind corridor should be at least 15 m wide and aligned with the wind at the downwind location.\(^80\)

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\(^79\) ETH Zurich 2017.

\(^80\) HKGBC 2017.
▪ **Preserve wetlands.** Wetlands are the link between land and water. They contribute to flood control, carbon sink and shoreline stability. Water has negligible diurnal temperature variation compared to land surface and thus it does not accumulate heat during daytime hours. The proximity to wetlands with high presence of vegetation increases comfort. Wetlands ecosystems provide shadowing due to vegetation and trees. They are also a sink of CO₂ and other greenhouse gases. The preservation of wetlands enhances ecosystems and mitigates UHI[^1].

▪ **Create water catchment areas.** Water catchment areas collect rainwater and drain it into other water bodies. They prevent the overheating of urban surfaces. The cooling effect depends on the size and distribution of water catchments and on wind direction. Large ones have a high temperature effect close to their edges and in downwind areas. Several smaller distributed ones produce locally a smaller temperature effect, but collectively influence a larger part of the city.

[^1]: ETH Zurich 2017.
**Water features**

Left: To integrate with proposed open spaces and landscape areas, water features could be applied in terms of ponds, fountains, water playgrounds and even mist sprays. Project and drawing by Qin Shuxu. 


**Design recommendations are as follows.**

- **Add ponds on roofs/ground floor.** Ponds prevent the urban surfaces overheating. Reducing roof surface temperatures lowers energy demand.

- **Use evaporative cooling.** Evaporative cooling systems cool the air through water evaporation. They provide instant cooling outdoors\(^82\).

- **Add fountains.** Strategic locations providing spray water are necessary for getting thermal comfort benefits. The wind environment conditions the impact of water spray.

**DESIGNING CONTEMPORARY BUILDINGS IN HOT AND HUMID CLIMATES**

The use of constant fresh air in buildings through natural or hybrid ventilation systems increases indoor health and occupant productivity while saving up to 50% on capital and ongoing costs. Natural ventilation helps reduce pollution and could be the most important step in making buildings more sustainable\(^83\).

Hot and humid climates present some of the most difficult challenges for sustainable designs. High temperatures and high humidity create extreme comfort problems. The complexities of designing for these climates make integrated approaches\(^84\) especially important. Because of the dynamics of hot and humid climates, insulation in envelope components may either beneficially or adversely impact energy performance. This depends on how hot the climate is, how high the building’s internal loads are and on the orientation of the surface in relation to solar gains\(^85\).

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\(^{82}\) Farnham et al. 2015.

\(^{83}\) Brisbane City Council 2014.

\(^{84}\) Guidelines: In Singapore, the guideline Building, Planning and Massing gives building owners, architects, engineering consultants and other parties in a building project information on sustainable building design, attributes of green buildings, the latest green building technologies, and design strategies and approaches. In Australia, Brisbane’s Buildings that Breathe guide is part of the Brisbane City Plan 2014 and aims to provide an inspirational design benchmark for practitioners, developers and professionals to design buildings that respond to the city’s sub-tropical climate, urban character and outdoor lifestyle.

\(^{85}\) Zhao et al. 2010.
1. **Design horizontal breezeways.** The lighting and ventilation of the spaces deep inside a large building form an intrinsic problem in hot and humid climates. To avoid the costly and non-sustainable use of artificial energy, it is recommended to slice apart the building mass by horizontal breezeways. As part of the design, the horizontal breezeways – extending the length or breadth of a building’s volume – perform as ‘no-dead-end’ corridors. Designers can shape them as funnels to hasten the speed of the breezes passing through. These breezeways can serve as social outdoor zones within the buildings. An aerodynamic design can direct breezes to community spaces, and a comfortable yet tropical microclimate will prevail throughout the building.

![School of the Arts, Singapore. WOHA Architects. Dynamic visual connections and generous circulation stairways within academic blocks. Three long rectangular blocks have a secured point of access yet are visually connected from all the circulation spaces, to the public areas below. This setting is simple, practical, bright, airy and is designed for maximum flexibility and sustainability. The breezeways in between the blocks are designed for maximum comfort and interaction, providing spaces for different sized groups to interact and relax. The wind-directing design has proved to be successful and extremely comfortable, with constant cooling breezes even in Singapore’s low wind environment. The rooftop is designed as a large recreation park in the sky. Photo: © Patrick Bingham-Hall.](image)

2. **Design breezeway atria.** Breezeway atria can rise across multiple levels as grand vertical volumes, which form three-dimensional shared spaces. They facilitate constant cross-ventilation and natural light while encouraging social interaction.

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86 An example is the Community Town Hub in Singapore designed by WOHA in 2011. The Community Town Hub comprises a set of six linear blocks, which are inflected to direct breezes in from the adjoining parkland. As angled walls smooth the passage of air, the velocity of its movement through the breezeways is increased.  

87 An example is the School of Arts in Singapore designed by WOHA in 2005. Rising above the 5th floor ground plane, a 6-level atrium provides a communal space for students.
3. **Design breezeway courtyards.** In the tropics, cooling breezes should flow through and within buildings. The surrounding buildings should not present an impenetrable mass, although they should maintain a sense of spatial enclosure. The ground floor of the buildings that surround a tropical courtyard should be designed to facilitate airflow. Breezes can then flow unimpeded throughout the site. Designers can treat the ground plane of the entire site as a continuous series of landscaped formal and informal spaces. Watercourses and bio-retention ponds can reduce ambient temperatures and improve the microclimate across the site. As part of a 3-dimensional site-wide matrix, the buildings can also incorporate sky gardens, sky parks, multiple ground levels, and horizontal breezeways.

![School of the Arts, Singapore. WOHA Architects. Generous portions of breezeways are designed as pocket gardens for students to mix and mingle. This project is a specialist high school for the visual and performing arts. The design strategy for this inner-city school creates two visually connected horizontal strata, a space for public communication below, and a space for safe, controlled interaction above. Photo: © Patrick Bingham-Hall.](Image)

4. **Design vertical breezeways.** Thermal displacement – when hot air rises as in a chimney – is a passive means for ventilation. Openings in the walls and from below spaces draw cool air into rooms. As it warms, air escapes through vents in the roof. The process (also known as the heat stack effect) is well suited in the tropics and in high-rise buildings. The temperature difference between the air at the top and at the base increases the air velocity. Vertical breezeways can form continuous internal voids. The gaps between adjacent buildings can also generate thermal displacement: micro-atmospheric convection
stimulates significant air flow in a cluster of buildings.

5. **Design breezeway towers.** This ventilates and cools clusters of towers in tropical cities by the breezes drawn through the voids between them. Breezeway towers – grouped on a staggered ‘zigzag’ plan and oriented to receive the prevailing winds – form a permeable three-dimensional lattice.

6. **Design one unit thick.** In sustainable buildings, apartments and small offices should open out on all four sides to the exterior or the internal voids to maximize natural lighting and ventilation and minimize energy loads. This will increase their resilience in case of power failure.

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Open buildings without air conditioning

The traditional design approach in hot, humid regions, such as South-east Asia, is to keep buildings open and naturally ventilated and lighted by the internal voids as well as by their external exposure. The larger volumes required for some academic activities are layered at various levels across the voids, without blocking the air movement through the building.

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**An example are the narrow and elongated voids between ‘blade buildings’ in Higienopolis neighbourhood in Sao Paulo.**

**An example is the School of the Arts in Singapore designed by WOHA. The blocks are one-classroom-thick, linked by a network of footbridges, and separated by open horizontal breezeways. Each classroom can be constantly ventilated naturally. This is one of the most effective ways to reduce buildings’ energy consumption. Natural or hybrid ventilation systems, including stack ventilation, introduce fresh air into naturally ventilated and lighted by the internal voids as well as by their external exposure. The larger volumes required for some academic activities are layered at various levels across the voids, without blocking the air movement through the building.**

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Based on Gruner and Zinecker 2020.
closed internal environments. A building design with many openings combined with high ceilings ensures a constant air flow with warm air drifting up and out under ceilings or roofs. Natural breezes can thus refresh the inhabitants. In humid climates, the distances between buildings are greater, making it easier for prevailing draughts to pass. The vegetation is arranged to provide maximum shade to buildings and open spaces without hampering ventilation.


- **Shape** – The building has an open layout, is not very compact and often with an adjacent or inner courtyard, combining open and closed spaces.
- **Walls** – The walls are light and have many openings and vents near the floor and ceiling, creating a pressure difference that causes air circulation and constant ventilation.
- **Roofs** – The roofs are well insulated and light-coloured with a reflective coating.
- **Shading** – Generous awnings and roof overhangs and external shading elements minimize solar radiation on façades and windows.
- **Windows** – Louvre windows or shutter windows facilitate continuous air flow.

- **Cooling** – Ceiling fans increase comfort during temperature peaks and when lacking outdoor air movement.

Closed buildings with air conditioning

In very hot and humid climates, mechanical cooling may be necessary to lower the humidity of the air and thus provide acceptable and comfortable indoor conditions. For these climates, a closed design with a high-performance building envelope with very effective air conditioning and dehumidification may be a solution. In a climate where the ambient temperature is very high only at a certain time, this closed building approach can also be combined with natural cross-ventilation for cooling at night. In this case, design the building to be controlled in a mixed mode with manually operated windows.

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91 Based on Gruner and Zinecker 2020.
- **Shape** – Compact building to reduce the surface area of the building envelope to a minimum to avoid excessive exposure to solar radiation.
- **Walls** – The walls are airtight and light to mid-weight with thermal insulation.
- **Roofs** – The roofs are light-coloured with a reflective coating and have thermal insulation.

- **Shading** – Generous awnings and roof overhangs and external shading elements mitigate solar radiation on façades and windows.
- **Windows** – The window to wall ratio is optimized to allow sufficient natural light to enter while minimizing internal heat gains. High-performance and airtight windows, with double glazing, are used.
CASE STUDY: GREEN SPACES INTERWOVEN IN THE URBAN FABRIC AT ALL SCALES IN SINGAPORE

The Super Trees in Marina Bay, Singapore.

Singapore has focused on the distribution and connectivity of parks, streets, building green walls, green roofs, sky gardens, at many different scales and tightly interwoven into the urban fabric, not just on the total area of green land. Singapore’s quality of life is based on its urban greenery throughout the city. Mandatory roadside planting has introduced trees with sufficient growing space to provide substantial canopy cover. Trees and parks develop in three dimensions on roofs and walls. They form sky gardens, sometimes stepped on several floors. They traverse and connect the buildings. They help reduce temperatures. They filter air pollution. They reduce street noise. When permeable, these surfaces facilitate storm water management.

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92 This box draws and adapts some content from New Climate Economy 2018.
Hundreds of kilometres of green, pedestrian park connectors, pocket parks, and sky gardens, mean that people have constant and easy access to green space despite high density living. Between 1986 and 2007, green cover in Singapore grew from 36% to 47%, despite a 68% increase in population\(^{93}\). Average temperature diminished by between 0.5 °C and 5 °C\(^{94}\). This builds resilience to climate change while also mitigating GHG emissions as a drop of 1 °C in air temperature lowers peak electricity demand by as much as 4%, which translates into reduced energy consumption and emissions\(^{95}\).

The government now requires property developers to replace any greenery lost during construction. This means achieving a Green Coverage Ratio of at least 100%. The government covers 50% of the costs for installing green roofs and walls on existing buildings. This spurs innovations to develop a lighter and more robust rooftop and vertical greening systems. These systems are also cheaper: the cost of greening fell from S$150/m\(^2\) to S$100/m\(^2\) in a two-year period\(^{96}\).

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\(^{93}\) Tan et al 2013  
\(^{94}\) Jusuf et al. 2007  
\(^{95}\) Jusuf et al. 2007.  
\(^{96}\) Newman 2014.
Traditionally, South-East Asian communities have gathered underneath huge trees, such as banyans, which provide shade and shelter. Similarly, the breadth of its roofs characterizes vernacular construction. Like banyan trees, they function as giant umbrellas. In contemporary projects, tropical community spaces – naturally lit and cross-ventilated – can be at ground level or at intermediate levels. A large open public space beneath or within – as a garden in the sky – an institutional or private building provides more than ventilation; it encourages sociability.\(^{97}\)

The Community Plaza in Kampung Admiralty is a fully public, porous and pedestrianized ground plane, designed as a community living room. Within this welcoming and inclusive space, the public can participate in organized events, join in the season’s festivities, shop, or eat at the hawker centre on the second storey. The Medical Centre above shades and shelters the breezy tropical plaza, allowing activities to continue regardless of rain or shine. Kampung Admiralty ground floor open communal space. Kampung Admiralty sky gardens. Photos: Patrick Bingham Hall.

\(^{97}\)WOHA 2016.
Breathing urban fabrics can offer outdoor community spaces at many scales and at multiple levels within a ‘3-dimensional green matrix’. An example is Kampung Admiralty. Singapore’s first integrated public development brings together a mix of housing, public facilities and services under one roof. The traditional approach is for each government agency to carve out their own plot of land, resulting in several standalone buildings. This integrated complex, on the other hand, maximizes land use, and is a prototype for meeting the needs of Singapore’s ageing population98. A terraced and forested sky park roofs the mixed-use Kampung Admiralty scheme. It can be directly accessed from the community and health-care facilities layered on the upper floors of the building.

98 WOHA 2016.
Kampung Admiralty is a stacked mixed-use structure. Source: WOHA 2016. The various components are stacked and layered within a single building. Markets, shops, plazas, health-care facilities and a rooftop park are integrated, not segregated.

Located on a tight 0.9 ha site with a height limit of 45 m, the scheme builds upon a layered approach. A ‘Vertical Kampung (village)’ is devised, with a Community Plaza in the lower stratum, a Medical Centre in the mid stratum, and a Community Park with apartments for seniors in the upper stratum. These three distinct strata juxtapose the various buildings uses to foster diversity of cross-programming and free up the ground level for activity generators.

Locating a Medical Centre in Kampung Admiralty means that residents need not go all the way to the hospital to consult a specialist, or to get a simple day surgery done. To promote wellness and healing, the centre’s consultation and waiting areas are washed in natural daylight from perimeter windows and through a central courtyard. Views toward the Community Plaza below, and the Community Park above also help seniors feel connected to nature and to other people. The close proximity to health-care, social, commercial and other amenities support intergenerational bonding and promote active ageing in place.

The Community Park is an intimately scaled, elevated village green where residents can actively come together to exercise, chat or tend community farms. Complementary programmes such as childcare and an Active Ageing Hub (including senior care) are side by side, bringing together young and old to live, eat and play. One hundred and four apartments are provided in two 11-storey blocks for elderly singles or couples. Shared entrances encourage seniors to come out of their homes and interact with their neighbours. The units adopt universal design principles and are designed for natural cross ventilation and optimum daylight.
Net-Zero Energy Building, School of Design and Environment, National University of Singapore (NZEB@SDE)

The School of Design and Environment is the first net-zero energy building of its kind in the tropics. It functions as a living laboratory to promote research collaboration with public agencies and industry partners. With a gross floor area of 8,514 m², it houses a mix of research laboratories, test-bedding façade, design studios, and teaching and common learning spaces.
Singapore (NZEB@SDE). Serie Architects.
One key aspect of the NZEB@SDE is its contemporary architecture design. It demonstrates a deep understanding of Singapore tropical climate. The design concept incorporates a large overhanging roof. Together with the double façades on the east and west, it shades the building from the sun’s heat and provides a cooler interior.

The building design also makes use of the ‘floating boxes’ architectural concept. Its shallow plan depth and porous layout allow for cross-breezes, natural lighting and outdoors views. The key design concept is to separate building masses with a language of platforms and boxes. The elements are configured to facilitate different activities. Each platform provides shade to the space below. An over-sailing roof covers the entire plot. It unifies and shades the whole composition. This roof accommodates an array of PV cells which generate electricity for the building.
| **Base case**  
The standard architectural form places an emphasis on enclosure and architecture as objects. |
| --- |

| **Language of platforms and boxes**  
The proposal is based on a series of platforms and boxes. These elements are configured to facilitate different activities. Each platform provides shade for the space below. |
| --- |

| **Over-sailing roof**  
Uniting the programmatic components is an over-sailing roof. This roof covers the entire plot and shades the whole composition. |
| --- |

| **Solar screens**  
Massive solar shading panels provide shade in the morning and evening. These screens also complete the architectural form. The roof accommodates an array of PV cells which generate electricity for the building. |
| --- |
Weather permitting, rooms can also be open to natural breezes, and air conditioning is used only where needed, reducing the electricity usage of the building. The result offers an experience that connects NUS staff and students to the campus’ natural surroundings.
<table>
<thead>
<tr>
<th>Wellness – separate building masses</th>
<th>Educational model – informal learning</th>
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<tbody>
<tr>
<td>A wealthy working environment requires access to daylight, views and natural ventilation. As the standard deep-plan office layout makes these requirements difficult to achieve, the proposal breaks down the building massing into smaller volumes. These volumes give students and faculty more immediate access to the light and natural ventilation of the outside.</td>
<td>Education requires interaction and collaboration between students and staff. Toward this end, a grand staircase forms the social heart of the educational community – this is where students and staff meet and share ideas. Each level is wrapped on three sides with an outdoor terrace. The terraces are breakout spaces that allow the work of the students to split into the outdoors.</td>
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<th>Living laboratory – research-based façade</th>
<th>Community-activating social spaces</th>
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<tbody>
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<td>The building itself is conceived as a laboratory. The façades on both sides aim at studying different forms of solar shading.</td>
<td>Different levels are dedicated to communal spaces. These include the front garden, the exhibition space (with the social plaza) for display of student work and visiting exhibitions, and different green terraces which provide a pleasant outdoor working environment.</td>
</tr>
</tbody>
</table>

| 4th and 5th storeys | 4th and 5th storeys |
Designed to be net-zero energy and to reduce cooling loads by 60%, NZEB@SDB derives its energy from on-site energy sourcing with rooftop photovoltaic panels. Water systems feature on-site water detention with a rainwater collection system and bio-swales. Thermal comfort is ensured by a combination of natural ventilation, mechanical ventilation, air conditioning and a new hybrid cooling system supplying tempered air that is augmented by ceiling fans. Most spaces do not need electrical lights during the day. NZEB@SDE consumes only as much energy as it produces. It harvests solar energy using more than 1,200 photovoltaic solar panels installed on the roof. On days when solar energy is insufficient, the building will draw energy from the power grid. Over the course of the year, the net amount taken from the grid will be zero – achieving net-zero energy consumption.

NZEB@SDB deploys many climatic strategies. The large overhanging roof and the double façades on east and west elevations, trim the incident solar load that might otherwise warm its interior, contributing to cooling load. The building’s southern exposure offers views and draws in daylight. Envelope glazing is amply shaded with glare reducing and light redirecting lamellas that reflect daylight deeper into teaching spaces. Air conditioning is used only where needed. Rooms can be opened to prevailing breezes when the weather permits. The spaces between these cooled rooms are naturally ventilated, acting as thermal buffers and social spaces, much like the traditional veranda.

Open façade. Ceiling fans.
Critical to the optimization of building systems is a rethink of air conditioning – typically the biggest consumer in Singapore buildings – which resulted in the design of an innovative hybrid cooling system. This system supplies rooms with cool air – albeit at higher temperatures and humidity levels than a conventional system – and augments this with elevated airsreads from ceiling fans. The cool, moving air creates a significantly better comfort than the over-cooled rooms currently experienced in Singapore.

The NZEB@SDE offers lessons to architects and engineers on how energy use and occupant comfort might be better balanced in future buildings. It also suggests that a building need not deliver the same conditions all day to everyone. Giving occupants the option to control comfort such as by adjusting fan speed, for instance, or switching to natural ventilation, would be viable solutions to achieve comfort.
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