5

Urban Planning and Urban Design

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Embedding Climate Change in Urban Planning and Urban Design

Urban planning and urban design have a critical role to play in the global response to climate change. Actions that simultaneously reduce greenhouse gas (GHG) emissions and build resilience to climate risks should be prioritized at all urban scales – metropolitan region, city, district/neighborhood, block, and building. This needs to be done in ways that are responsive to and appropriate for local conditions.

Major Findings

Urban planners and urban designers have a portfolio of climate change strategies that guide decisions on urban form and function:

- Urban waste heat and GHG emissions from infrastructure – including buildings, transportation, and industry – can be reduced through improvements in the efficiency of urban systems.

- Modifying the form and layout of buildings and urban districts can provide cooling and ventilation that reduces energy use and allow citizens to cope with higher temperatures and more intense runoff.

- Selecting low heat capacity construction materials and reflective coatings can improve building performance by managing heat exchange at the surface.

- Increasing the vegetative cover in a city can simultaneously lower outdoor temperatures, building cooling demand, runoff, and pollution, while sequestering carbon.

Key Messages

Integrated climate change mitigation and adaptation strategies should form a core element in urban planning and urban design, taking into account local conditions. This is because decisions on urban form have long-term (>50 years) consequences and thus strongly affect a city's capacity to reduce GHG emissions and to respond to climate hazards over time. Investing in mitigation strategies that yield concurrent adaptation benefits should be prioritized in order to achieve the transformations necessary to respond effectively to climate change.

Consideration needs to be given to how regional decisions may affect neighborhoods or individual parcels and vice versa, and tools are needed that assess conditions in the urban environment at city block and/or neighborhood scales.

There is a growing consensus around integrating urban planning and urban design, climate science, and policy to bring about desirable microclimates within compact, pedestrian-friendly built environments that address both mitigation and adaptation.

Urban planning and urban design should incorporate long-range mitigation and adaptation strategies for climate change that reach across physical scales, jurisdictions, and electoral timeframes. These activities need to deliver a high quality of life for urban citizens as the key performance outcome, as well as climate change benefits.

5.1 Introduction

Key concepts, challenges, and pathways for adaptation and mitigation of climate change through recent advances in the planning and design of cities are reviewed in this chapter. Section 5.2 presents the concept of integrated mitigation and adaptation as a framework and introduces the factors of urban-scale form and function as influences on urban climate. Section 5.3 explains how urban microclimates are embedded in zones of human occupation and links metropolitan-scale urbanization with heat and storm-water impacts. Section 5.4 focuses on planning and design innovations that can be applied to achieve integrated mitigation and adaptation. Section 5.5 describes a process for implementing climate-responsive urban planning and urban design. Section 5.6 identifies key climate-resilient urban planning and urban design stakeholders and a set of value propositions to engage a broader constituency. Section 5.7 describes the challenges in cross-sector linkages between the scientific, design, and policy-making communities. Section 5.8 identifies knowledge gaps and future research opportunities, and Section 5.9 presents conclusions and recommendations for practitioners and policy-makers. Case Studies are distributed throughout the chapter to illustrate on-the-ground, effective implementations of the planning and design strategies presented.

5.2 Framework for Sustainable and Resilient Cities

Urban planning and urban design encompasses multiple disciplines, providing critical input to inform systems, management, and governance for sustainability and resilience to climate change (see Box 5.1). They configure spatial outcomes that yield consequences for and constitute responses to climate change (see Figure 5.1). The spatial form of a city – from the scale of the metropolitan region to the neighborhood block – strongly predetermines per capita greenhouse gas (GHG) emissions. With each 10% reduction in urban sprawl, per capita emissions are reduced by 6% (Laidley, 2015). Although compact urban form generally contributes positively to mitigation, it can paradoxically exacerbate local climate effects, requiring creative forms of adaptation. Research in this area is expanding, and, as a result, planning and design strategies are increasingly providing win-win solutions for compact urban morphology.

However, not all existing urban areas are compact (see Figure 5.2). Low-density areas continue to contribute disproportionately to emissions because of the excess mobility required by long distances, few alternatives to the private car, and scant possibilities for shared building envelopes. Whether such patterns are the result of planning or a lack thereof, it is

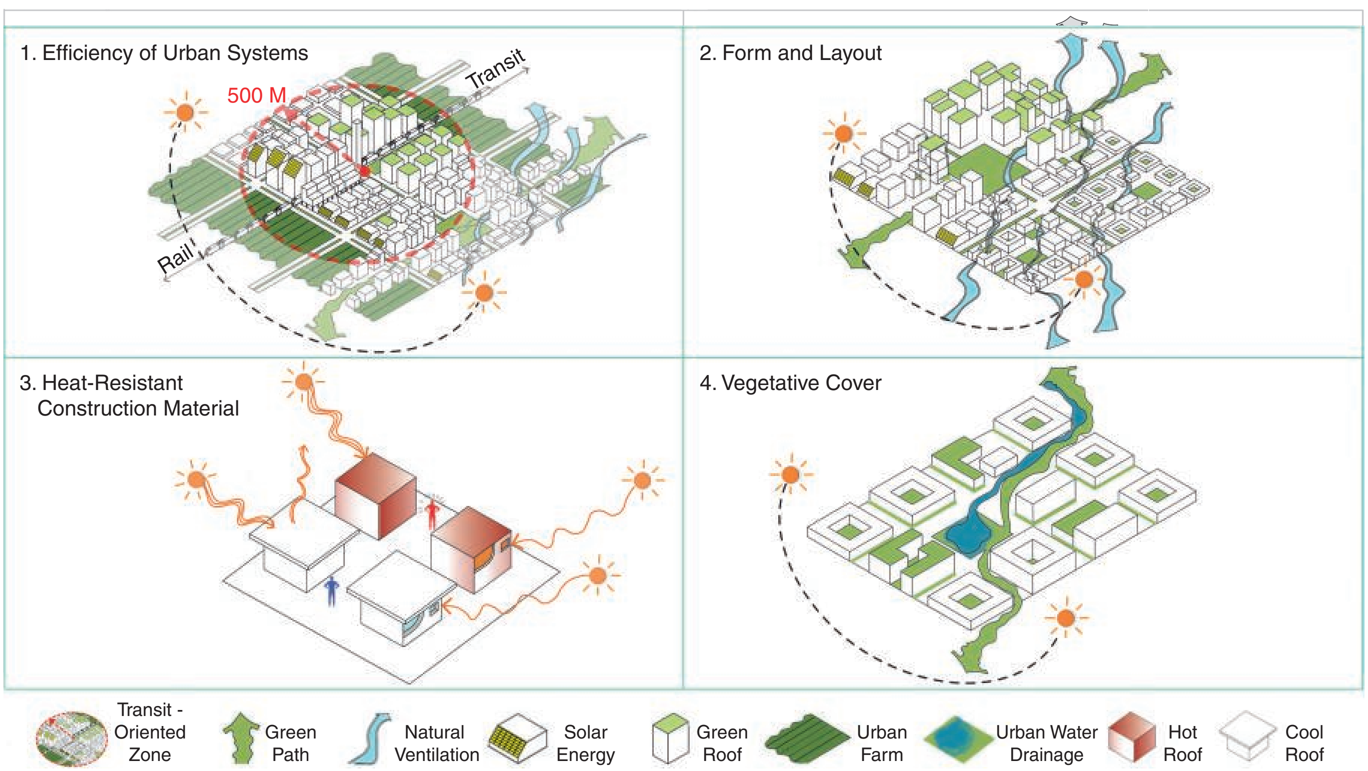


Figure 5.1 *Strategies used by urban planners and urban designers to facilitate integrated mitigation and adaptation in cities: (1) reducing waste heat and greenhouse gas emissions through energy efficiency, transit access, and walkability; (2) modifying form and layout of buildings and urban districts; (3) use of heat-resistant construction materials and reflective surface coatings; and (4) increasing vegetative cover.*

Source: Jeffrey Raven, 2016

Box 5.1 Key Definitions for Urban Planning and Urban Design

Urban planning: A field of practice that helps city leaders to transform a sustainable development vision into reality using space as a key resource for development and engaging a wide variety stakeholders in the process. It generally takes place at the scale of the city or metropolitan region whose overall spatial pattern it sets. Good urban planning formulates medium- and long-term objectives that reconcile a collective vision with the rational organization of the resources needed to achieve it. It makes the most of municipal budgets by informing infrastructure and services investments and balancing demands for growth with the need to protect the environment. And it ideally distributes economic development within a given urban area to reach wider social objectives (UN-Habitat 2013).

Urban design: Urban design involves the arrangement and design of buildings, public spaces, transport systems, services, and amenities. Urban design is the process of giving form, shape, and character to groups of buildings, to whole neighborhoods, and to a city. It is a framework that orders the elements into a network of streets, squares, and blocks. Urban design blends architecture, landscape architecture, and city planning together to make urban areas functional and attractive.

Urban design is about making connections between people and places, movement and urban form, nature and the built fabric. Urban design draws together the many strands of place-making, environmental stewardship, social equity, and economic viability into the creation of places with distinct beauty and identity. Urban design is derived from but transcends planning, transportation policy, architectural design, development economics, engineering, and landscape. It draws together create a vision for an urban area and then deploys the resources and skills needed to bring the vision to life (urbandesign.org).

clear that the planning and design disciplines will increasingly need to prioritize the retrofitting of these areas for greater land-use efficiency (UN-Habitat, 2012).

A high proportion of urban areas that will need to minimize GHG emissions and adapt to climate change have not yet been built. Beyond aiming for appropriate levels of compactness, new urban development can and must be strategic about location (avoiding, e.g., areas particularly vulnerable to heat, flooding, or landslides).

5.2.1 Integrated Mitigation and Adaptation

Urban planning and urban design can be critical platforms for integrated mitigation and adaptation responses to the challenges of climate change. They have the opportunity to expand on the traditional influence and capabilities of practitioners and policy-makers and integrate climate science, natural systems, and urban form – particularly compact urban form – to configure dynamic, desirable, and healthy communities.

Traditionally, urban planning and urban design have focused on settlement patterns, optimized land use, maximized proximity, community engagement, place-making, quality of life, and urban vitality. Their focus is increasingly expanding to include principles such as resilience, comfort, resource efficiency, and ecosystem services (see Chapter 8, Urban Ecosystems). Applying these principles to urban policy helps to identify and strengthen prescriptive measures and performance standards and broaden urban performance indicators.

If future cities are to be sustainable and resilient, they must develop the physical and institutional capacities to respond to constant change and uncertainty. This will require strategies for

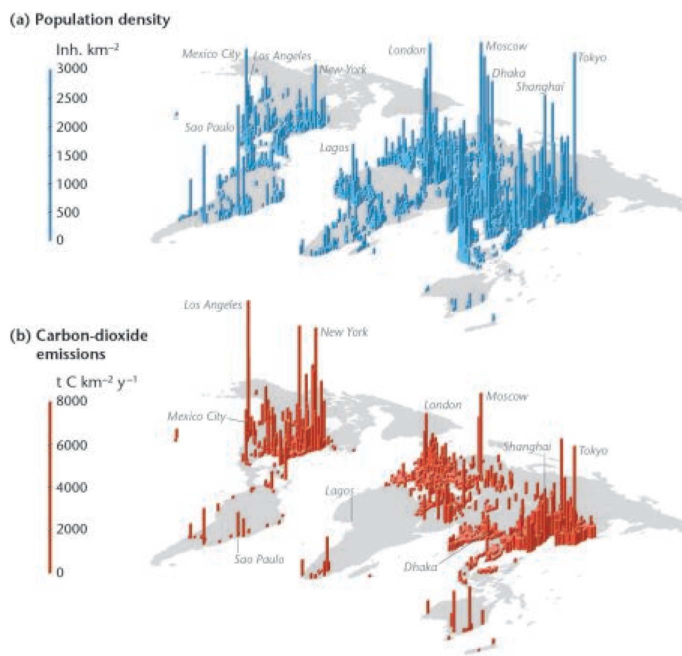


Figure 5.2 *Each bar represents an entire metropolitan area (i.e., the city and the continuous urban footprint surrounding it), including often much lower-density suburbs.*

Source: A. L. Brenkert, Oak Ridge National Laboratory. Maps created by Andreas Christen, UBC

long-term commitments across multiple electoral cycles and often among many political jurisdictions that constitute functional metropolitan areas (see Chapter 16, Governance and Policy).

Global climate risk is accumulated in urban areas because people, private and public assets, and economic activities become more concentrated in cities (Mehrotra et al., 2011; Revi et al., 2014). Recognition of the growing vulnerability of urban populations to climate-related health threats requires that the climate management activities of municipal governments be broadened (see Chapter 10, Urban Health).

One means of doing so is to prioritize investments in mitigation strategies that yield concurrent adaptive benefits over those that do not (see Chapter 4, Mitigation and Adaptation). At present, nonintegrated mitigation and adaptation is most commonly pursued, with the majority of mitigation funds directed to energy projects that produce no secondary benefits for local populations in the form of heat management and enhanced flood protection or reduced damage to private property and public infrastructure. For example, mitigation strategies involving the substitution of a lower carbon-intensive fuel, such as natural gas, for a higher carbon-intensive fuel, such as coal, are an effective means of lowering CO_2 emissions yet provide few benefits related to climate adaptation.

Figure 5.3 *"Green and blue fingers" in Thanh Hoa City, Vietnam, planned for 2020: Contiguous green corridors and canal circulation networks aligned with prevailing summer breezes, punctuated by stormwater retention bodies as urban design amenities.*

Source: Jeffrey Raven, Louis Berger Group, 2008

5.2.2 Form and Function

Forward-thinking cities are beginning to exploit the positive potential of built and natural systems – including green infrastructure, urban ventilation, and solar orientation – to "future-proof" the built environment in response to changing conditions (see Figure 5.3 and Box 5.2). These passive urban design strategies "lock in" long-term resilience and sustainability, protecting

Box 5.2 Urban Form and Function

The physical character of cities can be described by three aspects of form: land cover, urban materials, and morphology. On the other hand, the flow of materials through a city describes its metabolism, the character of which is regulated by its functions (see, e.g., Decker et al., 2000).

Surface cover (Form): The replacement of natural land covers by impermeable materials limits the infiltration of precipitation into the substrate, increases runoff, and decreases evapotranspiration.

Construction materials and surface coating (Form): Common urban materials such as concrete have high conductivity and heat capacity values that can store heat efficiently. Also, many urban materials are dark colored and reflect poorly (e.g., asphalt).

Morphology (Form): The configuration and orientation of the built environment, from regional settlement patterns to buildings, create a corrugated surface that slows and redirects near-surface airflow and traps radiation.

Urban activities (Function): Cities concentrate material, water, and energy use that must be acquired from a much larger area. Some is used to build the city (changing its form), but most is employed to sustain its economy and society. Once used, the wastes and emissions are deposited into the wider environment, degrading soil, water, and air quality, and increasing heat through the exacerbated greenhouse effect.

the city from future decisions that could undermine its adaptability. They also remove the risk of relying on bolted-on, applied technologies that may require expensive maintenance or become obsolete in a short time. These form-based, contextually specific urban planning and urban design strategies are the ultimate guarantors of successful life cycle costs, payback, and liveability.

Integrated mitigation and adaptation in cities can assume many forms across spatial scales, urban systems, and physical networks (see Figure 5.4); a wide range of strategies adopted in service of urban sustainability already advances this objective. Enhanced urban transit, for example, has the effect of reducing both carbon emissions from single-occupant vehicle use and waste heat emissions that contribute to the urban heat island (UHI) effect. Investments in pedestrian and cycling corridors, particularly when integrated with parks and other green spaces in cities, can reduce carbon emissions, enhance carbon sequestration, and, perhaps most effectively, cool cities through evapotranspiration and shading. Sustainability strategies across urban systems can contribute to climate management goals under the umbrella of integrated mitigation and adaptation (see Figure 5.5).

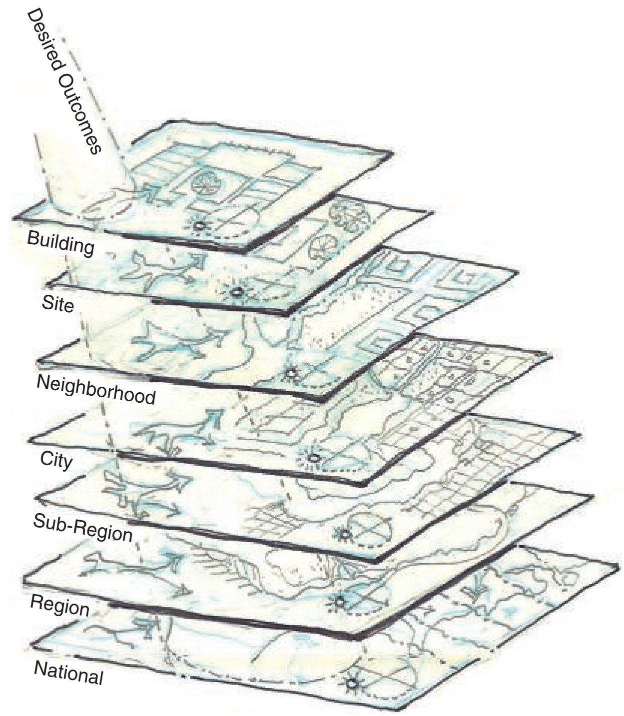


Figure 5.4 *Spatial scales relevant to urban planning and urban design for climate change mitigation and adaptation.*

Source: Jeffrey Raven, 2008

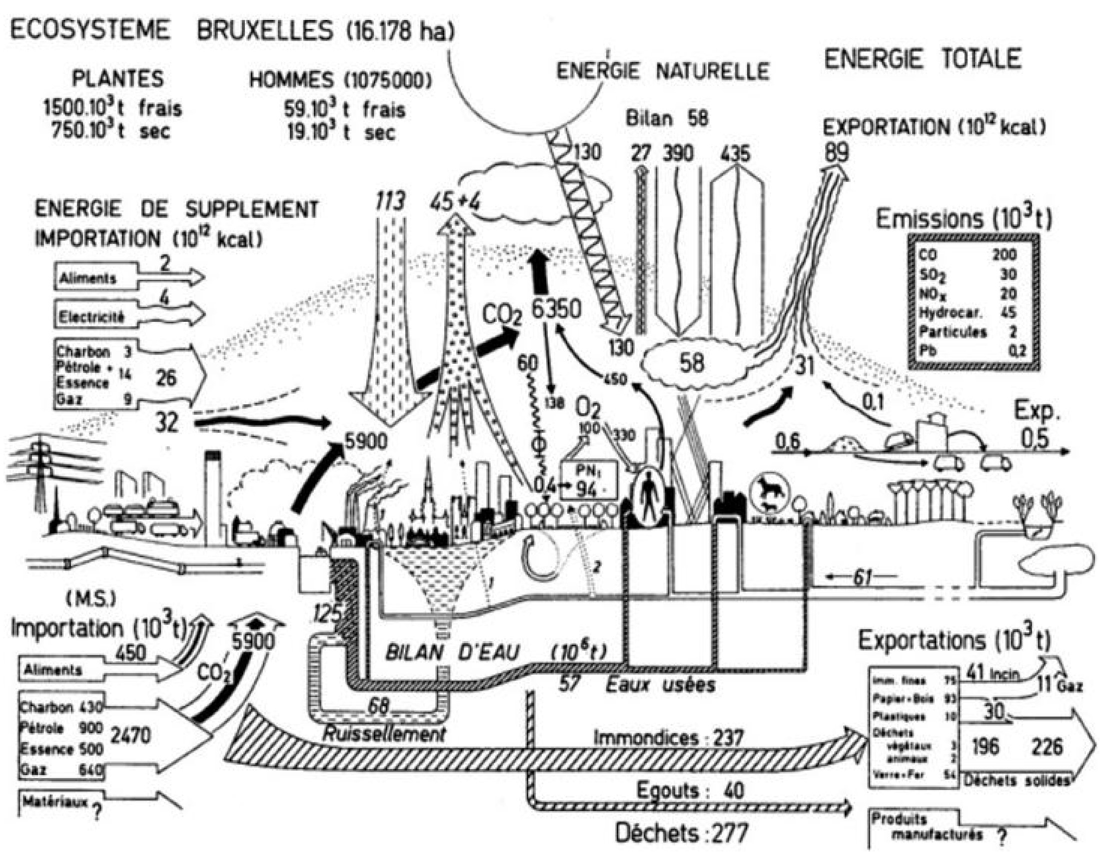


Figure 5.5 *L' Ecosystème Urbain (Urban Ecosystem).*

Source: Duvigneaud, P. and Denayer-de Smet, S., 1975

5.3 Climate in Cities

Urban areas occupy a small percentage (perhaps less than 3%) of the planet's land area, but this area is intensively modified (Miller and Small, 2003; Schneider et al., 2009). The landscape changes that accompany urbanization modify climate across a spectrum of scales, from the micro-scale (e.g., street), city-scale, and regional scales (see Chapter 2, Urban Climate Science).

The magnitude of the modification is evaluated by comparing the urban climate with its background climate, which is taken to be the "natural" climate. Because each city has a unique geographical region (latitude and topography primarily), the natural climate is assessed in the same region but over a non-urban surface (Lowry, 1977). One of the challenges posed by global climate change is that the background climate is itself changing and that cities contribute significantly to this change through the emission of GHGs.

The most profound changes occur in the layer of air below roof height. Here, access to sunlight is restricted, wind is slowed and diverted, and energy exchanges between buildings are the norm. The spatial heterogeneity of the urban landscape creates a myriad of microclimates associated with individual buildings and their relative disposition, streets, and parks (Errel et al., 2012). This is also the layer of intense human occupation, where building heating and cooling demand is met, emissions of waste heat and pollution from traffic are concentrated, and humans are exposed to a great variety of indoor and outdoor urban climates.

The climate effect of cities extends well beyond the urbanized area. As air flows over the urban surface, a boundary layer forms that deepens with distance from the upwind edge. This envelope may be 1–2 kilometers thick by mid-afternoon and is distinguishable as a warm and turbulent atmosphere that is enriched with contaminants, including GHGs. The extent of urban influence depends on the character of the city (e.g., its area, built density, and the intensity of its emissions) and on the background climate, which regulates the spread and dilution of the urban envelope. As a result, cities contribute significantly to regional and global air pollution (Guttikunda et al., 2003; Monks et al., 2009). Moreover, meeting urban energy demand accounts for up to three-quarters of CO_2 emissions from global energy use and thus represents a significant driver of global climate change (IPCC, 2014) (see Chapter 12, Urban Energy).

The magnitude of the urban climate effect is linked to both the form and function of cities (Box 5.2). The former refers to aspects of the physical character of cities, including the extent of paving and the density of buildings. The latter describes the nature of urban occupancy including the energy used in buildings, transport, and industry. *Integrated mitigation and adaptation* strategies focus on managing urban form and function together to moderate and respond to climate changes at urban, regional, and global scales.

5.3.1 Urban Climate Zones

The changes that accompany urbanization have profound impacts on the local environment and are clearly seen in aspects of climate and hydrology (Hough, 1989) (see Chapter 2 Urban Climate Science). The magnitude of these urban effects depends on both the form and functions of individual cities. However, cities are highly heterogeneous landscapes, and impacts vary across the urbanized area as well. Detailed mapping of urban layout, including aspects of form (e.g., impervious land cover) and of function (e.g., commercial land use), provides a basis for examining climate at a local scale.

For example, Stewart and Oke (2012) have developed a simple scheme that classifies urban neighborhoods mainly by form into local climate zones (LCZ) (see Figure 5.6). Each LCZ is characterized by typical building heights, street widths, vegetative cover, and paved area. Not surprisingly, the most intense local climate impacts are found where building density is greatest, streets are narrowest, and there is little vegetation (e.g., compact high-rises or dense slums). In many of these areas, the population is highly vulnerable due to poverty or age (see Chapter 6, Equity and Environmental Justice). Cities comprise many LCZ types that occupy varying proportions of the urbanized landscape. This

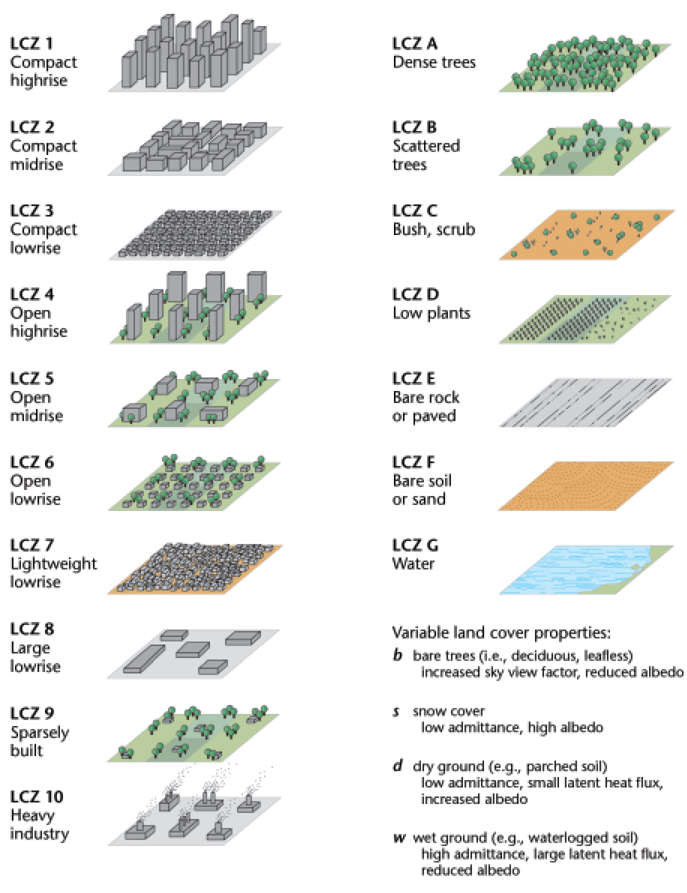


Figure 5.6 *Local climate zone type. Admittance, or thermal admittance, is a measure of a material's ability to absorb heat from, and release it to, a space over time.* Albedo *is the proportion of the incident light or radiation that is reflected by a surface back into space.*

Source: Stewart and Oke, 2012

chapter describes win-win form/function strategies to mitigate local climate impacts in compact districts.

5.3.2 Urbanization as Amplifier of Global Climate Change

Global climate change is modifying the background climate within which cities are situated, altering the frequency and intensity of extreme weather experienced (see Chapter 2, Urban Climate Science). The most recent Intergovernmental Panel on Climate Change (IPCC) assessment (IPCC, 2014a) concludes that global climate change has already resulted in warming both days and nights over most land areas and will cause more frequent hot days and nights in the future.

One of the most widely recognized climate impacts of urbanization is the UHI effect (e.g., Arnfield, 2003; Roth, 2007) (see Chapter 2, Urban Climate Science). The magnitude of the UHI is measured as the difference in air and surface temperatures between the city and proximate rural areas; these differences increase from the edge of the city to the center, where it is usually at a maximum. It is strongest during calm and clear weather but exhibits different impacts on surface and air temperatures. When measured as differences in air temperature between urban and non-urban surfaces, the UHI is strongest at night (due to heat retention), whereas differences in surface temperatures are largest during daytime (due to solar absorption).

Both types of UHI show a clear correlation with the amount of impervious surface cover and building density, whereas parks and green areas appear as cooler spots. The maximum value of the UHI as measured by air temperatures is likely to be between 2°C and 10°C, depending on the size and built density of the city, with largest values occurring in densely built and impervious neighborhoods (Oke, 1981). The magnitude of the surface temperature UHI depends greatly on the material characteristics of the surface, especially its albedo (i.e., reflectivity) and moisture status (see, e.g., Doulos et al., 2004).

In urban areas, the UHI adds to current warming trends due to global climate change contributes to poor air quality, increases energy demand for cooling, and elevates the incidence of heat stress (Akbari, et al., 2001; Grimmond, 2007; Oleson et al., 2015).

Once built, many aspects of the urban form are difficult to change (overall layout and morphology especially), so immediate emphasis must focus on altering aspects of surface cover and construction materials in the short term. At the same time, the role of urban planning to shape the potential doubling of cities' total physical footprint within the next 15 years must not be ignored because it represents a significant opportunity for mitigating future climate change at the global scale. New urban development – particularly since much future urban development will occur in warmer climate zones – can lower its emissions drastically by pursuing compact development that employs mixed-use zoning and public transit (Zhao et al., 2017; Resch et al., 2016).

Projections of climate change show that there will be distinct urban impacts. The locations of cities tend to be at low elevation, close to coasts and in river valleys/basins, which exposes urban areas to hazards such as high winds and flooding (McGranahan et al., 2007; Miller and Small, 2003). The concentration of population and infrastructure in cities makes them especially vulnerable to the impacts of natural hazards. Land-use and land-cover strategies designed to regulate these urban effects (such as urban greening to mitigate urban flooding and heating) can complement global climate change adaptation strategies that emphasize resilience.

Urbanization also has a dramatic impact on local hydrological processes and water quality (see, e.g., Brabec et al., 2002; Paul and Meyer, 2001). Impervious surface cover reduces the rate of infiltration to the underlying soil, thus limiting storage. While sewers and channelized rivers improve the hydraulic efficiency of drainage networks, the net effect is to increase the risk of flooding by increasing the volume and intensity of runoff (Kravčík et al., 2007; Konrad, 2003). In addition, the water that washes off impermeable urban surfaces during rain events adds warm and polluted water to river courses, further degrading water quality.

Moderating the magnitude of these urban effects in cities requires altering aspects of urban form, especially surface cover and materials. Vegetation in particular has an important role to play as a versatile tool that can cool surfaces through shading and cool air via evaporation (Shashua-Bar et al., 2010). Green areas can also play a key role in water management by delaying urban runoff and using soils as a filter to improve water quality. Where the landscape is densely built, green roofs can both insulate buildings, moderate air temperature above the urban surface, and slow urban runoff (Mentens et al., 2006). Similarly, changing surface albedo by applying surface coatings or replacing impervious surfaces with permeable materials can moderate urban effects (Gaffin et al., 2012; Santamouris, 2014). Altering urban morphology once in place is a more challenging prospect. However, where change is possible, design goals are to ensure access to the sun and provide shade, protection from wind, or ventilation by breezes (Bottema, 1999; Knowles, 2003; Emmanuel et al., 2007; Chen et al., 2010). Urban areas not yet built, particularly those in the developing world, have the advantage of being able to design along these parameters in advance of construction.

The role of urban design is critical because the urban climate impact is a product of both its physical character and the background climate. The best solution in a city where the climate is cool and wet will not be the same for a city in an arid and warm climate. Similarly, where cities are already substantially built, the opportunities for change will differ for each neighborhood. Nevertheless, managing the outdoor climate can have multiple benefits including reduced demand for indoor cooling/heating and increased use of outdoor spaces for health and improved air quality (Akbari et al., 2001) (see Case Study 5.4).

In cities, emissions of GHGs arise mainly from buildings (residential and commercial), transportation, and industries, but the proportions vary based on the character of the urban economy and the source of energy (Kennedy et al., 2009) (see Chapter 12, Urban Energy). The contributions of buildings and transport have received the most attention because each is amenable to management at the urban scale using a variety of measures, including building energy codes, public transit systems, and land-use management (ARUP, 2014). Much of the current evidence indicates that densely occupied cities are more efficient in their use of energy (and generate less waste heat as a consequence) (Resch et al., 2016). The evidence is especially strong for transport energy, which is largely based on cities where there are mass transit systems (Newman and Kenworthy, 1989). Increasing urban population density through policies that co-manage land-use and transport networks is an important strategy for reducing urban GHG emissions (Dulal et al., 2011).

Good urban planning and urban design are critical to achieving climate change objectives at city, regional, and global scales. Compact and densely occupied cities do not have to feature impermeable, densely built, and high-rise neighborhoods associated with unwanted urban effects. In a study of urban spatial structure and the occurrence of heat wave days across more than 50 large U.S. cities, for example, Stone et al. (2010) found the annual frequency of extreme heat events to be rising more slowly in compact cities than in sprawling cities. A wealth of studies find the enhancement of vegetation and surface reflectivity in dense urban environments to measurably reduce urban temperatures at the urban and regional scale (see Taha et al., 1999; USEPA, 2008; Gaffin et al. 2012; Stone et al., 2014). Further, tall buildings in cities impede direct sunlight from reaching the ground (see Figure 5.7).

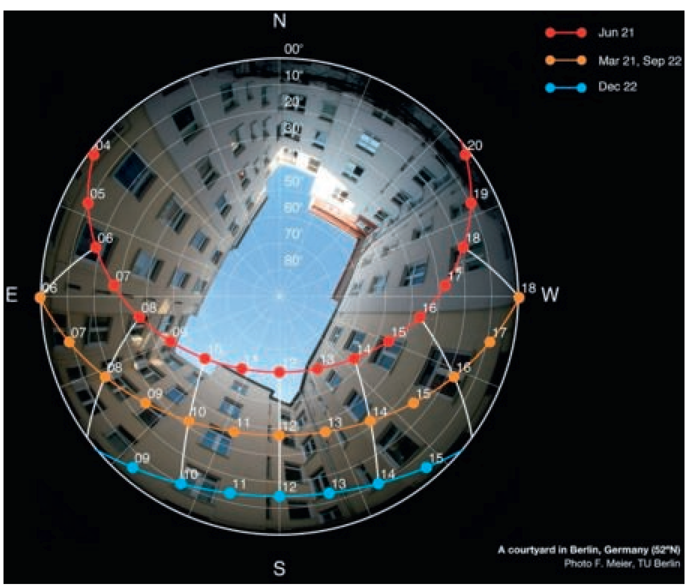


Figure 5.7 *The sky view from street level in Berlin, Germany. The hemispheric image shows the extent to which the sky is obscured by the surrounding buildings. The path of the sun at different times of the year is plotted to show the loss of direct sunlight at street level.*

Source: F. Meier, TU Berlin

5.4 Innovations

In this section of the chapter, we explore the implementation of strategies that utilize the four urban climate factors – urban function, form, construction materials, and surface cover – to achieve integrated mitigation and adaptation (see Figure 5.1).

5.4.1 Transportation, Energy, and Density

Since the middle of the 20th century, built environments the world over have tended to increase outward from central cities, consuming great swaths of previously undeveloped land while reinvestment in city centers falters. The infrastructure network needed to maintain this sprawling development pattern, particularly roads, has resulted in development that is land and infrastructure inefficient. It has also led to increased reliance on motor vehicles to get from one place to another. This reliance on motor vehicles has consequently led to a significant increase in vehicle miles (or kilometers) traveled (VMT), a concomitant increase in GHG emissions, and an amplification of the UHI effect through increased imperviousness, reduced green cover, and enhanced waste heat emissions (Stone et al., 2010). By developing in a denser, more compact form that mixes land use and supports mass transit use, cities may begin to reverse these trends (see Figure 5.8) (see Chapter 13, Urban Transportation).

If cities are to reduce VMT, then they must change their sprawling development pattern into one that relies on compact development. This focuses on regional accessibility through multiple transportation modes, including walking and bicycling, and clustered land-use patterns incentivized with vehicle distance traveled–based fees. At the core of this strategy is transit-oriented development (TOD) (Zheng and Peeta, 2015). TOD is compact, pedestrian-friendly development that incorporates housing, retail, and commercial growth within walking distance of public transportation, including commuter rail, light rail, ferry, and bus terminals (see Figure 5.8). It has become an essential and sustainable economic development strategy that responds to changing demographics and the need to reduce GHG emissions and health-related impacts.

Changing the built form from conventional suburban sprawl to compact, walkable, mixed-use and transit-oriented neighborhoods reduces travel distances (VMT). The meta-study *Effects of the Built Environment on Transportation: Energy Use, Greenhouse Gas Emissions, and Other Factors*, prepared by the National Renewable Energy Laboratory and Cambridge Systematics, Inc. (March 2013), notes that residents of compact, walkable neighborhoods have about 20–40% fewer VMTs per capita, on average, than residents of less-dense neighborhoods. Other studies have found a doubling of residential densities in U.S. cities to be associated with a 5–30% reduction in VMT (Gomez-Ibanez et al., 2009; Stone et al., 2010).

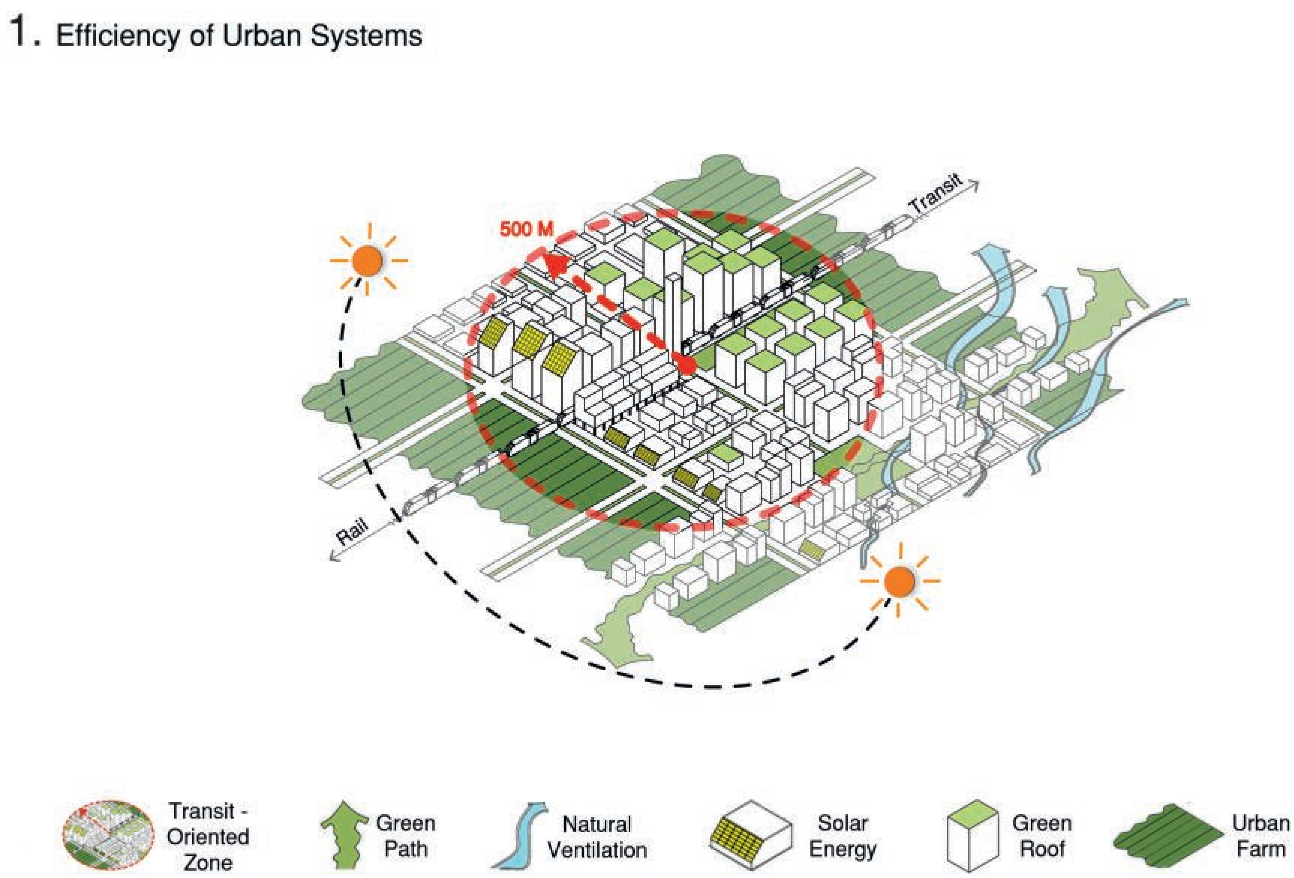


Figure 5.8 *Efficiency of urban systems.*

Source: Jeffrey Raven, 2016

Not only does compact, walkable TOD lower VMT, but it also requires less energy (see Chapter 12, Urban Energy). As Nolon (2012) reports, residential and commercial buildings used an extraordinary amount of electricity and energy in the past generation. In 2008, U.S. residential and commercial buildings consumed 29.29 quadrillion BTUs, which represented 73.2% of all electricity produced in the United States (Nolon, 2012). By 2035, the U.S. Department of Energy estimates that residential and commercial buildings will use 76.5% of the total electricity in the United States (Nolon, 2012). This energy consumption is also highly inefficient due to the systems used to produce and transmit it.

Two-thirds of the energy used to produce electricity in the United States is vented as waste heat that escapes into the atmosphere during generation and contributes to UHI formation (Nolon, 2012). Additionally, up to 15–20% of the net energy produced at these plants is then lost during electricity transmission (Nolon, 2012). By increasing the density of the built environment and reducing the distances that both electricity and people must travel, energy efficiency is notably increased in compact, transit-centered development (see Figure 5.8). As discussed in Jonathan Rose Companies (2011), a single-family home located in a compact, transit-oriented neighborhood uses 38% less energy than the same size home in a conventional suburban development (149 million BTU/year versus 240 million BTU/year).

Because compact development reduces VMTs and is more energy efficient, it also lessens GHG and waste heat emissions (see Figure 5.9). In a 2010 report to Congress, the U.S. Department of Transportation concluded that land-use strategies relying on compact, walkable, TOD could reduce U.S. GHG emissions by 28–84 million metric tons carbon dioxide equivalent (CO_2-eq) by the year 2030. Benefits would grow over time to possibly double that amount annually in 2050 (U.S. DOE, 2010).

Integrated mitigation and adaptation in urban planning and urban design can be successfully implemented through the configuration of low-carbon compact settlements configured for local microclimates. The mitigation perspective focuses on compact TOD prototypes reconfigured as low-carbon ecodistricts (see Box 5.3). The integrated mitigation and adaptation paradigm also addresses stormwater runoff and the UHI in high-density zones through material composition, urban morphology, and ecosystem services. This paradigm effectively “locks-in” long-term resilience.

The efficient use and recycling of energy and resources is a cornerstone of a resilient city and should be integral to the concept of integrated mitigation and adaptation, along with other climate-management strategies. This suggests the need for two levels of integrated mitigation and adaptation: passive and active. Passive Integrated Mitigation and Adaptation

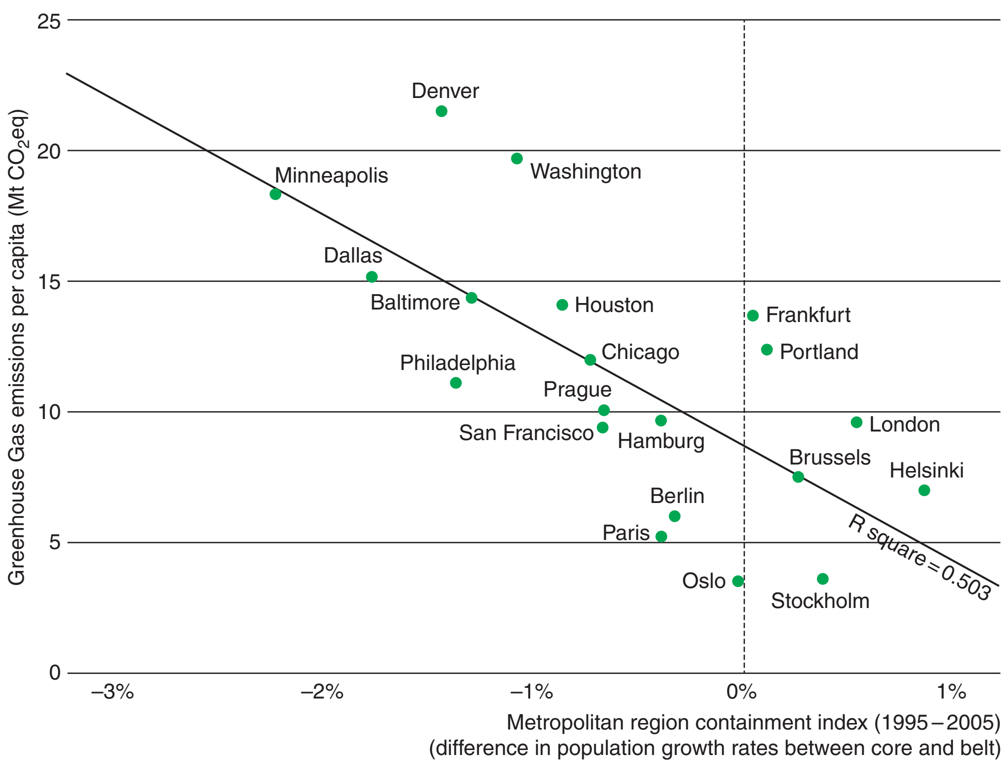


Figure 5.9 *Metropolitan region containment index (1995–2005).*

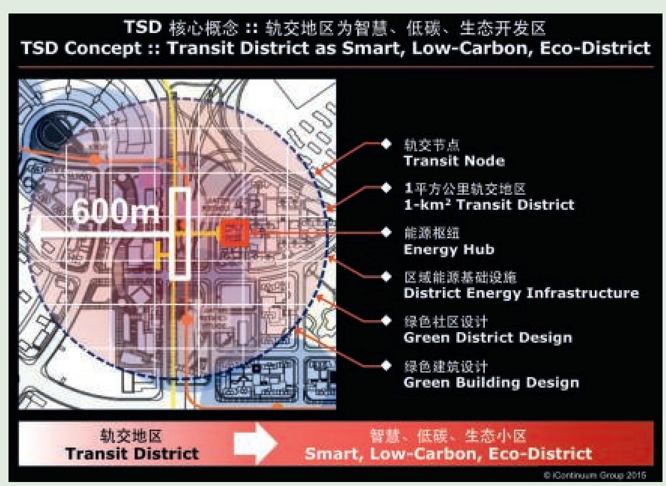
Source: Philipp Rode, 2012

Box 5.3 Multisectoral Synergies for Transit-Oriented, Low-Carbon Districts

Multisectoral approaches that integrate land use, mass transit, green buildings, and green districts to promote healthy, climate-resilient cities can be described as transit-synergized development (TSD). TSD leverages the greater scale, density, and economic value of transit-oriented development (TOD; nominal 1 km^2 urban districts around transit nodes) to create compact, vibrant, mixed-use communities that increase urban efficiency and reduce transport-related energy use, congestion, pollution, and greenhouse gas (GHG) emissions. As a co-benefit, the more compact development at the heart of TSD reduces pressures on interstitial spaces between transit corridors that can provide critical green infrastructure for managing climate impacts within dense urban zones. In China, promoting mass transit could generate up to 4 QBTUs (4.2 Exajoules) in energy savings per year (McKinsey Global Institute, March 2009). A number of cities in Canada and the United States are beginning to retrofit their urban fabric through TOD, and others in Latin America – most notably Curitiba, Brazil – have successfully used bus rapid transit (BRT) as a centerpiece of wider urban revitalization (Lindau et al., 2010).

TSD is a "node and network" model of sustainable urbanism. At each transit node, TSD combines passive and active green building design (high-performance envelope and mechanical, electrical, and plumbing [MEP] systems) with passive and active green district design (integrated urban design and advanced district infrastructure). District infrastructure provides a platform for the reuse and recycling of energy and resources among the buildings within the district. It is also a platform for innovation and "'forward integration'" of new technologies, important attributes of a robust, resilient, and adaptive community (Lee, 2012).

At the network level, the transit nodes collectively provide diversity, redundancy, and synergy, effectively transforming the transit network into a framework for a robust, resilient, and adaptive city (Walker and Salt, 2006).



Box Figure 5.3 Figure 1 *Transit-synergized development concept.*

Source: iContinuum Group

(PIMA) includes climate-responsive designs such as green cover, reflective ground surface, natural ventilation, and solar orientation. PIMA represents good design practice and should be the basic design strategy for all buildings and urban areas. In high-density urban districts, however, Active Integrated Mitigation and Adaptation (AIMA) may be required. AIMA deploys advanced building systems and district infrastructure such as integrated building energy management, renewable energy, energy storage, district energy systems, water recycling, and on-site wastewater treatment that actively reduce energy and climate impacts.

District-scale AIMA infrastructure can be inherently more cost-effective to "upgrade" than individual building systems and can therefore better "climate-proof" the built environment against changing conditions. An example of this is Singapore's Marina Bay District Cooling System, which is envisioned as an "energy platform that enables forward integration of new energy technologies" (Tey Peng Kee, Managing Director, Singapore District Cooling Pte Ltd.; Interview, 2012).

5.4.2 Climate-Resilient Urban Form

Urban morphology is defined as the three-dimensional form and layout of the built environment and settlement pattern. From regional, urban, and district scales to finer-grained street grids that promote walkability and social cohesion, climate-resilient planning and design strategies include configuration of urban morphology influenced by solar design, urban ventilation, and enhanced vegetation (see Figure 5.10). There are almost infinite combinations of different climate contexts, urban geometries, climate variables, and design objectives. A starting point in any project is to assess the micro- and macroclimatic characteristics of the site, an exercise that will indicate appropriate bioclimatic design strategies (Brophy et al., 2000). As the climate heats up, compact communities offer attractive alternatives to suburban sprawl by featuring comfortable, healthy microclimates with comparable natural amenities.

Wind velocities in cities are generally lower than those in the surrounding countryside due to the obstruction to air flow caused by buildings. In dense, compact communities, natural ventilation is challenging during warm months, often leading to increased cooling demand. This is partly because natural ventilation systems require very little energy but may need more space to accommodate low-resistance air paths (Thomas, 2003). Built-up areas with tall buildings may lead to complex air movement through a combination of wind channeling and resistance, often resulting in wind turbulence in some areas and concentrated pollution where there are wind shadows (Brophy et al., 2000). In general, denser developments result in a greater reduction in wind speeds but proportionally increased turbulence. Compact developments have less heat loss because there is generally less surface area for the volume enclosed due to shared wall space (Thomas, 2003).

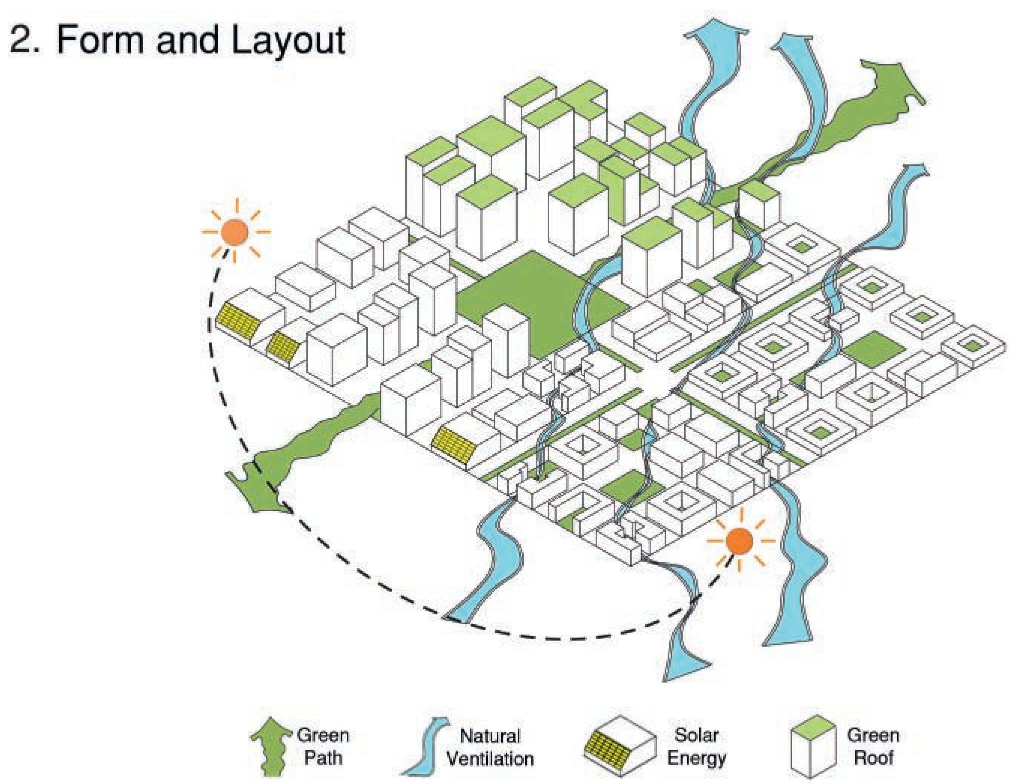


Figure 5.10 *Urban form and layout.*

Source: Jeffrey Raven, 2016

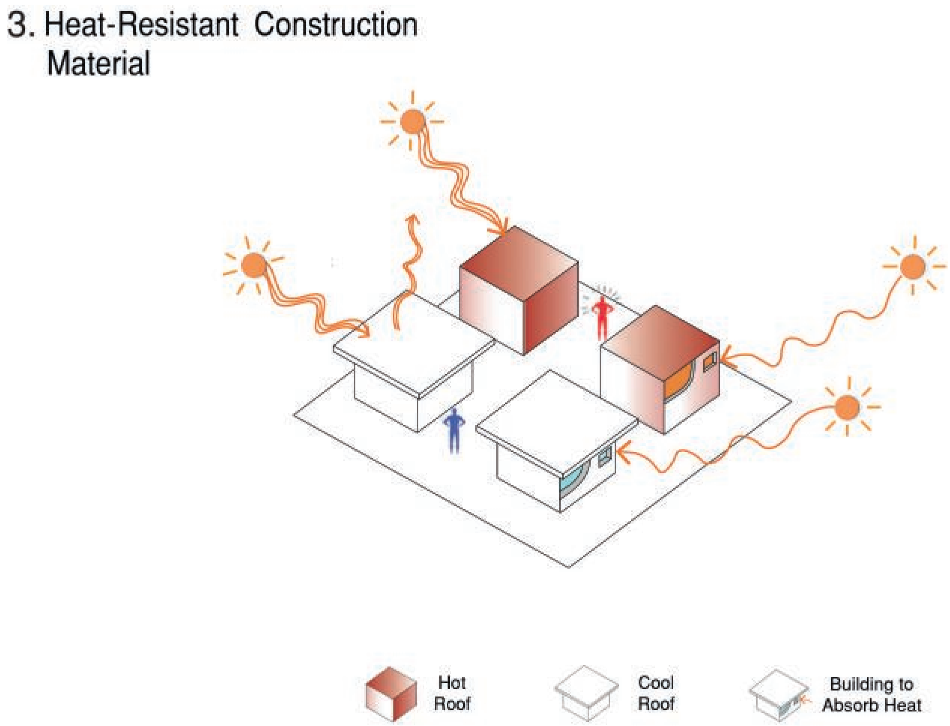


Figure 5.11 *Surface reflectivity.*

Source: Jeffrey Raven, 2016

Street-level ventilation for warm and humid climates is key, using approaches that do not necessarily require changing morphology. A simulation exercise of the likely urban warming effects of the planned urban growth trajectories in the warm, humid city of Colombo, Sri Lanka, indicates that there are significant differences in the likely warming rates between different urban growth trajectories (Emmanuel et al., 2007). A moderate increase in built cover (at an LCZ class of compact midrise) appears to lead to the least amount of warming. At the neighborhood scale, streets oriented to the prevailing wind directions with staggered building arrangements together with street trees appear to offer the best possibility to deal with urban warming in warm humid cities. The combined approach could eliminate the warming effect due to the heat island phenomenon. The Hong Kong example (see Case Study 5.3) illustrates how existing high-rise districts can be retrofitted to exploit passive urban ventilation.

Exploiting prevailing breezes is a key factor in implementing district-wide passive cooling strategies (see Figure 5.10). Wind affects temperature, rates of evaporative cooling, and plant transpiration and is thus an important factor at a microclimatic level (Brophy et al., 2000). Urban morphology is responsible for varying the "porosity" of the city and the extent of airflow through it, and it is a lynchpin for using passive cooling to reduce energy loads in the built environment (Smith et al., 2008). Wind flow across evapotranspiring surfaces and water bodies provide cooling benefits. The morphology and surface roughness of the built environment has significant impacts on the effectiveness of urban ventilation.

Passive methods to increase comfort and reduce energy loads through solar design include orienting street and public space layout to reduce solar gain during hot months, shading through the configuration of adjacent vegetation, orienting neighborhood configurations to the sun's path to maximize daylight in ground floor living rooms, placing tall buildings to the north edges of a neighborhood to preserve solar potential for photovoltaic arrays, varying building heights and breaks in the building line to reduce shadowing and increase solar access during cold months, and maximizing use of cool surfaces and reflective roofs in hot climates. Figures 5.10, 5.11, and the Masdar example (Case Study 5.4) illustrate these approaches.

5.4.3 Construction Materials

Increasing the surface reflectivity or *albedo* of urban materials is a well-established urban heat management strategy. Due to the darkly hued paving and roofing materials distributed throughout cities, a larger quantity of solar energy is often absorbed in cities than in adjacent rural areas with higher surface reflectivity, thus contributing to a lower albedo (see Chapter 2, Urban Climate Science). Unable to compensate for an enhanced absorption of solar energy through an increase in evapotranspiration, a larger percentage of this absorbed energy is returned to the atmosphere as sensible heat and longwave radiation, raising temperatures (see Figure 5.11).

Recognition of the potential to measurably cool cities through the application of highly reflective coatings to roofing surfaces

Case Study 5.1 Green Infrastructure as a Climate Change Adaptation Option for Overheating in Glasgow, UK

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Glasgow Caledonian University, Glasgow

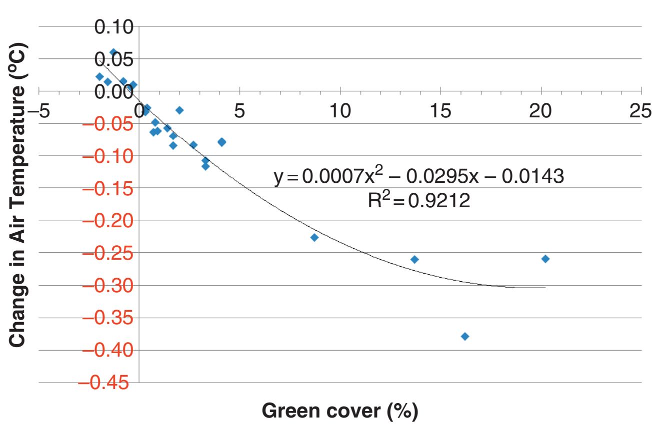
Keywords	Urban overheating, green infrastructure, green area ratio method, planning and design
Population (Metropolitan Region)[a]	606,340 (National Records of Scotland, 2016)
Area (Metropolitan Region)[b]	3,345.97 km² (Office for National Statistics, 2012)
Income per capita	US$42,390 (World Bank, 2017)
Climate zone	Cfb – Temperate, without dry season, warm summer (Peel et al., 2007)

[a] Counting the following Local Authority areas: East Dunbartonshire; East Renfrewshire; Glasgow City; Inverclyde; North Lanarkshire; Renfrewshire; South Lanarkshire; West Dunbartonshire

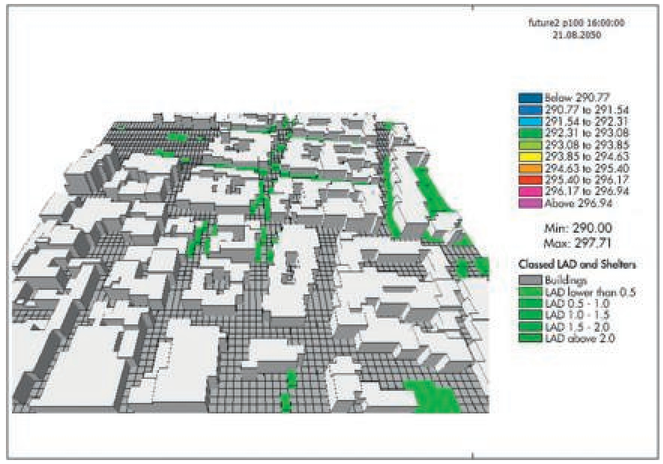
[b] Counting the following Local Authority areas: East Dunbartonshire; East Renfrewshire; Glasgow City; Inverclyde; North Lanarkshire; Renfrewshire; South Lanarkshire; West Dunbartonshire

From its medieval ecclesiastical origins, Glasgow (originally *Glaschu* – 'dear green place') expanded into a major port in the 18th century, and, with the advent of the Industrial Revolution, added a massive industrial base to its already well-developed built fabric. However, the success of its industrial base could not withstand the pressures of globalization, and, by the early 20th century, the city had begun to lose population. This decline appears to have been arrested in recent years. The long history of growth, decline, and regrowth provides Glasgow a historic opportunity to recreate its "green" past.

Emmanuel and Kruger (2012) showed that even when urban growth had subsided, Glasgow's local warming that results from urban morphology (increased built cover, lack of vegetation, pollution, anthropogenic heat generation) continues to generate local heat islands. Such heat islands are of the same order of magnitude as the predicted warming due to climate change by 2050. And the microscale variations are strongly related to local land cover/land-use patterns.



Case Study 5.1 Figure 1 *Summer daytime temperature.*



Case Study 5.1 Figure 2 *Extra green cover needed in reduction against green cover in Glasgow City Center to mitigate overheating.*

MITIGATING URBAN OVERHEATING

An option analysis exploring the role of green infrastructure (landscape strategies) in and around the Glasgow (Glasgow Clyde Valley, GCV) Region revealed the following (Emmanuel and Loconsole, 2015):

1. Green infrastructure could play a significant role in mitigating the urban overheating expected under a warming climate in the GCV Region.
2. A green cover increase of approximately 20% over the present level could eliminate a third to a half of the expected extra urban heat island (UHI) effect in 2050.
3. This level of increase in green cover could also lead to local reductions in surface temperature by up to 2°C.
4. More than half of street users would consider a 20% increase in green cover in the city center to be thermally acceptable, even under a warm 2050 scenario.

ACHIEVING GREEN COVER

Not all green areas contribute equally to local cooling, nor are they equal in their other environmental and sustainability benefits. Recognizing this, planners have begun to develop weighting systems that capture the relative environmental performance of different types of green cover. The most widely used among these is the Green Area Ratio (GAR) method (Keeley, 2011). GAR is currently implemented in Berlin and has been adapted in Malmo (Sweden), several cities in South Korea, and Seattle (USA). Elements of GAR include:

Impermeable surfaces (i.e., surfaces that do not allow the infiltration of water)

Includes roof surfaces, concrete, asphalt and pavers set upon impermeable surfaces or with sealed joints). = *0.0*

Impermeable surfaces from which all storm water is infiltrated on property

Includes surfaces that are disconnected from the sewer system. Collected water is instead allowed to infiltrate on site in

Case Study 5.1 Table 1 *Alternative approaches to increasing green cover by 20% in Glasgow City Center.*

Scenario	Permeable vegetated area (m²)	Street trees (Nos.)	Intensive roof gardens (m²)	Extensive roof gardens (m²)	Green façades
1. A single large park	1,056				
2. Street trees only		528			
3. 50% of additional greenery in street trees, balance intensive roof gardens		264	755		
4. 50% of additional greenery in street trees, balance extensive roof gardens		264		1,056	
5. Mix of intensive (50%) and extensive (50%) roof gardens			755	1,056	
6. 50% of all "sun facing (i.e., South & West) façade covered by green façades					1,268

a swale or rain garden. Guidelines for preventing groundwater and soil contamination must be followed. = *0.2*

Nonvegetated, semi-permeable surfaces
Includes cover types that allow water infiltration, but do not support plant growth. Example include brick, pavers and crushed stone. = *0.3*

Vegetated, semi-permeable surfaces
Includes cover types that allow water infiltration and integrate vegetation such as grass. Examples include wide-set pavers with grass joints, grass pavers, and gravel-reinforced grassy areas. = *0.5*

Green façades
Includes vines or climbing plants growing (often from ground) on training structures such as trellises that are attached to a building. The façade's area is measured as the vertical area the selected species could cover after 10 years of growth up to a height of 10 meters; window areas are subtracted from the calculation. = *0.5*

Extensive green roofs
Includes green roofs with substrate/soil depths of less than 80 centimeters. However, Berlin excludes green roofs constructed on high-rise buildings. = *0.5*

Intensive green roofs and areas underlain by shallow subterranean structures
Includes green roofs with substrate/soil depths of greater than 80 centimeters. This category includes subterranean garages. = *0.7*

Vegetated areas
Any area that allows unobstructed infiltration of water without evaluation of the quality or type of vegetation present. Examples range from lawns to gardens and naturalistic wooded areas. = *1.0*

A system of target setting is initially required that takes into account the severity of the environmental risk faced by a particular urban neighborhood. Once the target green cover is determined, the above-indicated weighting is used to develop alternate green infrastructure scenarios.

Case Study 5.1 Table 1 shows alternate approaches to a 20% increase in green cover in Glasgow city center. These employ an urban park, street trees, roof gardens, façade greening, or combinations of these.

and streets has led to the development of new product lines known as "cool" roofing and paving materials. For roofing surfaces concealed from ground view, such as atop a flat industrial building, very high-albedo, cool material coatings can be applied to reflect away a substantial percentage of incoming solar radiation. Industry analyses of these materials have found that the surface temperature of roofing materials can be reduced by as much as 50°F/10°C during periods of intense solar gain (Gaffin et al., 2012).

To explore the extent to which cool materials could reduce temperatures not only within the treated buildings themselves but also throughout the ambient urban environment, scientists at the Lawrence Berkeley Labs and the Columbia Center for Climate Systems Research have modeled extensive albedo enhancement strategies (Rosenzweig et al., 2014). Measured on a scale of 0 to 1, average surface albedos in U.S. cities tend to range from 0.10 to 0.20, much lower than the albedos of 0.6 to 0.8 associated with cool roofing and paving materials. In densely settled districts such as Manhattan, the potential to raise average albedos is great, but all cities can enhance their reflectivity through the use of higher albedo materials in routine resurfacing over time. Finding optimal values of reflectivity adjustment, rather than an all-out pursuit of maximum attainable values over large swaths of surface areas, will limit potential hydroclimatic trade-offs while still attaining temperature reduction goals (Georgescu et al., 2014; Jacobson and Ten Hoeve, 2012).

An important advantage of albedo enhancement over other urban climate management strategies is its relatively low cost. Cool roofing treatments can be applied to low-sloping roofs for a cost premium of between US$0.05 to US$0.10 per square foot, raising the cost of a 1,000 square foot roofing project by as little as US$100. Balanced against this low initial cost are annual energy savings estimated by the U.S. Environmental Protection Agency (EPA) to be about U.S. $0.50 per square foot, an estimate accounting for potentially greater winter heating costs (U.S. EPA, 2008). Also advantageous is the immediacy of beneficial returns from cool materials strategies, especially in semi-arid areas where the use of water for vegetation is not sustainable. In contrast to tree planting and other vegetative programs through which maximum cooling benefits are not realized until plants reach maturity, high-albedo coatings yield maximum benefits upon installation, with benefits diminishing somewhat thereafter with weathering, and as roofs become soiled.

5.4.4 Green and Blue Infrastructure

The interaction of green and blue components in the urban environment links together integrated mitigation and adaptation strategies at different scales – from buildings and open spaces design to landscape design and metropolitan region planning – and can yield many co-benefits (see Figure 5.12) (see Chapter 8, Urban Ecosystems). A comprehensive climate-based design supports developing and maintaining a network of green and blue infrastructure integrated with the built environment to conserve ecosystem functions and provide associated benefits to human populations (STAR Communities, 2014). Urban planning and urban design strategies focusing on green infrastructure and

Case Study 5.2 Adapting to Summer Overheating in Light Construction with Phase-Change Materials in Melbourne, Australia

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[2]*Heriot-Watt University, Dubai Campus*

Keywords	Thermal comfort, residential buildings, passive cooling, phase change materials, mitigation and adaptation, planning and design
Population (Metropolitan Region)	4,258,000 (UN, 2016)
Area (Metropolitan Region)	9,999.5 km² (Australian Bureau of Statistics, 2013)
Income per capita	US$54,420 (World Bank, 2017)
Climate zone	Cfb – Warm temperate, fully humid, warm summer (Peel et al., 2007)

Melbourne, ranked one of the most livable cities around the world since 2011, is the capital city in the state of Victoria and the second most populous city in Australia (2006 Census QuickStats). It has a population of 3.99 million living in the greater metropolis (Australian Bureau of Statistics, 2013).

As a result of recent rapid urbanization, the city has undergone an outward expansion. The recent construction boom in both the Central Business District and nearby suburbs has led to a significant change in land use. This may imply that more buildings will be constructed in the near future and, consequently, more greenhouse gas (GHG) emissions from building operations. Change in land use such as replacement of green space by construction and increasing concrete or paved roads can be anticipated if appropriate urban planning for climate adaptation is lacking.

Existing studies have recognized the challenges facing current urbanization posed by the urban heat island (UHI) effect and global warming. Exacerbated thermal conditions in the urban built environment and increasing human health issues can be expected without proper intervention. In this regard, we now face challenges not only in designing low-energy buildings to reduce GHG emissions for mitigating global warming but also to meet thermal comfort requirements without sacrificing indoor environment quality (IEQ) to actively adapt to climate change.

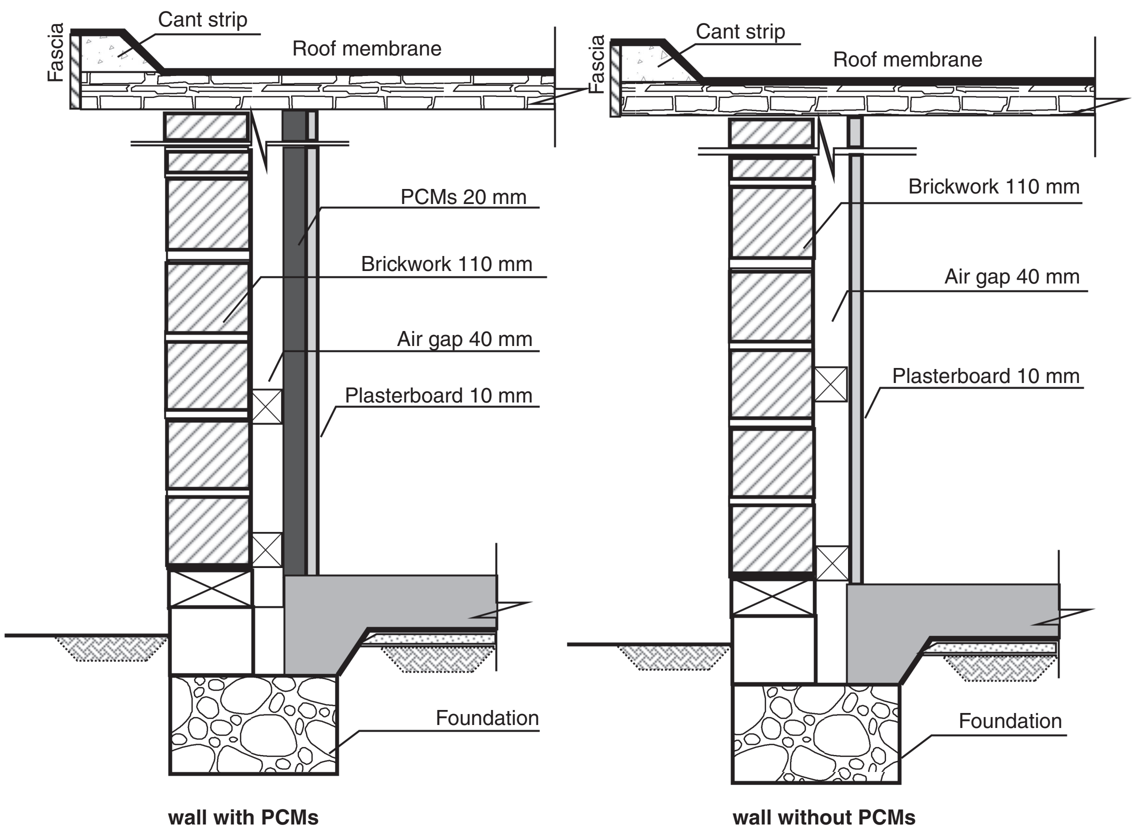
However, modern construction methods introduce more lightweight buildings. These methods employ offsite, prefabrication strategies to reduce construction time. Consequently, there is a potential risk of overheating and deteriorated thermal comfort conditions with lightweight construction products, which are likely to be exacerbated in a warming climate. Occupant thermal comfort in lightweight buildings therefore is receiving increasing attention among architects and designers.

In this Case Study, phase-change materials (PCMs) are used as a heat sink to absorb heat from the sun during the day and to reduce rapid room temperature rise due to added thermal stability. To examine the effectiveness of a lightweight building using PCMs, a one-dimensional numerical model was developed and solved by an enthalpy[1] method with an explicit scheme. The performance of PCMs for cooling a lightweight building with a brick veneer residential wall during the hot summer of 2009 in Melbourne was predicted numerically. The study reveals that application of PCMs in lightweight buildings could achieve better thermal comfort and energy savings in summer.

Bio-based PCM, applied instead of conventional wall insulation is made with a mix of soy-based chemicals that change from liquid to solid and vice versa at specific melting or solidification temperatures. The advantage of using PCMs is increased thermal storage capacity. It is estimated that about 30% of heating and cooling costs would be reduced.

Case Study 5.2 Figure 1 depicts the geometric configuration of the thermally enhanced brick veneer wall with PCMs and its original configuration without PCMs before modification. The thermally enhanced PCM wall is composed of 110-millimeter brickwork, 40-millimeter air gap, 20-millimeter PCMs, and 10-millimeter plasterboard.

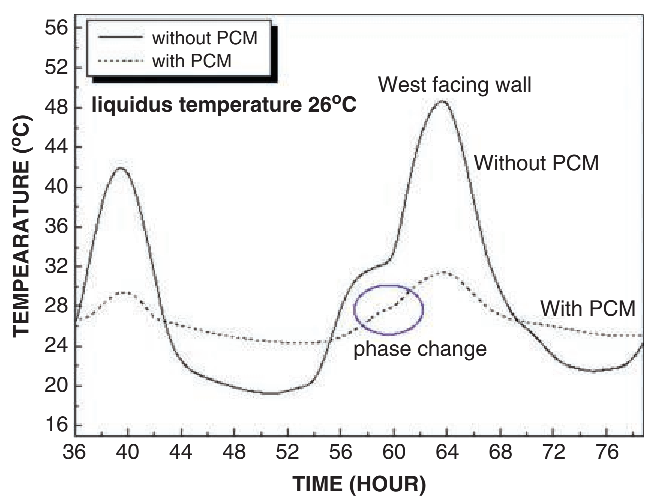
1 *Enthalpy* is the thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume.



Case Study 5.2 Figure 1 *Schematic of lightweight brick veneer wall with integrated phase-change materials (left), and without (right).*

To understand the occupancy comfort level, the peak wall temperatures were considered when evaluating the performance of the PCM wall. The interior surface temperatures for the west-facing walls are compared for the PCM brick veneer wall and for the reference wall without PCM, as shown in Case Study 5.2 Figure 2. It was found that the interior surface temperature of the PCM wall in the day is lower than the conventional wall due to the presence of PCM heat storage during the daytime. The maximum peak temperature of the conventional brick veneer wall reached almost 48°C, whereas the maximum of the PCM wall was around 32°C. It is generally believed that lower surface temperatures result in greater occupant thermal comfort and energy savings in summer. A significant peak cooling load reduction therefore would be expected.

The successful testing of PCMs in lightweight building materials in the weather conditions of Melbourne demonstrated the effectiveness and validity of both mitigation and adaptation strategies. Combined with other sustainable energy technologies as an integrated approach for climate change mitigation and adaptation, PCMs could be useful for other cities with similar conditions.



Case Study 5.2 Figure 2 *Surface temperature profiles of two west-facing walls with and without phase-change materials.*

sustainable water management help restore interactions between built and ecological environments. This is necessary to improve the resilience of urban systems, reduce the vulnerability of socio-economic systems, and preserve biodiversity (UNEP, 2010).

Integration of water management with urban planning and urban design represents an effective opportunity for climate change adaptation (UNEP, 2014) (see Figure 5.13). This has been demonstrated by the emerging *Water Sensitive Urban Design* (*WSUD*) approach (Ciria, 2013; ARUP, 2011; Flörke et al., 2011; Hoyer et al., 2011; BMT WBM, 2009). All the elements of the water cycle and their interconnections are considered to achieve together an outcome that sustains a healthy natural environment while addressing societal needs and reducing climate-related risks (Ciria, 2013). The implementation of integrated water cycle management as adaptive design strategy should be based on a

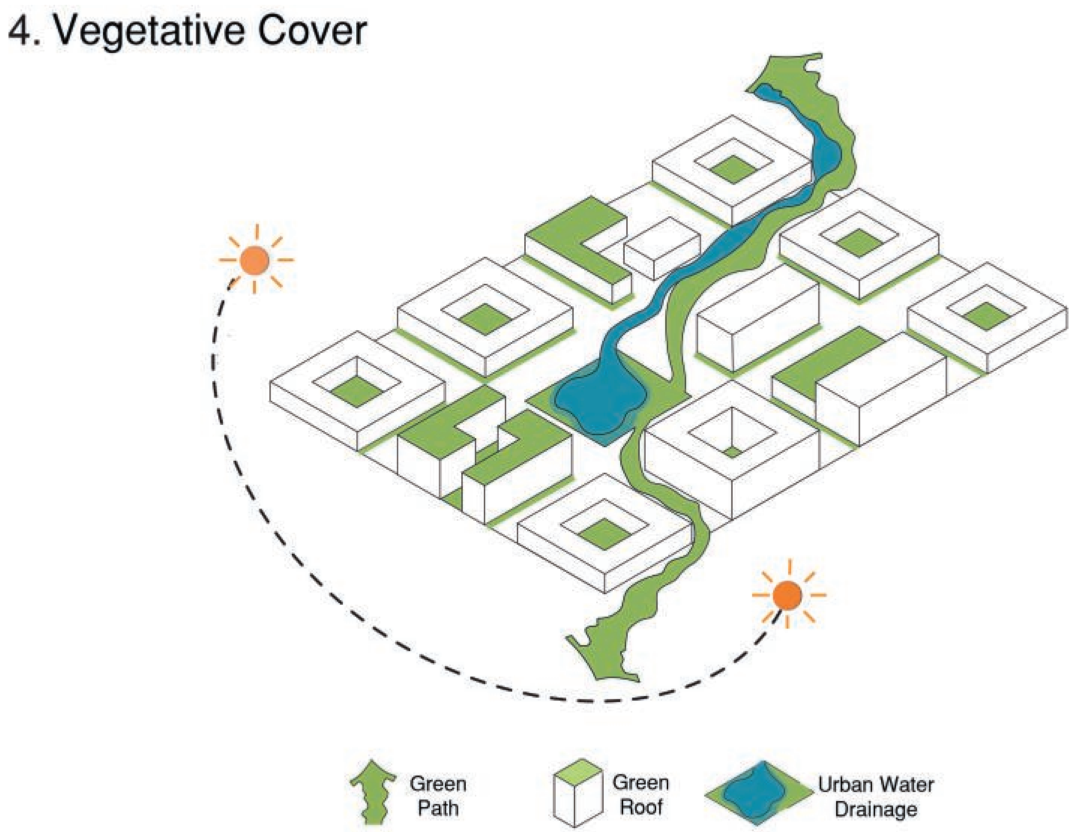


Figure 5.12 *Surface cover.*

Source: Jeffrey Raven, 2016

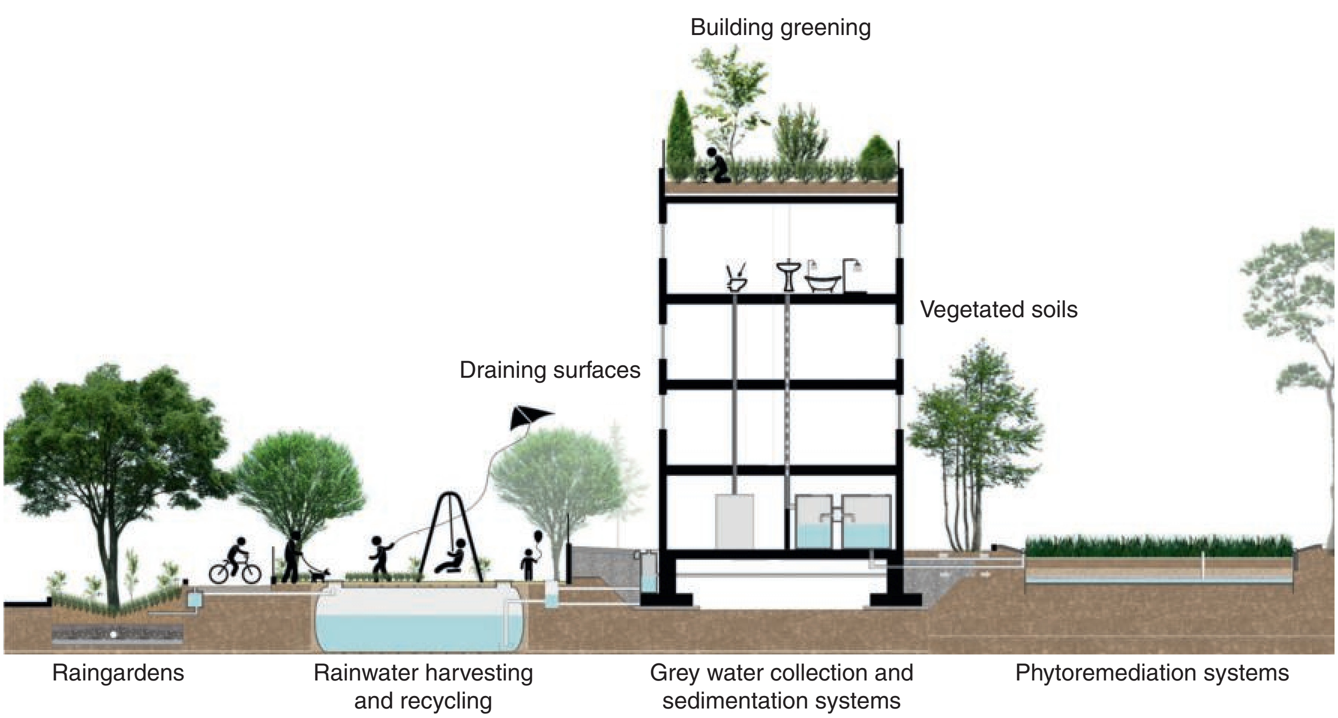


Figure 5.13 *Green and blue infrastructure design: building/open space scale, Naples, Italy.*

Source: Cristina Visconti and Mattia Leone

Case Study 5.3 Application of Urban Climatic Map to Urban Planning of High-Density Cities: An Experience from Hong Kong

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Lutz Katzschner

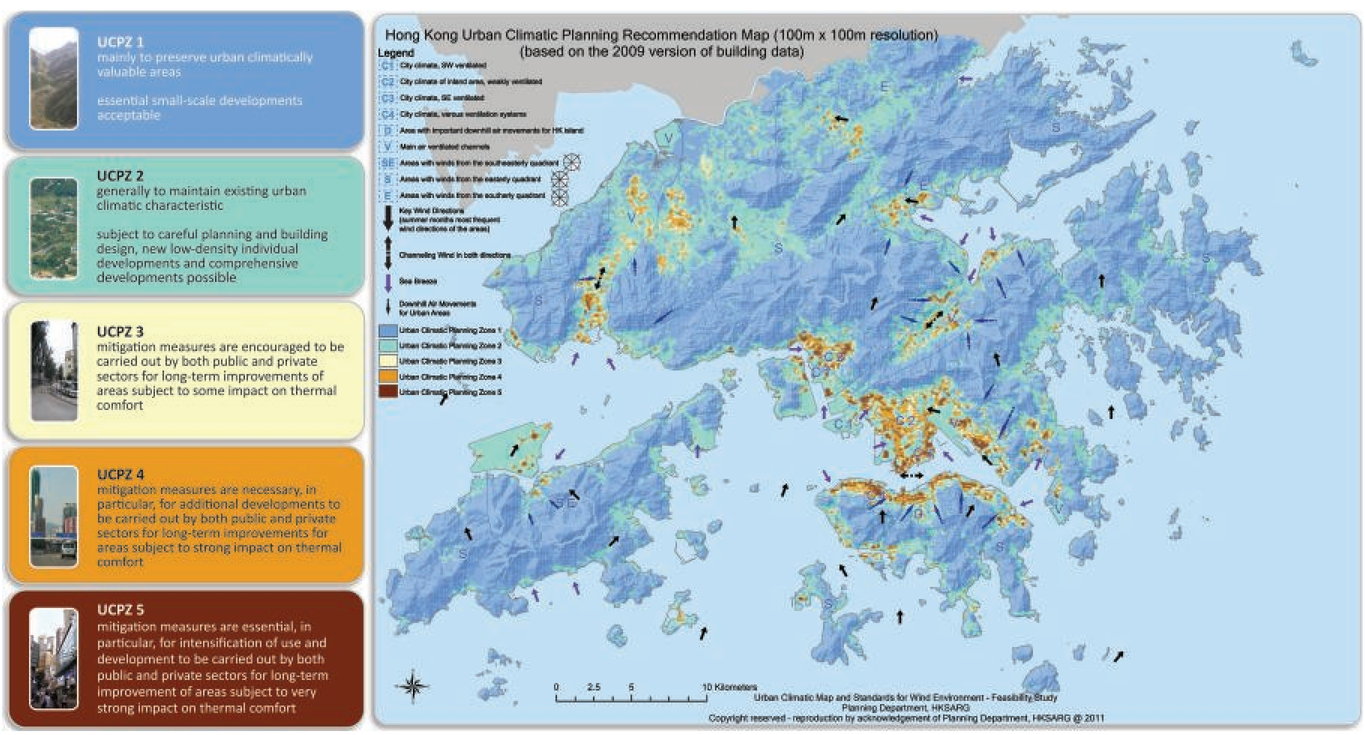
University of Kassel

Keywords	Heat island effect, high density, urban climatic map, ventilation corridors, planning and design
Population (Metropolitan Region)	7,310,000 (GovHK, 2016)
Area (Metropolitan Region)	1,105.7 km^2 (GovHK, 2016)
Income per capita	US$60,530 (World Bank, 2017)
Climate zone	Cwa – Monsoon-influenced humid subtropical, hot summer (Peel et al., 2007)

Hong Kong is located on China's south coast and situated in a subtropical climate region with hot and humid summers. As a high-density city with a population of 7.3 million living on 25 square kilometers of land, Hong Kong has a hilly topography and 40% of the territory is classified as country-park, where development is prohibited; hence only about 25% is built-up. Due to limited land area and increasing land prices, taller and bulkier buildings with higher building plot ratios, very limited open space, large podium structures, and high building-height-to-street ratios have been built. These tall and wall-like buildings in the urban areas block the incoming wind and sea breezes. This leads to a worsening of urban air ventilation and exacerbates the city's urban heat island (UHI) intensity. The number of very hot days (maximum air temperature greater than 33°C) and very hot nights (maximum air temperature greater than 28°C) has increased, whereas the mean wind speeds recorded in urban areas over the past 10 years have decreased. This intensifies uncomfortable urban living, heat stress, and related health problems and increases energy consumption.

The Hong Kong Observatory has conducted studies that note that Hong Kong's urban temperature has been increasing over the decades (Leung et al., 2004). Good urban air ventilation is an effective adaptation measure for the UHI effect and rising temperatures under climate change. However, Hong Kong's urban wind environment is deteriorating due to intensive urban development that increases the surface roughness and blocks the free flow of air, leading to weaker urban air ventilation and higher urban thermal heat stress. Higher air temperatures and a higher occurrence and longer duration of heat waves will have a severe impact on urban living; therefore, there is a need to plan and design the city to optimize urban climatic conditions and urban air ventilation based on a better understanding of the UHI phenomenon and the urban climate to reduce the impact of urban climate and climate change.

The Planning Department of the Hong Kong SAR Government produces the Hong Kong Urban Climatic Map System (PlanD, 2012) to provide an evidence-based tool for planning and decision making.



Case Study 5.3 Figure 1 *The Urban Climatic (Planning Recommendation) Map of Hong Kong.*

Source: Hong Kong Planning Department, HKSAR Government

The Urban Climatic (Planning Recommendation) Map classifies Hong Kong's urban and rural areas into five planning recommendation zones. General planning advice is given for each zone. Detailed advice is contained in the map's accompanying notes.

Based on a scientific understanding of the Hong Kong Urban Climatic Maps, future planning scenarios may be tested and effective adaptation measures (including advice on building density, site coverage, building height, building permeability, and greening) may be developed (PlanD, 2012). Prescriptive guidelines and performance-based methodologies in the Hong Kong Urban Climatic Map System provide further quantification. With a better understanding of urban climate, planners can balance various planning needs and requirements when making their final decisions.

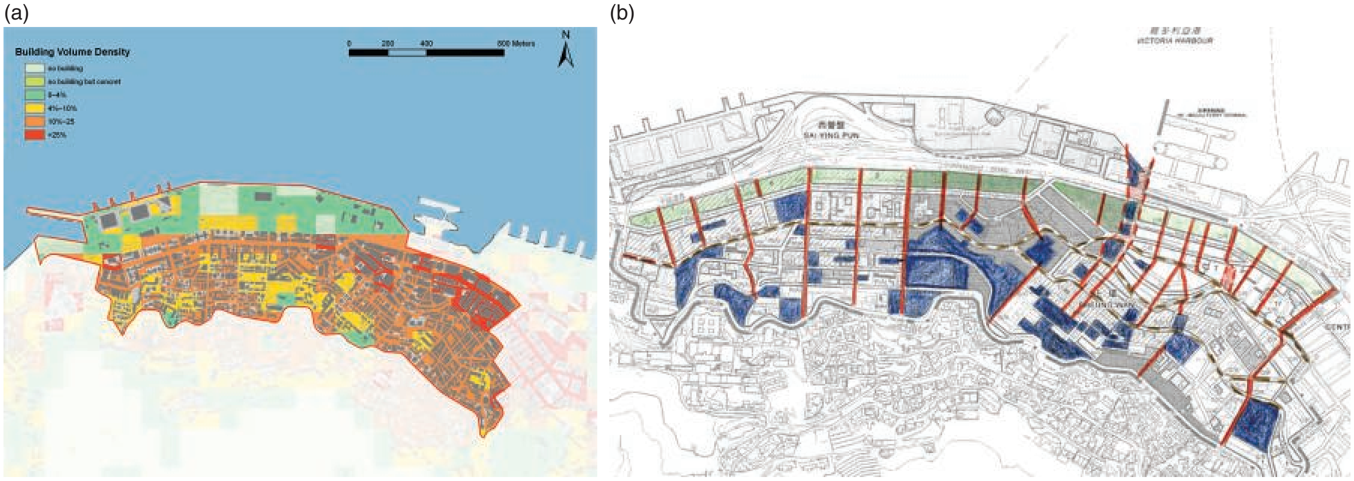
Based on an understanding of the Urban Climatic Maps, the following planning and design measures should thus be taken into account in project planning and in the formulation of development parameters. They could help improve the urban climate and reduce the impact of climate change:

The UC-ReMap provides a strategic and comprehensive urban climatic planning framework and information platform for Hong Kong that can be also applied to other high-density cities. It helps to clarify and identify appropriate planning and design measures for the formulation of planning guidelines on matters related to urban climate and climate change, and it provides a strategic urban planning and development process for future development (e.g., maximizing the adaptation opportunities within urban climate planning zones (UCPZs) 3, 4, and 5) and accommodating comprehensive new development areas in UCPZ 2 with prudent planning and building design measures (PlanD, 2012). It also provides an urban climatic planning framework for reviewing outline zoning plans and formulating suitable planning parameters.

Case Study 5.3 Table 1 *Planning and design measures to be taken into account in project planning.*

Planning parameters	Recommendations
Building volume	Site plot ratio of 5 or less. Higher plot area must be adapted using other planning parameters.
Building permeability	25–33% of the project site's frontal elevation. Lower permeability must be adapted using other planning parameters.
Building site coverage	70% of the site area. Higher site coverage must be adapted using other planning parameters.
Air paths and breezeways	Open spaces must be linked with landscaped pedestrianized streets from one end of the city to the other end in the direction of the prevailing wind.
Building heights	Vary building heights so that there is a mixture of building heights in the area with an average aggregated differential of 50%.
Greenery	20–30% of tree planting preferably at grade, or essentially in a position less than 20 m from the ground level. Trees with large canopy and a leaf area index of more than 6 are preferred.

(a) (b)



Case Study 5.3 Figure 2 *Building volume density study of the area (left); open spaces (blue) and air paths (red lines) suggested for the area (right), Hong Kong.*

Case Study 5.4 An Emerging Clean-Technology City: Masdar, Abu Dhabi, United Arab Emirates

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Foster + Partners, London

Keywords	Carbon-free technologies, nearly-zero energy buildings, microclimate comfort, planning and design
Population (Metropolitan Region)	1,179,000 (UN, 2016)
Area (Metropolitan Region)	803 km^2 (Demographia, 2016)
Income per capita	US$72,850 (World Bank, 2017)
Climate zone	Bwh – Arid, desert, hot (Peel et al., 2007)

Masdar City is an emerging clean-technology cluster located in what aims to be one of the world's most sustainable urban developments powered by renewable energy. The project continues to be a work in progress. Located about 17 kilometers from downtown Abu Dhabi, the area is intended to host companies, researchers, and academics from across the globe, creating an international hub focused on renewable energy and clean technologies. The master plan is designed to be highly flexible, to benefit from emergent technologies, and to respond to lessons learned during the implementation of the initial phases. Expansion has been anticipated from the outset, allowing for growth while avoiding the sprawl that besets so many cities (Bullis, 2009; Manghnani and Bajaj, 2014).

The aim of a new development settlement characterized by a comfortable living environment in such an extreme desert climate required the implementation of adaptive design strategies to effectively respond to issues related to scarcity of precipitation, seasonal drought, high temperatures, and wide daily temperature range. The carbon-free new development sets new standards for climate change mitigation in arid countries through the adoption of nearly zero energy standards and building-integrated energy production from renewable sources.

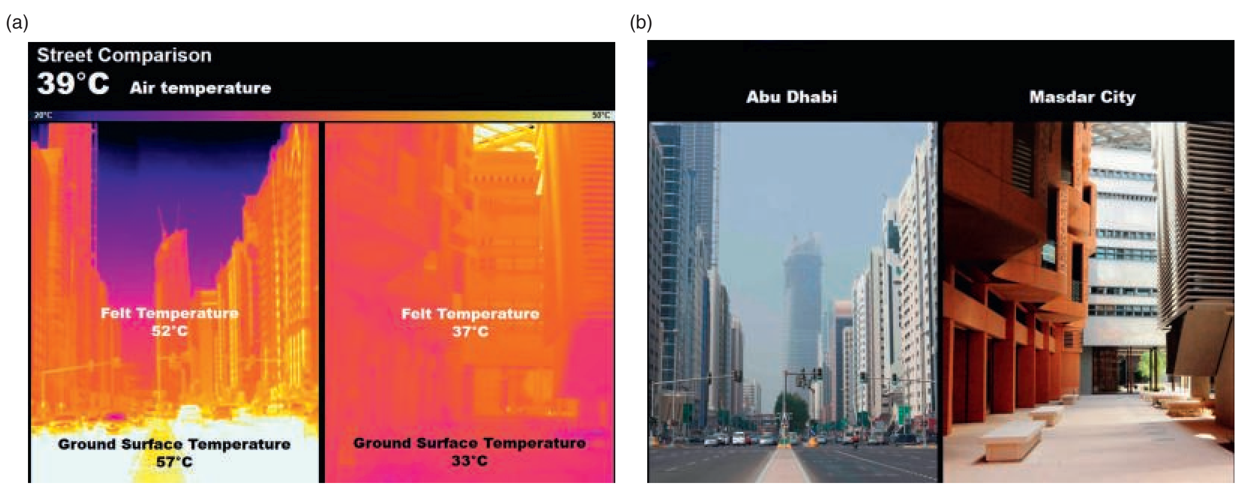
The design concept explores the adoption of sustainable technologies and planning principles of traditional Arab settlements combined with contemporary city spatial-functional needs and state-of-the-art technological solutions to develop a carbon-neutral and zero-waste community despite the extreme climatic conditions. The quest for a mixed-use, low-rise, and high-density development, entirely car-free, with a combination of personal and public transit systems and pedestrian areas, is achieved through an extensive use of traditional solutions such as narrow streets and optimal orientation; shaded windows; exterior walls and walkways to control solar radiation; thick-walled buildings to maximize thermal mass and reduce energy consumption; courtyards and wind towers for natural ventilation; and

Case Study 5.4 Figure 1 *Masdar, Carbon-Neutral Development Case Study: Abu Dhabi, UAE.*

Source: Foster + Partners

Case Study 5.4 Figure 2 *Masdar wind tower.*

Source: Foster + Partners



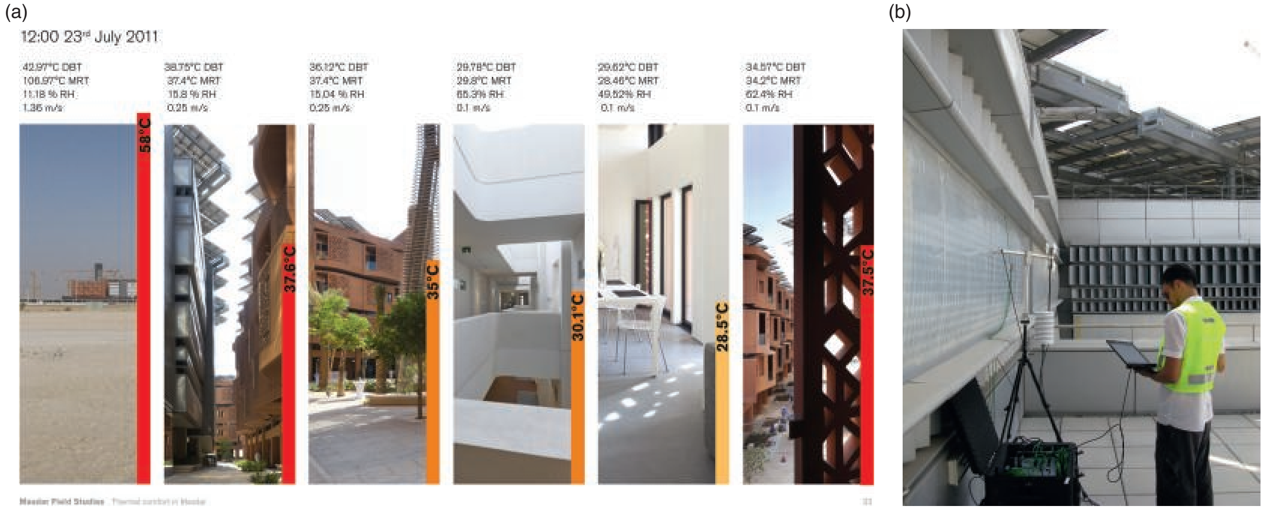
Case Study 5.4 Figure 3 *Thermal imaging comparing streetscapes in Abu Dhabi and Masdar City.*

Source: Foster + Partners

vegetation design with optimized water management to improve the local micro-climatic conditions of open spaces.

The northeast-southwest orientation of the city makes best use of the cooling night breezes and lessens the effect of hot daytime winds. Green parks separate built-up areas, not only to capture and direct cool breezes into the heart of the city, but also to reduce solar gain and provide cool pleasant oases throughout the city. The intelligent design of residential and commercial spaces, based on building standards currently set by internationally recognized organizations, reduces demand for artificial lighting and air conditioning. Such standards, adapted to the local climatic context, contributed to the development of Abu Dhabi's "Estidama" rating system for sustainable building (Abu Dhabi Estidama Program, 2008).

Carefully planned landscape and water features lower ambient temperatures while enhancing the quality of the street. The elimination of cars and trucks at street level not only makes the air cleaner for pedestrians, but also allows buildings to be closer together, providing more shade but allowing maximum natural light. The placement of residential, recreational, civic, leisure, retail, commercial, and light industrial areas across the master plan, along with the public transportation networks, ensures that the city is pedestrian friendly and a pleasant and convenient place in which to live and work.



Case Study 5.4 Figure 4 *Masdar field studies in the desert.*

Source: Foster + Partners

Wind towers, which can be found on both sides of the Arabic Gulf, are a traditional form of enhancing thermal comfort within the courtyard houses of the region. Masdar is exploring the possibility of using the principle to passively ventilate undercroft spaces and the public realm, thereby reducing the demand for mechanical ventilation systems.

Urban devices from local vernacular architecture – such as colonnades, wind towers, green canopies, and fountains – can bring the felt temperature down by 20 degrees compared to open desert. Cumulatively, all of these design principles have the effect of prolonging the moderate season in the city.

The land surrounding the city will contain wind and photovoltaic farms, as well as research fields and plantations, allowing the community to be entirely energy self-sufficient (Foster+Partners, 2009).

The design process has been based on studies and simulations of energy and thermal comfort, solar and wind analysis, material heat gain, and thermal imaging. Field measurement studies (Case Study 5.4 Figures 3 and 4) have been conducted to assess the microclimatic performance of spaces in Masdar City. Infrared thermal imaging was used in addition to hand-held equipment to track variations in temperature in urban spaces and then compared them to similar urban spaces in central Abu Dhabi and the desert. The comparisons of images show the superior performance of Masdar City due to the shade provided by built form, correct use of materials, natural ventilation, and evaporative cooling strategies.

dual definition of water as both resource and hazard (see Chapter 9, Coastal Zones). In the framework of urban design and planning, managing water as a resource addresses environmental quality and microclimate conditions of urban spaces, availability of water, rebalancing of ecosystem exchange, and the hydrological cycle in buildings and open spaces (ARUP, 2011). When considering water as a hazard, design should focus on the control of water discharge through runoff management and infiltration measures able to achieve wastewater retention and employing a decentralized sewage system.

Best practices of adaptation-driven urban policies worldwide provide significant examples of how the paradigm shift toward water-sensitive and water-resilient cities allows for the implementation of an integrated approach that combines risk prevention with a regeneration of urban fabric driven by adaptive design solutions (Kazmierczak and Carter, 2010). The Sydney Water Sensitive Urban Design (WSUD) Program and the post-Sandy "Rebuild by Design" initiatives in New York demonstrate such practices.

Recirculation of water on site is among the main concepts of a water-sensitive approach to urban design and planning. It represents a key priority for enhancing water resilience and requires an integrated set of complementary measures, including decentralization of water discharge, harvesting and recycling, draining, and vegetated surfaces, thus improving urban microclimate and flood prevention.

Evaporative cooling processes, fostered by the development of green spaces in cities, allow for sustainable management of the water cycle and a reduction of the UHI effect. Building greening measures (sustainable roofs and vegetative facades) reduce the amount of water flowing into sewage systems, mitigate temperature extremes, provide thermal insulation, and increase biodiversity in urban areas (Ciria, 2007b; Schimdt et al., 2009; Nolde et al., 2007, Steffan et al., 2010; UNEP, 2012). Green streetscapes, including the use of permeable paving, provide shade and reduce thermal radiation.

Greening and permeable paving, as elements of storm-water management, have the potential to retain water that is then evaporated while delaying and reducing runoff (Scholz and Grabowiecki, 2007). Such a design approach for urban open spaces is strengthened by the integration of sustainable drainage systems (SuDS). This is a set of measures aimed at retaining and infiltrating storm water (bio-swales, rain gardens, retention basins, bio-lakes, wetlands, rainwater harvesting systems). This allows for the control of water discharge and reduces flood risk (Ciria, 2007a, 2010; Charlesworth, 2010; Poleto, 2012) (see Chapter 14, Urban Ecosystems).

The location and form of green infrastructure should be determined in relation to the built environment and aligned in relation to natural systems, including water bodies, solar impacts, and prevailing winds. A network of local microclimates can comprise small green spaces, planted courtyards, shaded areas, and "urban forests" to moderate temperature, as demonstrated in the Manchester, United Kingdom, Case Study. Vegetation should be sited to maximize the absorption rate of solar radiation. Localized water bodies can moderate temperature extremes through their high thermal storage capacity and through evaporative cooling.

5.5 Steps to Implementation

A planning and design approach to urban climate intervention should follow a four-phase approach: climate analysis mapping, public space evaluation, planning and design intervention, and post-intervention evaluation (see Figure 5.14).

5.5.1 Climate Analysis and Mapping

Considering climate in urban planning and urban design, the first step is to understand large-scale climatic conditions and individual inner-city local climates, including their reciprocal interactions (see Figure 5.14). Considerations include:

- Regional occurrence and frequency of air masses exchange (ventilation) and their frequencies;
- Seasonal occurrence of the thermal and air quality effects of urban climate (stress areas, insolation rates, shading conditions);
- Regional presentation and evaluation of the impact area and stress areas; and
- Energy optimization of location based on urban climate analysis with regard to areas with heat load, cooler air areas, and building density.

One also has to address sectoral planning (see Table 5.1).

Climate analyses and maps provide a critical first step in identifying urban zones subject to the greatest impacts associated with rising temperatures, increasing precipitation, and extreme weather events (see Figure 5.14). A climate analysis map may be developed in consecutive steps on the basis of spatial reference data. The spatial resolution is tailored to the planning level (see Table 5.1). Commonly employed climate analysis maps include urban heat hotspot and flood zone maps routinely employed in urban planning applications. Geographical Information System (GIS) layers include topographical information, buildings, roughness and greenery needed to create an urban climate map (see Figure 5.14).

5.5.2 Evaluation of Public Space

Urban climate is an essential part of urban planning evaluation. Urban climate maps are increasingly used in the planning process for urban development as well as for open space design. The public should be involved at all stages through the

Table 5.1 *Meteorological scales for planning. Source: Lutz Katzschner*

Instruments and Plans		Scale, Spatial Resolution of Maps	Climate Analysis Components (Air Quality and Human Biometeorology)
Regional Planning	Regional Land-Use Plan	1:50,000 to 1: 100,000 ≥100 m	Meso-scale climate Comprehensive pollution control maps Thermal stress areas (overhead areas) Ventilation lanes Cool air production areas Planning recommendation map
Urban Planning Land-Use	Preliminary Urban Land Planning: Land-use plan	1:5000 to 1:25,000, 25 m to 100 m	Meso-scale climate Area-related ambient air quality maps Air exchange Thermal stress areas (overheated areas) Planning recommendation map
	Mandatory Urban Land Planning: Local development plan Planning permission and procedure	≤ (1:1000), 2m to 10 m	Micro-scale climate Local ambient quality calculations for "most severely affected areas" Neighborhood considerations Air exchange Human bio-meteorological suitability tests for "highly relevant areas" Planning recommendation map

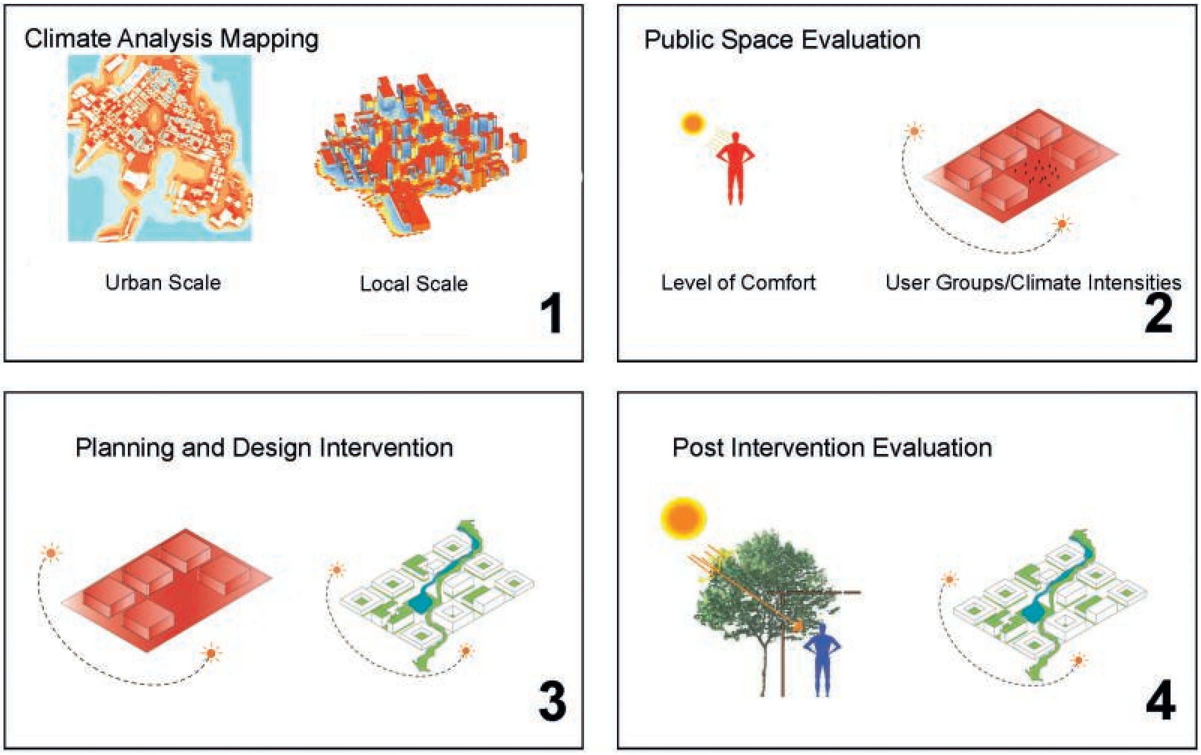


Figure 5.14 *Urban climate planning and design process.*

Source: Jeffrey Raven, 2016

use of interactive geographical information systems and/or surveys that help citizens foresee potential land-use changes (see Figure 5.14). This is enabled by climatic evaluation through spatial and temporal quantitative descriptions and specifications. At the regional level, areas worth protecting by virtue of their climatic functions, e.g., areas of heat load, fresh air supply, and ventilation pathways, are identified as key targets for planning measures.

5.5.3 Planning and Design Interventions

The task of planning and designing interventions relevant to urban climatology is to improve thermal conditions and air quality (see Figure 5.14):

- Reduction of UHIs (heat islands being an indication of thermal comfort/discomfort) through open space planning
- Optimization of urban ventilation via air exchange and wind corridors
- Prevention of stagnating air in stationary temperature inversion conditions by eliminating barriers to air exchange
- Maintenance and promotion of fresh air or cool air generation areas to further air exchange and improve air quality

Regional specifications may include sustaining cool air or fresh air generation areas (slopes) or ventilation lanes and taking into consideration building orientation, building height, and density of development. Such specifications may be implemented according to building codes in urban land-use planning. In addition, mandatory regulations for areas designated as open spaces due to urban climate analyses are possible in the zoning plan. Regulations at the regional level should also be reviewed. Climatic concerns are thus considered in regional as well as city planning.

5.5.4 Post-Intervention Evaluation

Field measurement studies (see Case Study 5.4) should be conducted to assess the microclimatic performance of the urban design and planning intervention (see Figure 5.14). Infrared thermal imaging and/or population surveys can be undertaken to assess temperature variations compared to conditions prior to intervention. Climate-resilient strategies can have the effect of prolonging moderate temperatures with associated benefits to public health and energy savings.

5.6 Stakeholders and Public Engagement

Building resilient urban environments through integrated mitigation and adaptation approaches requires a strong framework for ongoing engagement with a broad range of stakeholders – households, regional communities, and local and national tiers of government, as well as academia, private businesses, health care providers, and civil society organizations – that make up the urban landscape.

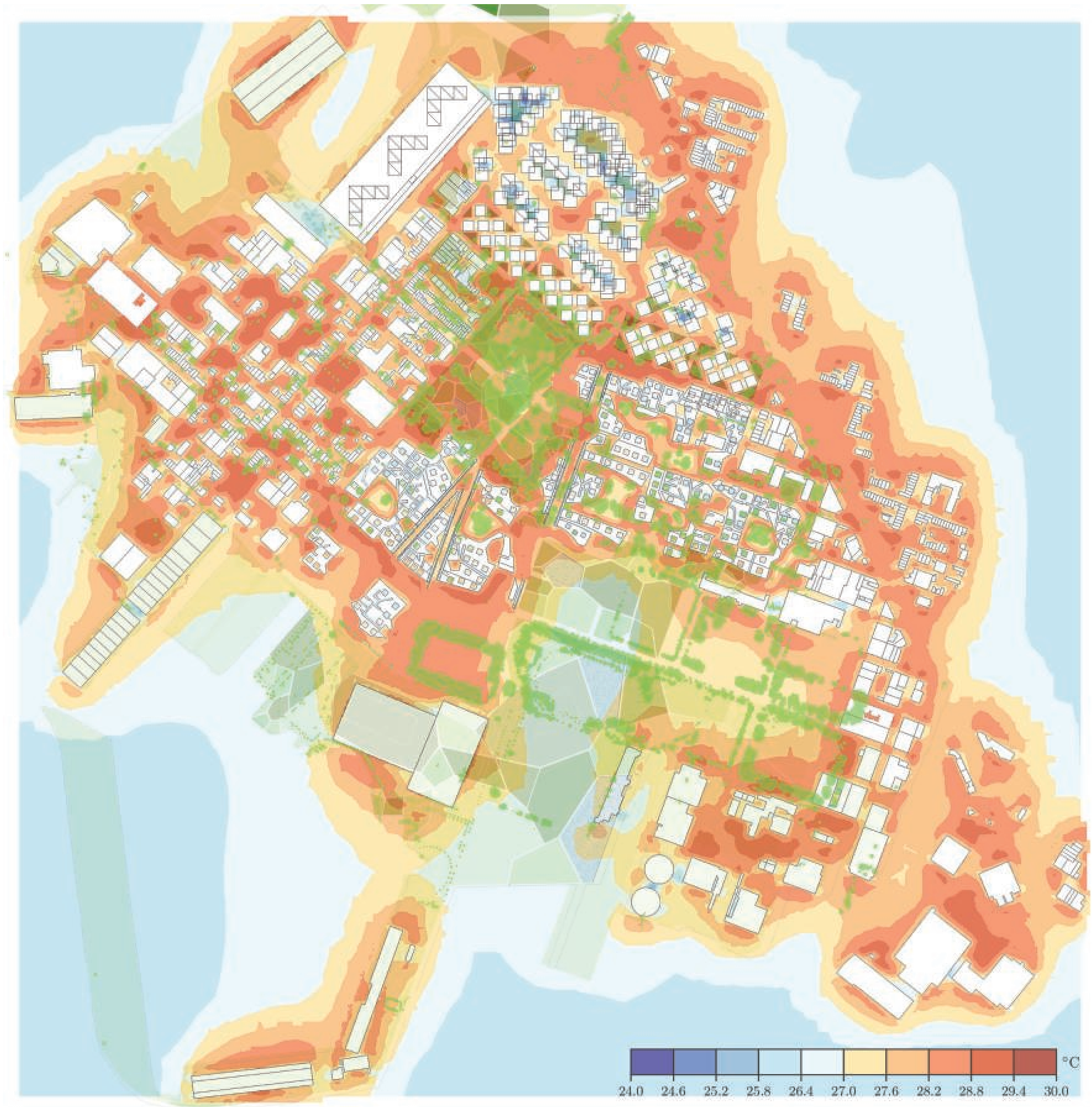


Figure 5.15 *Urban design intervention – future climate scenario.*

Source: Urban Climate Lab, Graduate Program in Urban & Regional Design, New York Institute of Technology with Klimaat Consulting, 2014

Public engagement is as much about discourse as it is about design. From an urban planning and urban design perspective, community engagement and public participation are essential for operationalizing any policy, program, or intervention and offer many tangible and intangible benefits. Despite the potential obstacles for developing and carrying out a successful public outreach process, the absence of a robust stakeholder engagement process has many higher costs and ramifications. For instance, it can result in the development of locally inappropriate solutions, increased conflict and tension between community groups, absence of a shared vision for the future, "rebound effect" (whereby appropriate solutions are not appropriately used due to lack of community awareness), and, ultimately, lack of preparedness and resiliency. Alternatively, structured conversations can facilitate participation, knowledge exchanges, shared decision-making, and ultimately, resiliency actions. While the process can often be messy and contentious because each group is pursuing different goals and interests, a robust public engagement process with genuine stakeholder participation and partnerships can ensure the sustained, inclusive, and meaningful transformation of regulations, built environments, and society (Kloprogge and Van Der Sluijs, 2006).

Community-led and place-based initiatives recognize and leverage local knowledge and expertise. Top-down or expert-driven outreach processes that lack genuine grassroots organizing and leave little opportunity for community-led initiatives can act as a barrier to an effective public outreach campaign. Civic engagement is often driven in an expert-dominated and exclusive manner (Velazquez et al., 2005). Participatory actions on the ground can be undermined or even neutralized by governing institutions' lack of willingness to change (Warburton and Yoshimura, 2005). These attitudes may lead to local resistance to implementing identified solutions. More functionally, simple, clear, and comprehensive resources must be readily available to the public in order to increase knowledge and awareness.

Even if decision-makers are actively seeking to develop genuine engagement and partnerships with stakeholders, an abundance of confusing and contradictory resources can serve as a barrier to robust engagement. Stakeholders and inhabitants must be provided tailored resources with clear and easy steps on how best to contribute to developing integrated mitigation and adaptation solutions for their communities. This not only helps ensure that integrated mitigation and adaptation solutions are appropriate for the local context (i.e., a good "fit" for the community and/or city), but also serves to empower communities and strengthen the relationships among government, the private sector, and citizens.

Public engagement is a means of ensuring the diverse needs of communities, particularly those of the most vulnerable groups, including populations with disabilities or chronic health conditions; seniors and children; those socially isolated, historically underrepresented, or otherwise marginalized; and people living below the poverty line. It is vital that these populations are integrated into the decision-making process and solutions (see Chapter 6, Equity and Environmental Justice).

Genuine and sustained stakeholder participation (as opposed to simply assessing opinions or asking for rubber-stamp approval on already-made plans) can draw out disagreements early, provide opportunities to work through different scenarios, and move plans toward a shared vision, thereby actually saving time, money, and political will. In order for stakeholders to be more committed, decision-makers and experts need to identify joint solutions that break down institutional and disciplinary silos. Urban governance can facilitate a robust civic participation process that creates mechanisms for systematic learning and capacity-building in communities as well as a transparent and open system in which responsibilities and accountabilities are clearly defined at the local level (see Chapter 6, Urban Governance). The dynamic and variable conditions that climate change introduces call for a robust stakeholder engagement process to help ensure integrated mitigation and adaptation responses are not simply implemented as one-off, discrete protection measures, but rather are incrementally adjusted and become part of the mechanisms for systematic learning, engagement, and transformation in a community. Community engagement offers decision-makers an opportunity to prototype a wider range of innovative solutions by creatively brainstorming, testing, and iterating. Despite focus by decision-makers on formal planned responses, most adaptation responses are actually carried out informally by individuals, households, and organizations. Therefore, communities that have been provided with information and resources and that possess increased knowledge about complex climate challenges and the integrated mitigation and adaptation solutions needed to adequately address them will more likely be willing to adopt resilient practices and policies (Yohe and Leichenko, 2010).

Although physical interventions often provide protection from only a single hazard or risk, communities that are integrated into the mitigation and adaptation planning process increase their capacity to prepare for, withstand, and recover from a wider range of climate-related disasters (not just a single hazard) as well as everyday challenges that span health, income, and equity considerations. Given that most cities have pre-existing vulnerabilities and that the potential for institutional and/or systems failures is ever-present, iterative, flexible, and redundant responses are needed to build ongoing capacity for adaptation. In other words, a robust stakeholder outreach process can yield benefits beyond simply helping to implement policies and instead offer opportunities for improved quality of life, public health, and equity.

The role of local authorities in the public engagement process is evolving as integrated mitigation and adaptation and sustainable urban development goals become a more significant priority for urban residents (Kloprogge and Van Der Sluijs, 2006). Local authorities must help facilitate and negotiate competing interests between urban challenges (sprawl, fragmentation of spaces, complexity of scales), social necessities (health, education, employment, culture, access to basic services), and environmental concerns (GHG emissions, ecosystems protection, resource management, and conservation) (Broto, 2017).

Local decision-makers can use a range of urban planning and urban design tools to overcome the obstacles to engaging the public. There are different levels of local participation (Donzelot, 2009). The lowest level is the simple distribution of information to inhabitants, whereas the highest level is direct engagement of communities to share decision-making and prioritize the results of consultations (Donzelot, 2009). For example, *charrettes*, an intense, multiday design exercise with the community, are commonly used in urban planning and design projects to engage the community to help create a plan for a particular site, area, or neighborhood.

The private sector is also at the forefront of eco-innovation systems to develop more sustainable cities (see Chapter 7, Economics, Finance, and the Private Sector). Examples include smarter solutions for energy efficiency and energy provision, development of renewable energy like geothermal systems, braking energy recovery from light rail systems, energy smart grids, and solutions to improve intermodal transport.

Although public engagement is a critical and necessary step for scaling integrated mitigation and adaptation solutions, there are real challenges that can inhibit ongoing engagement and, ultimately, action. As Bai et al. (2010) suggest, there is frequently an inherent temporal ("not in my term"), spatial ("not in my patch"), and institutional ("not my business")-scale mismatch between urban decision-making and global environmental concerns. Also, the involvement of stakeholders requires a general level of trust and cooperation (Tilly, 2005). A complication lies in the fact that decision-makers must often act as referees to solve potential conflicts and facilitate negotiations. However, to create consensus, promote cooperation, and move toward an equitable environmental management process, an intimate understanding of the motivations and drivers of the different stakeholder groups is needed (Schaltegger, 2003). Lack of transparency between the public and the private sectors can be a key obstacle to reaching consensus among different stakeholders. Stakeholders need to know who is accountable for the local decisions on sustainability and climate solutions and how they can contribute to the decision-making process.

5.7 Sector Linkages

There is a growing consensus around integrating urban planning and urban design, climate science, and policy to bring about desirable microclimates within compact, pedestrian-friendly built environments. However, there remains much work to do to bridge the gaps in tools, methods, and language between the scientific, design, and policy-making communities. Conveying a compelling investment/payback narrative also remains a challenge for setting priorities with stakeholder groups. *Ad hoc*, disconnected approaches fail to exploit synergies between professional practitioners, and departments within government administrations are often insufficiently coordinated to capitalize on cross-disciplinary actions. Silos of expertise are difficult to harness over the long-term due to different departmental missions. A central challenge remains the poor interdisciplinary connections between the various policy experts, technical specialists, and urban planners/urban designers. The absence of objective evaluation methodologies in the practice of climate-resilient urban design illustrates this divergence, as does the lack of a common interdisciplinary methodology for addressing various spatial scales (Odeleye et al., 2008). For example, urban climatology research produces sophisticated but theoretical results that resist easy integration with empirical, design-oriented findings of urban design (Ali-Toudert et al., 2005).

Although experts in sustainable buildings and ecological footprints are familiar with sustainability metrics to measure progress, the absence of objective evaluation of urban morphology across spatial scales is a challenge in the urban design profession. In a recent survey on sustainability methods and indicators in three built-environment professions in the United Kingdom (planning, urban design, and architecture), sustainability guidance documents had not led to a range of formal, systemic, or morphological sustainability indicators in the urban design sector – instead continuing to emphasize "place-making" and the quality/vitality of the public realm (Odeleye et al., 2008).

Although there has been extensive research on the UHI effect, the relationship between urban geometry and thermal comfort is by far less well understood and the numbers of studies are very few (Ali-Toudert et al., 2005). Traditional urban design tools must be refined and expanded to serve climate-resilient urban design.

From parcel and neighborhood scale to municipal and regional scale, a discontinuity of policy between scales challenges the public's understanding of holistic urban form. Consideration needs to be given to how regional decisions may affect neighborhoods or individual parcels and vice versa, and few tools have been developed to assess conditions in the urban environment at city block or neighborhood scale (Brophy et al., 2000; Miller et al., 2008).

For urban areas, the key is a coordinated response that addresses issues simultaneously rather than individually. For example, an important concern underlying natural ventilation is air quality, which means that transport management and building microclimate need to be linked. Whereas one of the most effective passive ventilation strategies is to introduce cooler night air to the perimeters of buildings, excessive pollution from nearby vehicles and industry often undermines this strategy in compact communities. This anthropogenic pollution is exacerbated by lack of space for air movement, resulting in insufficient ground-level air movement to disperse pollutants (Odeleye, 2008). The totality of the environment – including noise, activity, climate, and pollution – affects human health and well-being.

For compact development, proximity is the principal goal. Proximity requires integrating infrastructure, housing, and sustainable development into land-use planning to reduce the carbon footprint through compact development patterns. At the urban scale, a comprehensive approach to transportation from the perspective of sustainable development requires a holistic view of planning (see Chapter 13, Urban Transportation). The challenge remains to establish national frameworks and policies for integrated mitigation and adaptation to address sustainable development that encourages all sectors to coordinate and integrate their activities (Hall, 2006) (see Chapter 16, Governance and Policy).

5.8 Knowledge Gaps and Future Research

Urban areas alter their regional climates by adjusting the overlying airshed. A substantial number of observational studies across the world have illustrated the prevalence of warmer and drier conditions within cities, degraded air quality regimes, and altered hydrological patterns resulting from impacts on precipitation and changes in drainage associated with increased impervious cover. Advances in the physical understanding of the urban climate system together with progress in computing technologies has enabled the development and refinement of complex process-based models that characterize urban areas and their interaction with the overlying atmosphere in a mathematical framework (Chen et al., 2011). Such process-based models have considerable planning and design utility and are increasingly applied to examine the impact of urban expansion and of commonly proposed urban adaptation strategies to a long-term globally changing climate (Georgescu et al., 2014).

To support utility for the planning and design process of cities, such process-based models require two important improvements. The spatial extent and morphology of urban areas remain simplistic in contemporary modeling approaches (Chen et al., 2011). The nature of this representation is assumed to vary by urban land use and land cover, which is conditional on the density of urban structures. However, implied in this assumption is that a diversity of key morphological characteristics (e.g., sky view factor) within a particular urban cover (e.g., high-density residential) is nonexistent, an important condition that presents limitations for place-based planning and design decisions. Therefore, the realistically heterogeneous representation of cities within current modeling frameworks remains an important but as-yet unrealized objective. How effective landscape configuration can be as an adaptive strategy has only recently become a ripe area of research in climate modeling (Connors et al., 2013; Rosenzweig et al., 2014).

Waste heat resulting from energy use within cities (primarily from building heating, ventilation, and air conditioning [HVAC] systems) is also only crudely accounted for in current representations (Sailor, 2011). There does not yet exist a database of waste heat profiles for modeling applications for a diverse set of cities, and although efforts are under way to develop spatially explicit and time-varying heating profiles, such datasets remain absent for most urban areas (Chow et al., 2014). In regard to energy use, suburbs in the United States account for roughly 50% of the total domestic household carbon footprint due to longer commutes (Jones and Kammen 2014).

Such concerns highlight the importance of future cooperation between urban climatologists, planners, urban designers and architects. A key asset of process-based urban climate modeling frameworks is their ability to offer insights by examining the adaptive capacity of "what-if" growth scenarios and growth management strategies to inform the planning and design process prior to incipient stages of development.

Other major knowledge gaps concern the GHG emissions of different cities and the association between GHG emissions and different urban forms. The IPCC AR5 highlights the importance of the next several decades for influencing low-carbon urbanization. It is essential to develop urban GHG emission inventories and experiment with alternative urbanization patterns that facilitate low-carbon urban development. This is crucially related to medium-sized cities in developing counties such as China and India, which are expected to accommodate the majority of expected urban population growth.

The impacts of medium-sized cities on the climate at urban, regional, and global scales is a topic of considerable debate, but their comparatively small size poses a conundrum for researchers: how do we acquire and incorporate the relevant information into global understanding? Much research has focused on mapping these urban centers using demographic and administrative information often supplemented by remote sensing. However, these data provide little information on the internal makeup of cities, which is crucially important for understanding their GHG emissions and vulnerabilities. The absence of such information inhibits international comparisons, knowledge transfer, and effective integrated mitigation and adaptation.

5.9 Conclusions

This chapter has endorsed the concept of integrated mitigation and adaptation: climate management activities designed to reduce global GHG emissions while producing regional benefits related to urban heat, flooding, and other extremes.

Cities shaped by integrated mitigation and adaptation principles can reduce energy consumption in the built environment, strengthen community adaptability to climate change, and enhance the quality of the public realm. Through energy-efficient planning and urban design, compact morphology can work synergistically with high-performance construction and landscape configuration to create interconnected, protective, and attractive microclimates. The long-term benefits are also significant, ranging from economic savings through lowered energy consumption to the improved ability of communities to thrive despite climate-related impacts (Raven, 2011). A community's capacity to cope with adversity, adapt to future challenges, and transform in anticipation of future crises yields greater social resilience with particularly positive benefits for poor and marginalized populations (Keck and Sakdapolrak, 2013).

Annex 5.1 Stakeholder Engagement

The contributors to the ARC3.2 chapter on Urban Planning and Urban Design engaged stakeholder groups and experts throughout the chapter production process, with specific forums in Asia, Europe, and the United States. The International Conference on Urban Climate (ICUC9), held in Toulouse, France, in July 2015, is an international forum for global urban climatologists. Chapter Coordinating Lead Authors (CLAs), Lead Authors, Contributing Authors, and Case Study Authors participated in the conference, including Gerald Mills, Lutz Katzschner, Matei Georgescu, and Jeffrey Raven. The Chapter Key Findings and Major Messages were presented by the chapter CLA at the launch of the Urban Climate Change Research Network (UCCRN) European Hub, in partnership with the Centre National de la Recherche Scientifique, the Pierre and Marie Curie University, and l'Atelier International du Grand Paris launched in Paris, July 2015.

At the ARC3.2 Midterm Authors Workshop in London, in September 2014, which was attended by key chapter stakeholders, the Coordinating Lead Author and Lead Authors configured the scientific basis for the chapter's Major Messages and Key Findings. The chapter CLA presented Major Messages and Key Findings at Beijing University for Civil Engineering and Architecture (BUCEA) and Tongji University in Shanghai, in October 2014.

The 4th China–Europa Forum in Paris was held in December 2014, focusing on the theme "Facing Climate Change: Rethinking Our Global Development Model," in preparation for the UN FCCC Conference of the Parties (COP21) in Paris 2015. It brought together more than 300 participants through two plenary sessions and three round tables as well as twelve thematic workshops. As part of the conference, at the Project EAST workshop with lead author Pascaline Gaborit in Brussels, the Chapter CLA presented ARC3.2 key scientific findings and other research findings. At the closing plenary held on December 5 at the Town Hall of the 4th Arrondissement of Paris, ARC3.2 CLA Raven presented the ARC3.2 draft Major Messages. This included the most relevant points in the ARC3.2 chapter that will guide urban decision-makers.

At the New York City Department of City Planning, the ARC3 draft chapter Key Findings and Major Messages were presented to experts in the city government. Co-presenters included ARC3.2 lead author Gerald Mills, CLA Jeffrey Raven, and the President of the American Institute of Architects (AIANY). The ARC3.2-based presentation provided an operational framework, Case Studies, and a policy framework for NYC municipal government. The chapter CLA and editor introduced draft chapter Key Findings in discussions during the National Science Foundation Research Coordination Network project. The chapter CLA presented chapter Key Findings to climate and health experts at the Center for Disease Control in Atlanta, July 2014. The chapter CLA presented chapter Key Findings at the American Institute of Architects Dialogues on the Edge of Practice, February 2015, and presented ARC3.2 chapter Key Findings and Major Messages at the Center for Architecture in NYC, April 2015. Lead author Brian Stone and CLA Raven presented climate-resilient urban planning and urban design research related to the ARC3.2 chapter at the New York conference Extreme Heat: Hot Cities, November 2015.

The chapter's Key Findings and Major Messages was presented by the CLA at the New York Institute of Technology-Peking University Sustainable Megacities conference in Beijing, China in October 2015. A Critical Climate Change Debrief: COP21 Paris Conference was held at the Center for Architecture in New York, January 2016, where chapter CLA Jeffrey Raven presented how ARC3.2 strategies were tested in a Paris district during COP21, in collaboration with lead authors Gerald Mills and Mattia Leone.

The ARC3.2 Urban Planning and Urban Design chapter abstract was presented at the Design Solutions for Climate Change in Urban Areas conference in Naples, Italy, in July 2016. Jeffrey Raven (CLA), and Lead Author Mattia Leone each led sessions during the conference. Joining them in presenting ARC3.2's integrated cross-disciplinary framework was Chantal Pacteau who is Coordinating Lead Author of the ARC3.2 Mitigation and Adaptation chapter and Co-Director of the UCCRN European Hub. Jeffrey Raven (CLA) presented ARC3.2 urban planning and urban design research-action at the National Science Foundation Workshop, International Conference on Sustainable Infrastructure (ICSI), Shenzhen, China, in October 2016.

5 Urban Planning and Urban Design

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