Chapter 1
Climate Change, Cities, and the Importance of Cooling Strategies, Practices, and Policies

Ali Cheshmehzangi, Bao-Jie He, Ayyoob Sharifi, and Andreas Matzarakis

Abstract Cities, the prominent place of human settlements, face various mega challenges. Among them, extreme heat challenge, the combined effect of heat waves and heat islands, is the deadliest disaster (Anderson and Bell in Environmental Health Perspectives 119(2):210–218, 2011; City of Sydney, Adapting for climate change: A long term strategy for the city of Sydney, 2015; De Bono et al., Environment Alert Bulletin, 2:4, 2004). For instance, the extreme heat event in Europe in 2003 killed about 72,000 people (WMO, United Nations News, 2021), and the extreme heat event in June–August 2022 caused more than 53,000 deaths.

1 Prologue: Climate Change and Cooling Cities

Cities, the prominent place of human settlements, face various mega challenges. Among them, extreme heat challenge, the combined effect of heat waves and heat islands, is the deadliest disaster (Anderson & Bell, 2011; City of Sydney, 2015; De Bono et al., 2004). For instance, the extreme heat event in Europe in 2003 killed about 72,000 people (WMO, 2021), and the extreme heat event in June–August 2022 caused more than 53,000 deaths (EU, 2022). Beyond health and lives, extreme

A. Cheshmehzangi (✉)
School of Architecture, Qingdao City University (QCU), Qingdao, China
e-mail: Ali.Chesh@qdc.edu.cn

A. Cheshmehzangi · B.-J. He
Network for Education and Research On Peace and Sustainability (NERPS), Hiroshima University, Hiroshima, Japan

B.-J. He
Centre for Climate–Resilient and Low–Carbon Cities, School of Architecture and Urban Planning, Key Laboratory of New Technology for Construction of Cities in Mountain Area, Ministry of Education, Chongqing University, Chongqing 400045, China

B.-J. He (✉)
Institute for Smart City, Chongqing University, Liyang 213300, Jiangsu, China
e-mail: baojie.he@cqu.edu.cn

A. Cheshmehzangi et al. (eds.), *Climate Change and Cooling Cities*, Urban Sustainability, https://doi.org/10.1007/978-981-99-3675-5_1

heat is evidenced as the culprit of excessive energy and water consumption, environmental deterioration, economic losses, social inequality, biodiversity loss, etc. (Butters & Cheshmehzangi, 2018; Cheshmehzangi & Butters, 2015; Cheshmehzangi et al., 2021; He et al., 2021). What's worse, extreme heat challenges will be more frequent, severe, and intense, along with climate change and urbanization. Therefore, addressing global warming or urban warming is urgent to ensure human survival and prosperity.

Moreover, extreme heat and its impacts are interlinked with many other mega challenges. Through the lens of Sustainable Development Goals proposed by the United Nations, extreme heat deteriorates goals of Good health and well-being (Goal 3), Gender Equality (Goal 5), Clean water and sanitation (Goal 6), Affordable and clean energy (Goal 7), Decent work and economic growth (Goal 8), Reduced inequalities (Goal 10), Sustainable cities and communities (Goal 11), Climate Action (Goal 13), and Peace, justice, and strong institutions (Goal 16) (Khosla et al., 2021). Accordingly, taking action to address urban heat challenges is an approach to promoting and securing urban sustainability. Such an argument is true since extreme heat is or will be a new normal for many cities in the coming years.

Since Howard identified the heat island phenomenon in London in 1818, numerous scholars and experts have made efforts to address heat-related challenges in cities and have shaped extreme heat studies as a transdisciplinary subject consisting of urban meteorology, urban physics, landscape ecology, planning and design, urban governance, and public health (He et al., 2023). For instance, in the 1930s–1980s, urban meteorologists focused on the confirmation of the heat island phenomenon across cities in North America, Europe, and East Asia (He et al., 2023), and some scholars, represented by Oke (1988), explored the surface energy balance model to explain heat island formation. Afterward, scientific efforts emerged into four clusters, including (He et al., 2023):

- Heat island impact assessment and cause identification, characterized by the understanding of the spatiotemporal variations of land surface temperature based on "remote sensing" techniques and datasets and its relationship between land use/land cover (Fletcher et al, 2021) or typically local climate zones (Stewart & Oke, 2012).

A. Sharifi (✉)
The IDEC Institute, Hiroshima University, Higashi-Hiroshima, Japan
e-mail: sharifi@hiroshima-u.ac.jp

A. Matzarakis (✉)
German Meteorological Service, Research Centre Human Biometeorology, 79104 Freiburg, Germany
e-mail: Andreas.Matzarakis@dwd.de

Chair of Environmental Meteorology, Faculty of Environment and Natural Resources, University of Freiburg, 79085 Freiburg, Germany

- Microclimate regulation and human thermal comfort assessment, characterized by analysis of microclimatic parameters such as airborne temperature, wind speed, relative humidity, and mean radiant temperature based on fixed or mobile measurement, and assessment of human thermal comfort based on thermal comfort indicators (e.g., PET, UTCI) (Matzarakis et al., 1999; Mayer & Höppe, 1987; Staiger et al., 2019) and analytical models (e.g., RayMan, ENVI-met) (Bruse & Fleer, 1998; Matzarakis et al., 2007, 2021).
- Climate-related health impact assessment and adaptation, characterized by the analysis of heat-related vulnerability, health, mortality, and air pollution based on long-term data from professional or governmental authorities (e.g., medical centre, hospitals, statistical bureau, public health department) (Hatvani-Kovacs et al., 2016; Matzarakis, 2020; Matzarakis et al., 2020; Santamouris, 2020), and the development of adaptation plans based on an education campaign for awareness and knowledge enhancement (Kotharkar & Ghosh, 2022; Matzarakis, 2021; Yang et al., 2021).
- Mitigation strategy and technique development and performance assessment, characterized by the development of reflective, retro-reflective materials, chromic materials, super cool materials, and permeable materials based on laboratory experiments and field experiment (Santamouris & Yun, 2020; Wang et al., 2022), and the analysis of the energy saving potential based on numerical simulation (Cui et al., 2017; Santamouris & Kolokotsa, 2015).

However, the arrival of various subjects brings diverse goals and targets, making the efforts for addressing urban heat challenges isolated and delayed to force the transformation from research into practice for creating cool cities and communities on site (Cheshmehzangi & Butters, 2017; Dawodu & Cheshmehzangi, 2017; He et al., 2023; Matzarakis, 2021). How to eliminate the gaps, conflicts, and disputes that hinder the integration of cooling strategies and techniques into urban planning and design is a critical issue for consideration. To achieve so, we are dedicated to mainstream urban cooling into urban planning, design, construction, operation, and maintenance through the collective action of (i) assessment, identification, and projection of extreme heat, (ii) development and performance assessment of mitigation and adaptation strategies and techniques, and (iii) piloting projects and promoting the application of mitigation and adaptation strategies and techniques through addressing social, economic, technical and policy barriers.

2 The Aim and Objectives of the Book

This book aims to bring together the latest research outcomes on climate change and cooling cities for a comprehensive framework for urban cooling implementation in order to address gaps, barriers, conflicts, and disputes in mainstreaming urban cooling. In particular, the development of such a framework is in alignment with the Sendai Framework by balancing mitigation and adaptation actions to enhance prevention, mitigation, preparedness, response, recovery, and rehabilitation capacity on the one hand and to enhance awareness and knowledge of disaster risk, promote behavioural and operation change, strengthen disaster risk governance, and invest in disaster reduction on the other. Given this, the objectives of this book include:

- Presenting emerging, innovative and comprehensive thoughts on climate change and cooling cities;
- Showcasing the applications of mitigation and adaptation strategies in different; contexts, accompanied by reporting the cooling performance in temperature, thermal comfort, and energy saving; and
- Exploring drivers to the extreme heat challenges to inform urban development policy, governmental regulations, planning practice, and design schemes.

Overall, this book is innovative in demonstrating a scientific roadmap to achieving targets covering emerging concepts, theories, trends, strategies, techniques, methods, models, policies, and regulations. This book is also advantageous to provide governmental and built environment professionals with insights into actual actions on urban planning and design by demonstrating practical cases in the context of developing and developed cities across the world.

3 Structure of the Book

The book is intentionally divided into three parts, addressing key aspects related to concepts and trends, mitigation and adaptation strategies, and policies. For each part, we have invited contributors from around the globe, where they present their study findings, case study work, or specific concepts, strategies, and policies. These three parts are structured as:

1. Concepts, Theories and Trends;
2. Mitigation and Adaptation Strategies; and
3. Policies (Fig. 1).

PART I: Concepts, Theories, and Trends

The first part looks into four examples of 'concepts, theories, and trends', exploring four key areas of urban heat mitigation strategies, biophilic design and nature-based techniques, urban thermal field variance index under rapid urbanization, and Urban Heat Island (UHI) implications. Below is the summary of the four chapters included in this part.

Chapter 2: Urban Heat Mitigation Strategies

By: Jinda Qi, and Bao-Jie He
Urban heat has been detected in many cities worldwide and has negatively impacted the urban environment and human well-being. Many strategies have been developed to mitigate urban heat, collectively called urban heat mitigation strategies (UHMSs).

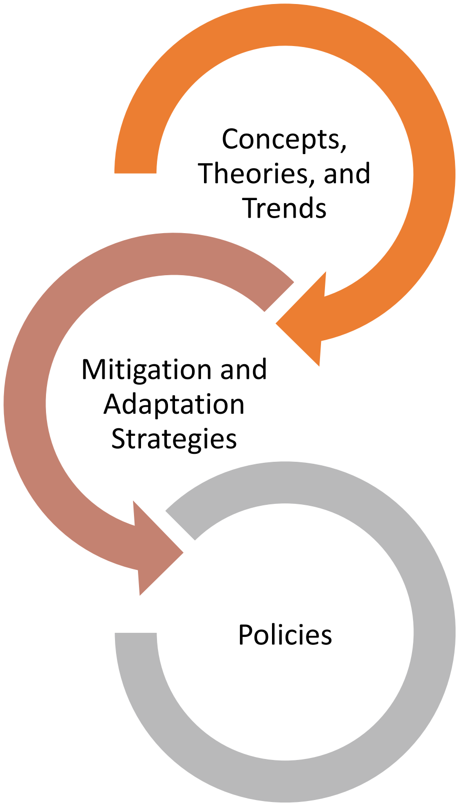

Fig. 1 Summary of three parts of the book

This study reviewed the four types of passive UHMSs (i.e., greenery, cool materials, evaporation techniques, and shading devices) from an implementation perspective to support urban heat mitigation. The definitions, mitigation performance, planning and design variables, and cost-benefits of these UHMSs are elaborated from three categories, according to the place of application: private realm, public realm, and combinations. The results show that green infrastructures have high performance in cooling and energy saving in private and public realms, and their effectivenesses are affected by many factors, such as vegetation species. For cool materials, reflective materials generally have higher cooling potentials and lower costs than heat storage materials and heat harvesting materials. The predominant planning and design variables for cooling effectiveness are the colour and construction materials, and coating materials. The evaporation techniques can reduce ambient temperature significantly due to the high cooling potential of latent heat. The main variables include water flow rate, water particle size, area and shape of water bodies etc. To achieve optimal cooling performance, it is required to properly define the surface temperature of the evaporative cooling pads for evaporative cooling towers and shading structures and slat angles for shading. Also, UHMS combinations can have higher mitigation performance than a single one. All these findings help decision-makers better understand the implementation of UHMS in detail, supporting the proper selection and application of strategies for urban heat mitigation.

Chapter 3: Biophilic Design: Pinpointing Nature-Based Techniques in Urban Areas to Combat Global Warming

By: Abdollah Baghaei Daemei, Masoumeh Mazandarani, and Mahshid Motamed

The rate of global warming has increased rapidly in recent decades, and experts agree that climate change is exacerbating dangerously high temperatures around the world, which will ultimately lead to an increase in urban heat islands (UHI), longer warm seasons, and severe health-related issues. This study aims to provide strategies, exemplars, and approaches to tackle the mentioned problems. Hence, this research proposed biophilic design elements as a promising technique to mitigate UHI resulting from global warming, to examine the importance of vegetation and plants in urban areas. The Rhino software, and Grasshopper and Ladybug plug-ins have been deployed to simulate UHI; referred to as Urban Weather Generator (UWG). The humid climate of Rasht was selected as an example of the study area in this research. Thus, findings showed that adequate vegetation could help drop the average monthly temperature by approximately 2 °C, and this mean temperature could vary between 9 and 19 °C annually.

Chapter 4: Warming Cities in Pakistan: Evaluating Spatial–Temporal Dynamics of Urban Thermal Field Variance Index Under Rapid Urbanization

By: Mirza Waleed, and Muhammad Sajjad

With ~57% of the world population living in cities, the global urban population is increasing at an alarming rate, which further stimulates the urbanization process. Consequently, the increasing impervious surfaces in cities and associated variabilities in local/regional climatic characteristics pose several challenges to citizens (i.e., heat-related health issues, higher energy demands, and flooding among many others). Currently, cities contribute 75% of Green House Gases emissions, which is further worsening climate change impacts through global warming. Pakistan, the 6th most populated country globally, with ~220 million people, is among the top 10 most-affected nations vulnerable to climate change. Hence, studies addressing climate variability in local geographical regions have important implications to address the adverse urbanization-associated challenges, such as sustainability of the land resource and mitigating urban heat island (UHI) impacts in the context of climate change mitigation/adaptation. Due to temperature differences between urban, suburban, and rural areas, mapping city zones prone to the UHI effect is essential to provide actionable references. In connection with this, the present study analyses 15 megacities in Pakistan regarding their temperature variability in response to built-up area increment and highlights heat stress zones using the Urban Thermal Field Variance Index (UTFVI). The cloud-computing-based Google Earth Engine platform is employed to explore spatial–temporal variation in Land Surface Temperature (LST), which further leads to the identification of top-15 cities in terms of LST increase and the further evaluation of UTFVI for each city. The findings of this study suggest that the strongest UTFVI zones are concentrated around city-core areas, which are pure impervious surfaces with little or no green space. Moreover, in the last three decades (1990–2020), most of the weak and strong-strength UTFVI areas have been converted into the strongest strength primarily because of a rapid increase in the built-up areas. The findings of this study can help urban policymakers to identify priority intervention areas and design/implement strategies to counter the UTFVI and associated challenges. With proper land-use planning and on-time policy implementation, people residing in higher UTFVI zone areas can be safeguarded from noxious heatstroke-like health consequences along with mitigating and adapting to changing environmental conditions in cities.

Chapter 5: Urban Heat Island (UHI) Implications and a Holistic Management Framework

By: Hafiza Saba Islam, Talib Elahi Butt, Shaker Mahmood Mayo, Siddiqa Amin, and Maria Ali

The Urban Heat Island (UHI) effect is one of the most debated phenomena among the urban researchers and city planners. In addition to fast urbanization, climate change actors are rendering major cites thermal hubs of the modern global civilization. Climate models consistently predict that the frequency, severity, and duration of extreme weather conditions which also include heat wave are on the increase and would be significantly by the end of the twenty-first century. Therefore, there is an emergent and urgent need to rethink the assessment and management of the UHI phenomenon (Cheshmehzangi et al., 2022). This study aims to establish the existing knowledge regarding UHI implications by categorically identifying and systematically grouping the factors and sub-factors that contribute UHI phenomenon. The aforesaid aim is based on the literature review, investigation of models, and the thematic analysis. Some new insights are produced by categorizing UHI implications into two main groups climate change and non-climate change related. This leads to a more comprehensive conceptualization of UHI at different tiers which is discussed and presented schematically. Founding on this conceptualization a new, integrated and holistic framework of the assessment and management of UHI is developed. The UHI framework is also schematically delineated. This UHI framework can be used as a basis for further research and development in the form of a ready-to-use/off-the-shelf tool for urban planners, decision-makers, and other associated stakeholders. The framework can also be communal platform of effective communication between diverse stakeholders with varying background and interests.

PART II: Mitigation and Adaptation Strategies

In the second part, we focus more on 'practices', mainly from the mitigation and adaptation strategies. We particularly explore best practices that are considered as urban planning interventions, urban design innovations, and new approaches to either mitigate or adapt climate change impacts on cities. This part includes seven case study chapters. These include a wide range of topics such as UHI effect mitigation, densification strategies, traditional dwellings, climate-responsive design, bioclimatic design, etc. Below is the summary of the seven chapters included in this part.

Chapter 6: Contribution of Bodies of Water to the Mitigation of UHI Effect in Urban Canyon: A Parametric Study Approach

By: Nedyomukti Imam Syafii, and Masayuki Ichinose

To find effective design solutions for bodies of water for better urban thermal environment, a series of comprehensive studies have been conducted utilising an outdoor scale model canopy in Saitama, Japan, and coupled numerical model. The simple form of the outdoor scale model has the advantages of enabling the observation of various physical phenomena under actual climate conditions and conducting comprehensive measurements of a relatively uniform area, thus providing results that are easy to interpret. Meanwhile, numerical modelling allows a series of various bodies of water configurations to be analysed and compared.

By modifying its basic physical properties, the present study shows evidence of the positive contribution of water ponds to the urban thermal environment. The presence of water ponds inside an urban canyon reduced the air and radiant temperatures throughout the day. The result also shows that, generally, a bigger pond has greater cooling benefits. A bigger pond tends to absorb more heat and has a more evaporation surface. As shown in the measured air temperature, water temperature and globe temperature profile, a larger portion of the radiant energy absorbed within the canyon is dissipated by evaporation rather than converted into sensible heat. This phenomenon shows the critical role of the bodies of water's thermal capacity while also opening the possibility of manipulating these parameters for a better urban thermal environment. When there is a space constraint within urban spaces, introducing chilled water may help further improve the cooling benefits of urban bodies of water bodies.

Chapter 7: The Challenge of Cooling Rapidly Growing Cities: The Case of Densification and Sprawl in Ho Chi Minh City and Adaptation Responses

By: Antje Katzschner, Nguyen Kieu Diem, Thanh Hung Dang, and Nigel K. Downes

Climate change and social-economic development are expected to compound climate changes risks. For southeast Asian cities, the phenomenon of urban heat islands and extreme heat waves are a current and future concern for public health, well-being and household energy consumption due to increased cooling demands of urban residents and limited resources to cope. Urban heat island studies using remotely sensed imagery have already revealed that Vietnam's major cities are characterized by strong temperature differences between urban and rural areas. As a result, implementing adaptation measures based on solid science is critical to mitigating the negative effects of heat on urban residents and adapting infrastructure. While different adaptation measures are currently debated by the political authorities in Vietnam, decision-making is hampered by multiple scientific knowledge gaps and the lack of practical tools to support decision-making. This chapter presents methods to investigate and monitor recent urban development in Ho Chi Minh City, an emerging megacity and economic powerhouse of Vietnam.

Chapter 8: Traditional Dwellings in Four Middle Eastern Cities: Adaptation Strategies to Harsh Climate in Privacy

By: Hirou Karimi, Mohammad Anvar Adibhesami, Maryam Ghasemi, and Borhan Sepehri

Climate change is one of the most serious environmental issues of the twenty-first century, compelling designers to adapt their work to completely new climate-change-adapted settings. The Middle East's dry environment causes issues with rising temperatures and decreasing humidity. Environmental harmony has long been a priority in Middle Eastern architecture. Designers changed nature to accommodate the limited supply and demand for energy. Concerns about privacy and climate change influence home construction in areas with similar religious and climatic conditions. As a result, the purpose of this research is to look into the environmental and privacy-enhancing characteristics of historic and contemporary buildings. To accomplish this goal, observations and reviews of relevant literature were used to collect qualitative data. Analysis from a variety of research and climate-tested data was used in the following: This study's data and analysis include traditional homes, the Koppen climatic classification, and contemporary house design. Furthermore, research methods have been used in areas with well-established internal residential characteristics, such as Baghdad, Riyadh, Mukalla, and Kashan. The climate and isolation of each instance were studied and compared to nearby, modern dwellings. Our data show that these communities' older buildings made good use of natural heating and cooling resources. Summer and winter rooms are available for rent in historic mansions in Kashan and Baghdad. Summers in these regions are scorching, and winters are bitterly cold due to the different positions of the sun. We have not yet investigated any sun-facing locations in modern architecture. Wind turbines are also very important. The wind tower passively cools the structure's air. In modern homes, air conditioning provides ventilation. These items are both expensive and energy-intensive.

Chapter 9: Urban Thermal Environment Under Urban Expansion and Climate Change: A Regional Perspective from Southeast Asian Big Cities

By: Can Trong Nguyen, Amnat Chidthaisong, Rungnapa Kaewthongrach, and Wijitbusaba Marome

Southeast Asia (SEA) is a hotspot of rapid urbanisation and climate change, which is supposed to influence millions of people. They altogether exacerbate urban thermal environments and amplify urban heat islands (UHIs). The chapter provides a comprehensive assessment of urban warming trends in SEA big cities over the past thirty years in a connection with urban expansion and climate changes; of which climate change is represented by temperature extremes as an additional element deteriorating UHIs. It reveals a significant warming trend in nighttime extreme indices across the cities against daytime. Manila and Kula Lumpur have confronted the most prominent temperature variations. There were drastic transformations in urban areas, urbanisation patterns, and landscape characteristics during urbanisation. The fastest-growing cities during this period are Jakarta, Bangkok, and Ho Chi Minh City. The degradation of the urban thermal environment was also confirmed via spatiotemporal escalations of both land surface temperature (LST) and surface UHI (SUHI) over time. The aggravation in urban thermal environments was mainly driven by urbanisation-related elements and temperature extremes as a background climate factor. The changes in surface characteristics are the main driving factors across the cities. Yet, the stimulations of climate on thermal environment degradation are uneven among the cities. Ho Chi Minh City, Jakarta, and Manila are the most vulnerable cities due to combined impacts rather than others. It verifies the integrated impacts of climate change and urbanisation on urban microclimate change, it therefore should have long-term strategies to mitigate the adverse effects of SUHI. The general principle is to reduce horizontal urban expansion, ensure urban spatial planning and urban green spaces, and mainstream climate change into urban planning.

Chapter 10: Climate-Responsive Designs to Enhance Outdoor Thermal Comfort in Urban Residential Areas

By: Tingting Yuan, Hongyun Qu, and Bo Hong

Our study aims to determine relationships among microclimate, outdoor thermal perception, and residents' behavior in a residential area in Xi'an, China. Four typical open spaces in the residential area were investigated using meteorological measurements, questionnaire survey, and behavioral records to determine how individuals' thermal comfort relates to their outdoor activities. Physiological Equivalent Temperature (PET) was applied to quantitatively determine the outdoor thermal benchmarks in Xi'an, and climate-responsive strategies for open spaces were proposed based on thermal benchmarks. Results showed that: (1) spaces differed significantly in air temperature, wind speed, solar radiation, globe temperature, mean radiative temperature, and PET, but not relatively humidity, (2) in summer, residents preferred activities in shaded environments and attendance was inversely linearly related to PET, and (3) optimum design strategies for open spaces were proposed to consider shelterbelts, shaded facilities, plants, water, and underlying surfaces. These results will help urban designers improve their understanding of the relationship between behavior and thermal comfort and provide design advice for open spaces in residential areas in China's cold region.

Chapter 11: Dynamic annual solstice patterns and urban morphology: Bioclimatic lessons for in-situ adaptation measures within the warming city of Ankara, Türkiye

By: Andre Santos Nouri, José Abel Rodriguez-Algecíras, and Andreas Matzarakis

Within the existing literature, there already is a wealthy initiation into how different types of local adaptation measures can help urban fabrics respond to increasing temperatures as a result of climate change. Arguably propelled by the climate change adaptation agenda, different typologies of thermal sensitive measures are becoming continually more organised and solidified to improve the bioclimatic responsiveness of the consolidated urban fabric. Along with this growing body of knowledge, is the recognition that the in-situ efficacy of different measure typologies in counteracting increasing urban heat levels depends on two interrelated factors, these being: (1) how well the dynamic microclimatic conditions are assessed and understood; and (2) how well characteristics such as urban morphology are understood. Following this line of reasoning, in order to be utilised to their full potential, and moreover avoid symptoms of mal-adaptation, thermal sensitive adaptation measures must account for the unremitting and symbiotic cause-and-effect between these factors.

Today, it is widely known that mean radiant temperature (MRT) is one of the most significant factors upon human thermophysiological thresholds. In addition, it is furthermore a particularly dynamic variable as a result of the continuously shifting annual solstice. Accordingly, MRT must be understood as a variable which modifies not just on a diurnal bases, but in addition one which oscillates throughout the different months and seasons of the year. Depending on the time of year, as dictated by the Urban Energy Balance, radiation fluxes interact with the static structures of the urban fabric through different seasonal energy exchange patterns/quantities. Such an understanding calls upon the approach of both yearly and different seasonal analytical scopes to better comprehend the symbiotic relationship of urban morphology and solstice patterns. It permits a finer understanding of the impacts associated to crucial climatic variables that play a significant role in human thermal comfort. Invariably, this consequently includes the fundamental role of in-situ dynamic radiation fluxes that are undeniably dictated by modifying yearly/seasonal solstice patterns. Grippingly, and unlike encircling air temperature, MRT can more easily be manipulated through different measure typologies within the urban fabric, and in addition, presents means to alter the cause-and-effect relationship with other encircling microclimatic variables.

Within this book chapter, a structured reflection will be undertaken for Ankara, Türkiye—and how an innovative methodical case study presents bioclimatic lessons pertinent to the crucial role of in-situ dynamic radiation fluxes within a densifying and warming urban fabric in an era of growing climate change.

Chapter 12: Comparison of Thermal Indices in Urban Environments with SkyHelios Model

By: Marcel Gangwisch, and Andreas Matzarakis

Global climate change and its thermal implications on cities makes it necessary to react with long-term climate-adaptive urban planning. This should be part of heat action plans to be implemented by municipalities, to minimize future risks of overheated city districts on the city dwellers and especially on risk and vulnerable groups. The evaluation of the thermal impact, based on thermal indices (depicting human thermoregulation) is most important in order to allow for a safe and risk-minimized but also human-adapted urban planning.

The assessment of thermal impacts can be achieved using numerical urban microscale models, which are suitable to analyse the human thermal outdoor conditions of future building- and local climate- scenarios. This chapter aims to demonstrate the applicability of the urban microscale model SkyHelios and thermal indices to an urban district in Freiburg, Germany. The findings demonstrate the thermal vulnerabilities, strengths and similarities of the indices and provide additional information for future action.

PART III: Policies

In the third part, we delve into 'policies' relevant to climate change strategies in cities and communities, particularly those with case study examples, framework development, and policy development directions. Divided into four chapters, this part includes studies on urban heat island effect, thermal comfort assessment frameworks and models, climate justice, and urban biometeorology. Below is the summary of the four chapters included in this part.

Chapter 13: Urbanisation and Urban Heat Island in a Mekong Delta City: From Monitoring to Dominant Factors

By: Phan Kieu Diem, Nguyen Kieu Diem, Can Trong Nguyen, and Nguyen Thi Hong Diep

Urbanisation is an indispensable process along with socio-economic development. However, this is also the root of various challenges in urban areas from social to environmental and microclimate changes such as urban heat islands (UHI). This book chapter showcases a case study regarding rapid urbanisation, dynamic of surface urban heat island (SUHI), and controlling factors of UHI in Can Tho city—a regional newly developing city in the Mekong delta since 2005. Using an integrated methodology framework of earth observation analyses and Analytic Hierarchy Process (AHP), we assessed the urbanisation trends based on urban density and annual growth rate (AGR). The deterioration of SUHI was analysed using land surface temperature (LST) retrieved from Landsat thermal infrared band. AHP is a social approach via expert interviews to identify the key elements and their contribution weights to UHI under the local conditions. It revealed that urban areas have continuously expanded outwards since 2005 towards the Western and main roads along the Bassac river. The AGR is about 0.73%/year over the period of 2005–2019. In particular, the city center has experienced a relatively high rate of urbanisation compared to other areas (i.e., 3.98–5.04% versus 0.5%/year). LST increased significantly and the growth of SUHI was more moderate in terms of intensity and spatial patterns. SUHI is frequently observed in industrial zones and densely populated areas. Urban sprawl was found to significantly stimulate the variations of SUHI intensity. Regards to the driving factors of UHI, five (05) main factors including nature, society, infrastructure, policy and environment are found contributing to form of UHI at this specific areas. In which, the natural factors including coverage ratio of vegetation and water surface are the most contributors to UHI. The key analytical factors from AHP are likely to be prioritised elements, which should be mainstreamed into urban planning to mitigate UHI towards a cooling city.

Chapter 14: A Study on Thermal Comfort Assessment Frameworks and Models in Cities

By: Hadi Alizadeh, and Ayyoob Sharifi

Considering the increasing trends of urbanization, climatic change, and air temperature in cities, the issue of urban heat island mitigation for ensuring thermal comfort is of high importance. Enhancing thermal comfort also has implications for human health, well-being, and productivity. In recent decades, several assessment frameworks and models have been proposed to measure and predict thermal comfort in cities. This chapter tries to explore major assessment frameworks and models that explain and measure thermal comfort in cities by considering physical, physiological, psychological, and behavioral dimensions. It shows that thermal comfort models could be divided into two major categories, namely, knowledge-based thermal comfort methods and data-driven thermal comfort models. Each of these two has subset models for thermal comfort testing in cities. The findings indicate that recent trends in measuring thermal comfort are focused on data-driven models based on simulation algorithms.

Chapter 15: Who benefits more from urban cooling strategies? Exploring climate justice in vulnerable groups' Access to Blue-green Infrastructure in Mashhad City, Iran

By: Safoora Mokhtarzadeh, and Mahdi Suleimany

Climate change and consequently global warming have made the decision-makers adopt a set of urban cooling strategies and policies. These policies, the most common of which is the development of blue-green infrastructures, lead to a decrease in the ambient temperature of cities. However, many studies suggest that the uneven development of these infrastructures has led to climate injustice in many cities. In other words, developing blue-green infrastructure to meet predefined standards is one side of the coin in coping with global warming, which indicates the efficiency of urban resiliency measures. While ensuring equitable access to these services and infrastructures is the other side, which shows the effectiveness of adaptation programs. Therefore, in this research, we have analysed climate justice in a case (Mashhad metropolis, Iran) considering vulnerable groups' access to blue-green infrastructure. We have implemented spatial analysis techniques and multi-scale geographic weighted regression (MGWR) model to identify the patterns of the aforementioned climate (in)justice at two scales of city and neighbourhoods. The results have indicated the significant climate injustice in low-income groups' access to blue and green infrastructures on both scales. Besides, the findings have depicted patterns of climate injustice in the access of sensitive age groups, the disabled, and immigrants to blue infrastructure. The most important reason for this injustice is the uneven distribution and development of blue infrastructures and their spatial concentration in the western half of the city which arose from the inequitable decisions of city management and planning. Although these findings are context-specific, the research process is applicable to any other context. We have also provided some recommendations to promote climate justice in the adoption of urban cooling policies.

Chapter 16: Urban Biometeorology of Tropical Climate: Af, Am, Aw, a Propensity of 34 Provincial Cities in Indonesia

By: Beta Paramita, Hanson E. Kusuma, and Andreas Matzarakis

Indonesia lies between 6° North Latitude–11° South Latitude and 95°–141° East Longitude. Located in the eastern hemisphere, this geographical location causes Indonesia to be included in the equatorial zone and has a tropical climate. Indonesia is the largest archipelagic country in the world with 17,000 islands, 416 districts and 98 cities in 34 provinces. In general, there are three city characteristic that are in the coast (+0 masl) have maximum temperatures above 33°°C. In lowland areas (10–20 masl) the maximum air temperature recorded above 30 °C. Meanwhile the cities located in the hills area (above 500 masl) which are not many in number, have the lowest maximum air temperature between 25 and 28°C. Based on Köppen-Geiger, climate of Indonesia is almost entirely tropical. Dominated by the tropical rainforest climate (Af); tropical monsoon (Am); and tropical savannah (Aw) that occurs on every Indonesian island. This article then reveals the perspective of biometeorology of 34 cities of provincial capital in Indonesia. Cities that represent the tropical rainforest climate such as Medan, Balikpapan, Padang, and Pontianak. Meanwhile Jakarta, Semarang, and Yogyakarta represent cities with tropical monsoon climate. Last, Denpasar and Surabaya represent cities with tropical savannah climate. The climate data is generated from 2009 to 2019 that provides a link between the microclimate elements and human activities that affected on human perception in their living space. The biometeorology perspective for each climate characteristic gives an understanding on meteorological vulnerability and physiological aspects in the city inhabitant, such as thermal stress.

4 A Summary

The book concludes with several reflective views, lessons learnt, and pathways for future cooling strategies in cities. The last chapter serves as a summary chapter, concluding with some extracted lessons for cooling cities, now and in the near future.

Part I is of importance to present holistic and emerging concepts, theories, and trends for urban heat mitigation and adaptation. In particular, Part I develops a novel urban thermal environment assessment indicator of UTFVI and applies it to 15 megacities in Pakistan to explain how land surface temperature varied spatiotemporally. Such an indicator and demonstration enhance urban managers' understanding of heat island formation and strengthens policymakers' capability of identifying vulnerable areas and adding proper planning/design interventions. A comprehensive urban heat mitigation framework was developed for urban greening, cool materials, evaporative techniques, and shading strategies. The novelties lie in identifying cooling effectiveness and key planning and design variables, allowing urban planners and designers to make evidence-based decisions on the selection of cooling strategies and techniques. Part I also explores the co-benefits approach, which can cost-effectively address more than challenges synergistically, with the integration of nature-based techniques to achieve the dual goals of biophilic design and urban cooling. Furthermore, Part I conceptualises a new, integrated and holistic framework of heat island assessment and management by identifying heat island drivers into climate and non-climate-related types. Such a framework supports the development of ready-to-use/off-the-shelf tools for enhancing the communication of urban planners, decision-makers, and other associated stakeholders.

Part II broadly showcases and explores the mitigation and adaptation strategies and techniques across urban planning, urban design, and building design scales. The analysis and identification of heat island evolution in Ho Chi Minh City, Vietnam, is of significance to provide Southeast Asian cities which are under rapid urbanization insights into planning interventions for adaptation. A comparison of the heat island development over 30 years in several southeast Asian cities (e.g., Jakarta, Bangkok, Ho Chi Minh City, Manila, and Kula Lumpur) was more intuitive to verify the impact of climate change and urbanisation on the urban thermal environment deterioration, and consolidate the urgency of reducing horizontal urban expansion, ensuring urban spatial planning and urban green spaces, and mainstreaming climate change into urban planning. This part also presents the parametric design of water bodies tailoring to Saitama, Japan, for cooling performance enhancement. It suggests the climate-responsive design of open spaces in Xi'an, China, based on shelterbelts, shaded facilities, plants, and water for outdoor thermal comfort improvement. This part also adds new knowledge of bioclimatic lessons by exploring how urban morphology counters urban heat challenges based on the mean radiant temperature assessment indicator by an empirical study in Ankara, Türkiye. Meanwhile, the relationship of urban morphology with urban heat challenges is more broadly explored based on thermal indices of Physiologically Equivalent Temperature, Perceived Temperature, and Universal Thermal Climate Index in an urban district in Rieselfeld in Freiburg, Germany. Such studies promote the understanding of safe and risk-minimized but also human-adapted urban planning. In addition, an analysis of the built form of traditional dwellings in four middle eastern cities of Baghdad, Riyadh, Mukalla, and Kashan reveals the formula of such buildings adapting to harsh climates. Moreover, the study in Freiburg, Germany, also presents the sensitivity of the SkyHelios Model in predicting different thermal indices, which is conducive to enhancing the methodological understanding of microclimate modelling.

Part III generates wide implications on urban planning policy, governmental regulations, planning practice, and design schemes by identifying dominant factors of heat islands, thermal comfort assessment frameworks and models, climate justice, and urban biometeorology. The adoption of the Analytic Hierarchy Process method to explore the land surface temperature variations in Can The city highlights five key driving factors in aspects of nature, society, infrastructure, policy, and environment. This provides the planning directions for urban heat alleviation in Mekong Delta City. More importantly, this study demonstrates an exemplary method for many other cities to identify key drivers and main priorities for cooling actions accurately. This part also delineates the assessment framework of thermal comfort that is a function of physical, physiological, psychological, and behavioral factors and categorises various methods into knowledge-based methods and data-driven models. Such work is conducive to providing scholars with proper justifications for using either knowledge-based methods or data-driven models for thermal comfort assessment. This work also answers who is the beneficiary of urban cooling strategies from the perspective of heat vulnerability and climate (in)justice, which is beneficial for avoiding the occurrence of process-related injustice relevant to improper decisions. The last study in the context of 34 provincial cities restructures the way to describe urban climate by linking microclimate elements and human activities, enabling urban planners and designers to better understand meteorological vulnerability and physiological responses/feelings.

The specific examples in the following 15 chapters would help us highlight the importance of (1) concepts, theories, and trends (see Chaps. 2–5), (2) mitigation and adaptation strategies (see Chaps. 6–12), and (3) policies (see Chaps. 13–16). The following chapters provide global case study examples beyond the existing and current policies and practices and highlight some of the main concepts, best practices, and policies around the globe. This volume helps considering cooling strategies in cities, communities, and the built environments in combatting climate change and its impacts on the living environments.

References

Anderson, G. B., & Bell, M. L. (2011). Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. *Environmental Health Perspectives, 119*(2), 210–218. https://doi.org/10.1289/ehp.1002313

Bruse, M., & Fleer, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling & Software, 13*(3–4), 373–384.

Butters, C., & Cheshmehzangi, A. (2018). Cities, climate and cooling. In: *Designing cooler cities: Energy, cooling and urban form: The Asian perspective* (pp. 5–19). Palgrave Macmillan, Springer.

Cheshmehzangi, A., & Butters, C. (2015). Refining the complex urban: The study of urban residential typologies for reduced future energy and climate impacts. In *Proceedings of 8th Conference of the International Forum on Urbanism.*

Cheshmehzangi, A., & Butters, C. (Eds.). (2017). *Designing cooler cities: Energy, cooling and urban form: The Asian perspective.* Palgrave Macmillan, Springer.

Cheshmehzangi, A., Butters, C., Cheshmehzangi, A., Dawodu, A., Jin, R., & Mangi, E. (2022). Urban design in the age of climate change: Paradigms and directions. *Design for vulnerable communities* (pp. 133–154). Springer International Publishing.

Cheshmehzangi, A., Dawodu, A., & Sharifi, A. (2021). *Sustainable urbanism in China.* Routledge.

City of Sydney. (2015). *Adapting for climate change: A long term strategy for the city of Sydney.* https://www.cityofsydney.nsw.gov.au/strategies-action-plans/adapting-for-climate-change

Cui, Y., Yan, D., Hong, T., & Ma, J. (2017). Temporal and spatial characteristics of the urban heat island in Beijing and the impact on building design and energy performance. *Energy, 130*, 286–297.

Dawodu, A., & Cheshmehzangi, A. (2017). Passive cooling energy systems SWOT analyses for energy-use reductions at three spatial levels. *Energy Procedia, 105*, 3411–3418.

De Bono, A., Peduzzi, P., Kluser, S., & Giuliani, G. (2004). Impacts of summer 2003 heat wave in Europe. *Environment Alert Bulletin, 2*, 4. https://archive-ouverte.unige.ch/unige:32255

Fletcher, D. H., Likongwe, P. J., Chiotha, S. S., Nduwayezu, G., Mallick, D., Md, N. U., Rahman, A., Golovátina-Mora, P., Lotero, L., Bricker, S., Tsirizeni, M., Fitch, A., Panagi, M., Villena, C. R., Arnhardt, C., Hey, J. V., Gornall, R., & Jones, L. (2021). Using demand mapping to assess the benefits of urban green and blue space in cities from four continents. *Science of the Total Environment, 785*, 147238.

EU. (2022). EU saw 53,000 excess deaths in July amid record heatwave: Report. *Global News*. https://globalnews.ca/news/9134651/european-union-excess-deaths-july/

Hatvani-Kovacs, G., Belusko, M., Skinner, N., Pockett, J., & Boland, J. (2016). Drivers and barriers to heat stress resilience. *Science of the Total Environment, 571*, 603–614.

He, B. J., Zhao, D., Xiong, K., Qi, J., Ulpiani, G., Pignatta, G., Prasad, D., & Jones, P. (2021). A framework for addressing urban heat challenges and associated adaptive behavior by the public and the issue of willingness to pay for heat resilient infrastructure in Chongqing, China. *Sustainable Cities and Society, 75*, 103361. https://doi.org/10.1016/j.scs.2021.103361

He, B. J., Wang, W., Sharifi, A., & Liu, X. (2023). Progress, knowledge gap and future directions of urban heat mitigation and adaptation research through a bibliometric review of history and evolution. *Energy and Buildings, 287*, 112976. https://doi.org/10.1016/j.enbuild.2023.112976

Khosla, R., Miranda, N. D., Trotter, P. A., Mazzone, A., Renaldi, R., McElroy, C., Cohen, F., Jani, A., Perera-Salazar, R., & McCulloch, M. (2021). Cooling for sustainable development. *Nature Sustainability, 4*(3), 201–208.

Kotharkar, R., & Ghosh, A. (2022). Progress in extreme heat management and warning systems: A systematic review of heat-health action plans (1995–2020). *Sustainable Cities and Society, 76*, 103487.

Matzarakis, A. (2020). A note on the assessment of the effect of atmospheric factors and components on humans. *Atmosphere, 11*(1283), 1–18.

Matzarakis, A. (2021). Comments about urban bioclimate aspects for consideration in urban climate and planning issues in the era of climate change. *Atmosphere, 12*(546), 1–8.

Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: Physiological equivalent temperature. *International Journal of Biometeorology, 43*, 76–84.

Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxes in simple and complex environments—Application of the RayMan model. *International Journal of Biometeorology, 51*, 323–334.

Matzarakis, A., Laschewski, G., & Muthers, S. (2020). The heat health warning system in Germany—Application and warnings for 2005 to 2019. *Atmosphere, 11*(170), 1–13.

Matzarakis, A., Gangwisch, M., & Fröhlich, D. (2021). RayMan and SkyHelios model. In: M. Palme & A. Salvati (Eds.), *Urban microclimate modelling for comfort and energy studies* (pp. 339–361). Springer.

Mayer, H., & Höppe, P. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology, 38*, 43–49.

Oke, T. R. (1988). The urban energy balance. *Progress in Physical Geography, 12*(4), 471–508.

Santamouris, M., & Kolokotsa, D. (2015). On the impact of urban overheating and extreme climatic conditions on housing, energy, comfort and environmental quality of vulnerable population in Europe. *Energy and Buildings, 98*, 125–133.

Santamouris, M. (2020). Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. *Energy and Buildings, 207*, 109482.

Santamouris, M., & Yun, G. Y. (2020). Recent development and research priorities on cool and super cool materials to mitigate urban heat island. *Renewable Energy, 161*, 792–807.

Staiger, H., Laschewski, G., & Matzarakis, A. (2019). Selection of appropriate thermal indices for applications in human biometeorological studies. *Atmosphere, 10*(18), 1–15.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society, 93*(12), 1879–1900.

Wang, J., Meng, Q., Zou, Y., Qi, Q., Tan, K., Santamouris, M., & He, B. J. (2022). Performance synergism of pervious pavement on stormwater management and urban heat island mitigation: A review of its benefits, key parameters, and co-benefits approach. *Water Research*, 118755.

WMO. (2021). Climate and weather related disasters surge five-fold over 50 years, but early warnings save lives. *United Nations News* (World Meteorological Organization [WMO] and

UN Office for Disaster Risk Reduction [UNDRR]). https://news.un.org/en/story/2021/2009/1098662

Yang, H., Lee, T., & Juhola, S. (2021). The old and the climate adaptation: Climate justice, risks, and urban adaptation plan. *Sustainable Cities and Society, 67*, 102755.