BEATING THE HEAT: INVESTING IN PRO-POOR SOLUTIONS FOR URBAN RESILIENCE

AUGUST 2022

ASIAN DEVELOPMENT BANK

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The cover design is by Lowil Fred Espada and it depicts an urban area at high risk of heat waves.

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Foreword

Countries in Asia are experiencing extreme heat events, with temperatures reaching record highs. Such heat waves, or periods of abnormally hot weather, are projected to become more common—with adverse impacts on the lives, livelihoods, health, and productivity of the population. Urban areas are particularly at risk due to their high concentration of built infrastructure and reducing blue and green spaces to accommodate rapid growth. Within urban spaces, poor and vulnerable populations are the hardest hit because of their inadequate living conditions, harsh work environments in informal and often outdoor work, and limited adaptive capacity.

Given this reality, cities in Asia and the Pacific need to prepare for a warmer world. This will require a wide range of pro-poor policies and investments based on long-term planning and must include actions at all scales: individual and household, neighborhood, and city. Such actions also need to respect different contexts, and include strengthening health preparedness; improving housing design, construction, and maintenance; enhancing infrastructure for informal outdoor livelihoods; performing climate-sensitive urban planning and urban design by using innovative technology and practices; and promoting green and blue urban infrastructure.

As countries in Asia and the Pacific step up their climate commitments in the context of urban development, they open many opportunities for pursuing pro-poor urban resilience initiatives to reduce the increasing impacts of heat stress that urban areas face—in particular, the urban poor population. With this publication, we aim to increase awareness of such opportunities in countries. The report provides eight key recommendations that also offer a good basis for the Asian Development Bank (ADB) to scale up support for countries in dealing with issues relating to extreme heat. These recommended actions will succeed if cities adopt people-centered and integrated solutions in urban planning, delivery of basic services, health, social protection, livelihoods, gender equality, and environmental management.

Recognizing the importance of these recommendations to achieving ADB's climate and urban priorities under Strategy 2030, this publication is the result of a multidisciplinary collaboration comprising the Urban Sector Group and the Climate Change and Disaster Risk Management Thematic Group, with support from the Urban Climate Change Resilience Trust Fund.

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The report was prepared under the overall guidance of Arghya Sinha Roy, principal climate change specialist (Climate Change Adaptation), Sustainable Development and Climate Change Department (SDCC). The development of the report was led by a team of technical experts coordinated by Robert Wilby. The consultant team included Ashna Singh Mathema (housing), Belinda Tato (urban planning and urban design including related graphics), Katherine Gough (livelihoods), Mohamed El-Sioufi (urban basic services and infrastructure), Robert Wilby (physical climate risk and health), and Tord Kjellstrom (local economy and productivity). Tom Matthews produced the heat index maps in Chapter 2, Kae Sugawara edited the manuscript, and Lowil Espada produced the layout. Production and finalization were supported by Sugar Gonzales, climate change officer (Climate Change Adaptation), SDCC.

The report benefited significantly from comments received from Joris van Etten, senior urban development specialist, Southeast Asia Department; Tiffany M. Tran, human settlements expert (consultant), Southeast Asia Department; Hikaru Shoji, senior urban development specialist, South Asia Department; members of the UCCRTF team: Virinder Sharma, principal urban development specialist, SDCC, and Joy Amor Bailey (consultant); and Rowena Mantaring (TA coordinator). The report also benefited from inputs and discussions with Charles Rodgers, senior climate adaptation advisor (consultant); and Alex Fowler, climate resilience specialist (consultant).

Abbreviations

ADB	Asian Development Bank
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
NWS	National Weather Service
RCP	representative concentration pathway
SSP	shared socioeconomic pathway
UHI	urban heat island
WBGT	WetBulb Globe Temperature

Highlights

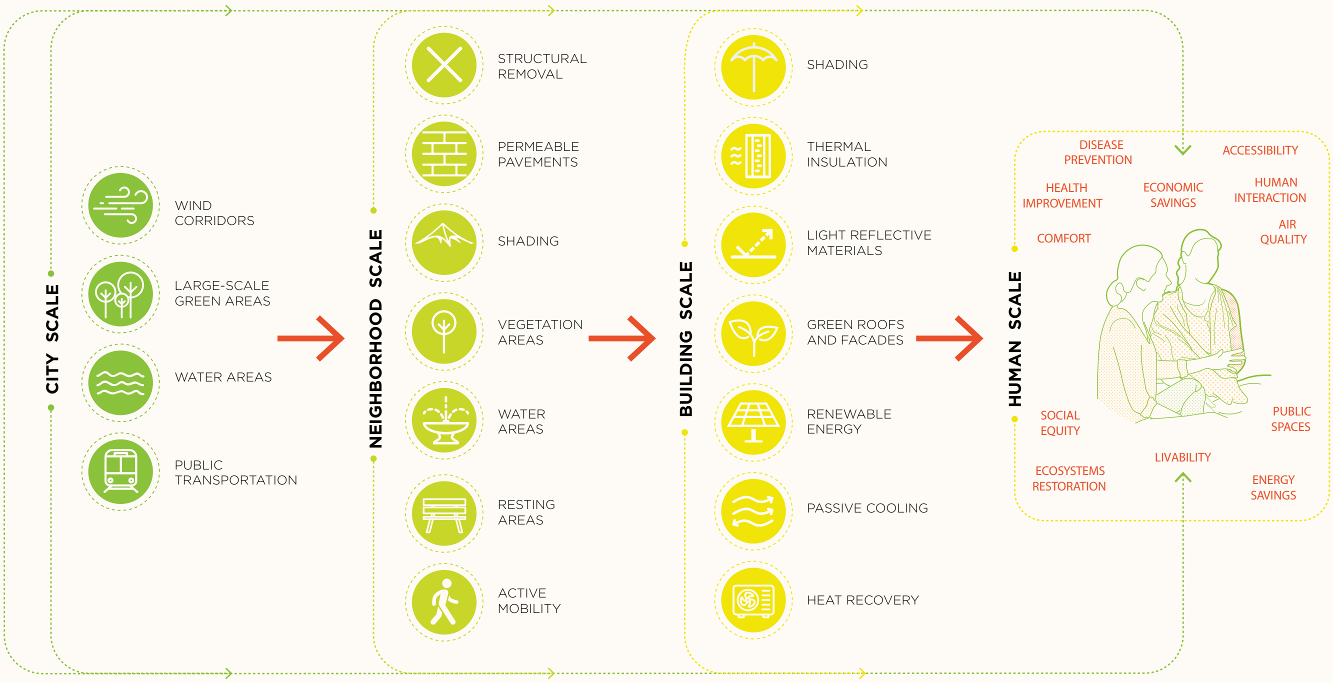
Heat waves, periods of 7–10 days of abnormally hot weather, are an increasingly common hazard in Asia and the Pacific—with impacts on health and productivity of millions of people. Heat waves are projected to become more likely, more severe, and more persistent with global warming. According to estimates, global warming of 1.5°C could expose 14% of the world population to severe heat waves at least once every 5 years, and this figure rises to 37% under a 2°C warming scenario. Concurrent heat waves affecting several cities at the same time, and simultaneous heat wave–drought events, are also expected to become more likely.

Urban populations in the tropics and subtropics are particularly vulnerable to heat stress because of high humidity. These conditions are exacerbated by the "heat island" effect: higher temperatures in urban areas caused by the concentration of buildings, roads, and other infrastructure, as well as limited amount of so-called blue and green spaces. This has widespread impacts on the health and productivity of citizens, delivery of urban basic services, and wider urban economy. Assessments undertaken for this report identified that the most exposed areas of the region to heat stress under present climate conditions include areas across Pakistan, the Ganges–Brahmaputra basin, northern Philippines, and the Lower Mekong. Climate model experiments suggest that future heat waves could become more intense, frequent, and persistent in South Asia and Southeast Asia, especially during the pre-monsoon period. The report also derived humid heat indices for around 180 cities to evaluate the risks and inform decisions related to climate policies and adaptation investments.

Within built landscapes, the urban poor—including people living in informal settlements—are most at risk from heat stress. Such communities typically live in low-quality and overcrowded housing without adequate ventilation and limited access to cooling. They are typically involved in the informal economy, often engaged in outdoor work under the sun, thus affecting their health and productivity. They also tend to have limited coping capacity to deal with increases in food prices due to the impact of heat stress on food production in rural and peri-urban areas, thus impacting their health and nutrition. The urban poor may also rely on fragile water, energy, and health services.

As the Asia and Pacific region urbanizes, and wider structural transformations related to labor markets occur, it is critical to scale up pro-poor investments to deal with heat stress. Such investments are needed at different scales—human, building, neighborhood, and city—to limit exposure of the urban poor to heat stress through a range of climate adaptation measures (see figure that follows). Scaling up such measures will likely require adopting people-centered approaches, with multisector and cross-scale solutions; measures that promote coping, incremental, and transformational changes; and activities that are contextually appropriate to maximize the mitigation co-benefits and avoid potential maladaptation.

Pro-Poor Solutions to Reduce Exposure to Heat Stress in Urban Areas



Source: Authors.

This report recommends the following eight key policy and investment-related pro-poor measures to deal with heat stress:

1. **Improve preparedness through heat action plans**. Institutionalize the process of developing and implementing heat action plans at the city level, with standard operating procedures for improving preparedness in the health sector.

2. **Adopt heat-responsive building design standards**. Revisit standards, construction codes, and guidance available for housing, public buildings, pavement design, and street furniture to ensure they reduce the exposure of the urban poor to extreme heat.

3. **Undertake risk-based land use management**. Implement urban land use management processes such as land use planning, development controls, green space development, and urban redevelopment to provide opportunities for reducing exposure to extreme heat.

4. **Improve employment and labor market-related regulations to protect workers from extreme heat**. Adopt employment and labor market-related policies through regulations, codes, and guidelines that consider the protection of both outdoor and indoor workers from extreme heat.

5. **Implement large-scale "cool roof" programs**. Undertake a large-scale "cool roof" program for formal sector lower-income housing and informal settlements using a combination of technical assistance, subsidies, and access to finance for both investing in and maintaining cool roofs.

6. **Scale up investments in blue and green solutions as part of urban infrastructure**. Invest in locally sensitive blue and green infrastructure that provides opportunities to adapting to extreme heat, while contributing to other social, economic, and environmental benefits.

7. **Invest in early warning systems and effective dissemination of alerts to vulnerable people**. Strengthen surveillance, warning, and dissemination systems for heat waves to reduce the impact of heat waves on the urban poor and wider urban population.

8. **Invest in research and development**. Scale up investments in heat stress-related research, especially to understand the impacts at a local level.

The recommendations provided in this report offer a basis for the Asian Development Bank to scale up extreme heat-related adaptation support in urban areas of Asia and the Pacific, and thereby contribute to the climate priorities and climate adaptation finance targets under Strategy 2030. Support could include a range of instruments, such as providing developing member countries with technical assistance to assess the risks related to extreme heat; strengthening policies, regulations, guidelines, and standards; and building the capacity of local government units to implement such policies. Support could also include providing grant resources to help high-risk cities update their land use management processes to integrate extreme heat-related considerations, to undertake pilots on “cool roof” programs, and to introduce urban agriculture. Investment projects can integrate features to deal with extreme heat through resources for green and blue infrastructure, social housing, and early warning systems. Such support could be provided in the context of urban operations, as well as operations related to social development, health, and finance. Apart from sovereign operations, nonsovereign operations can also be undertaken to promote adaptation to extreme heat in the context of housing finance, small and medium-sized enterprise development, and financial inclusion. Supporting countries in implementing such actions would also require facilitating partnerships between urban local governments and community-based organizations, academic establishments to undertake research and development, and local financial institutions.

Chapter 1

Introduction

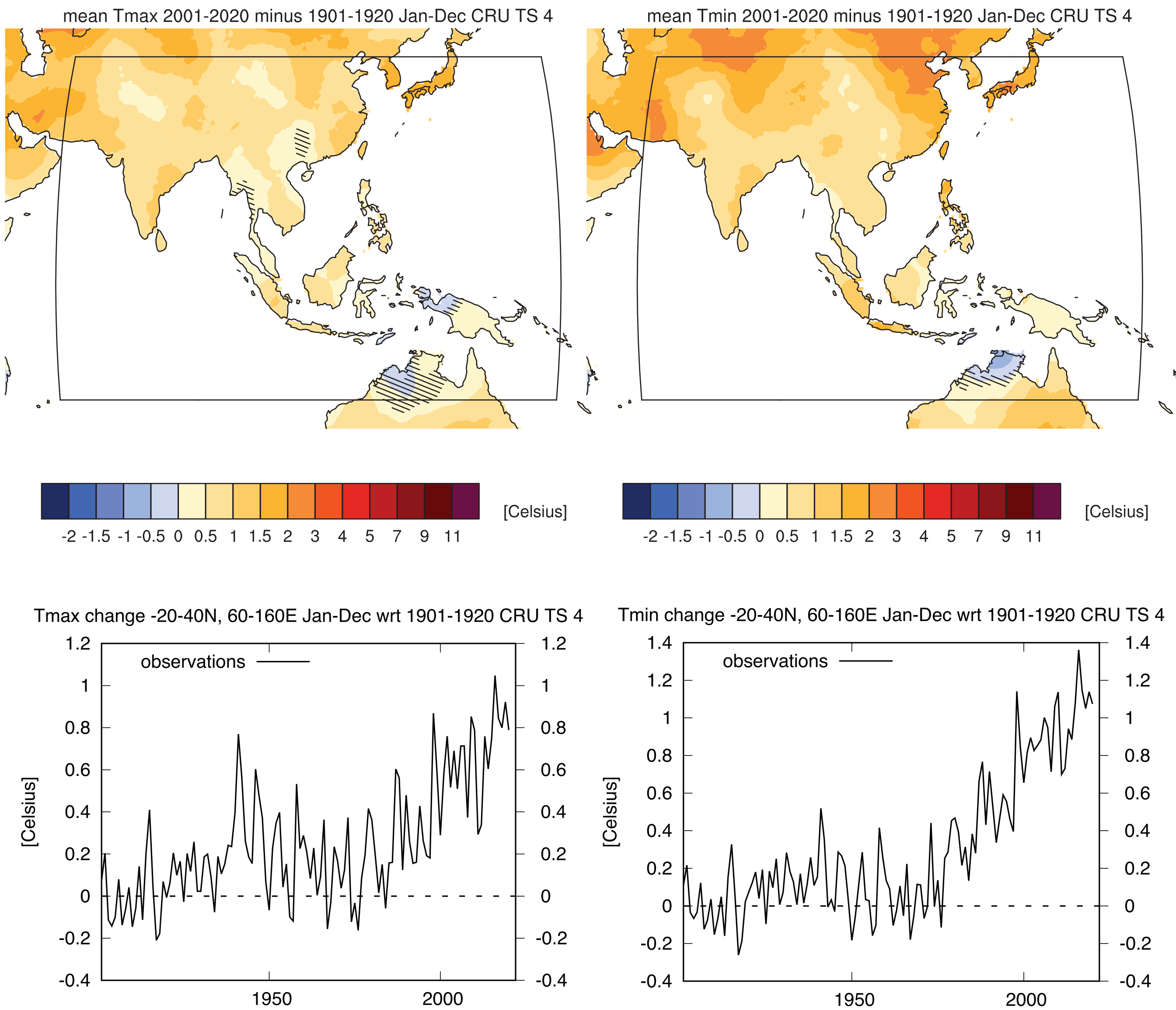
1.1 Why This Report?

Millions of people are already exposed to heat waves in Asia and the Pacific. Heat waves, as defined by the Intergovernmental Panel on Climate Change, are a period of abnormally hot weather. They are becoming a more common feature, with millions in Asia and the Pacific region experiencing sublethal impacts on their health and productivity (Khan et al. 2019). Particularly deadly episodes with air temperatures of 45°C–50°C struck in 1998 in India (Andhra Pradesh, Gujarat, Madhya Pradesh, Odisha, Rajasthan, and Uttar Pradesh) and in 2015 in India (Andhra Pradesh, New Delhi, and Odisha) and Pakistan (Punjab and Sindh). According to the Emergency Events Database (EM-DAT), heat waves have killed 15,341 people in Bangladesh, India, and Pakistan since the 1950s, with most deaths occurring in the last 30 years. Historically, most heat wave fatalities in these countries transpired during May–June, the pre-monsoon period. Regional statistics are difficult to compile and compare because of inconsistent reporting of mortality between countries.

Long-term records suggest that maximum and minimum air temperatures have risen by about 1°C–1.5°C across Asia and the Pacific over the last century. Most rapid warming has been observed over parts of India (Andhra Pradesh and Odisha) and Pakistan (Punjab and Sindh) (Figure 1.1). Marked urban growth and loss of green space may have contributed a further 5°C–6°C of local warming in cities such as New Delhi, India (Mohan, Sati, and Bhati 2020) and Lahore, Pakistan (Imran and Mehmood 2020).

Heat waves are projected to become more likely, severe, and persistent with global warming (Dong et al. 2015; Li, Yuan, and Kopp 2020; Schwingshackl et al. 2021;

Figure 1.1: Change in Annual Mean Maximum (left) and Minimum (right) Air Temperatures between 1901–1920 and 2001–2020



Note: Hashed areas on the maps denote changes within the range of historic variability.
Data Source: CRU TS4. Plotter: KNMI Climate Change Atlas.

Zhao et al. 2015). Moreover, the likelihood of concurrent heat waves affecting multiple cities at the same as well as compound heat wave–drought events are expected to increase (IPCC 2022). One analysis found that 30% of the global population is already exposed to potentially lethal heat for at least 20 days per year (Mora et al. 2017). This figure could rise to approximately 48% by 2100, even with significant reductions in greenhouse gas emissions. Another study found that with only 1.5°C of global warming and midrange

Table 1.1: Cities Defined as Heat Stressed in 1979–2005 for Various Levels of Global Mean Warming

Present	+1.5°C	+2.7°C	+4.0°C
Delhi, India	Mumbai, India	Manila, Philippines	Bangalore, India
Kolkata, India	Ho Chi Minh City, Viet Nam	Jakarta, Indonesia	
Dhaka, Bangladesh	Chittagong, Bangladesh	Hyderabad, India	
Karachi, Pakistan		Pune, India	
Chennai, India			
Lahore, Pakistan			
Bangkok, Thailand			
Ahmedabad, India			
Ha Noi, Viet Nam			

Note: Heat stressed refers to being in the 99.9th percentile of the heat index above 40°C.
Source: Matthews, T.K., R.L. Wilby, and C. Murphy. 2017.

population growth, a further 350 million people living in megacities could be exposed to deadly heat by 2050 (Matthews, Wilby, and Murphy 2017). The impact of heat waves is intensified due to associated air pollution and disruption to key infrastructure and services such as water, energy, health, and information and communication technology (ICT) systems.

Urban populations in the tropics and subtropics are particularly vulnerable to heat stress because of high atmospheric humidity (Coffel et al. 2017; Herold et al. 2017; Jagarnath, Thambiran, and Gebreslasie 2020; Raymond, Matthews, and Horton 2020). This humid heat stress is exacerbated by the higher temperatures due to the urban heat island effect in dense cities relative to surrounding rural areas (Jacobs et al. 2019; Oleson et al. 2015; Wilby 2007). The high concentration of buildings, roads and other infrastructure, and limited green spaces make urban areas "islands" of higher temperatures. Heat islands experience higher daytime temperatures, reduced nighttime cooling, and higher air pollution levels, which in turn have widespread impacts on the health and productivity of citizens, delivery of basic urban services, and functioning of the wider urban economy. Extreme heat already causes fatalities on some days in New Delhi, India, but this could also become the case in Ho Chi Minh City, Viet Nam (with global mean warming of +1.5°C), Manila, Philippines (with +2.7°C), and Bangalore, India (with +4.0°C) (Table 1.1).

Low-income population groups are disproportionately vulnerable to heat stress. Within urban landscapes, the urban poor, including people living in informal settlements, are most at risk because they typically live in low-quality and overcrowded housing (Sverdlik 2011) without adequate ventilation and limited access to cooling; are involved in the informal economy, which often requires outdoor work, thereby affecting their health and productivity; have limited coping capacity to deal with shocks in food prices due to the impact of heat stress on food production in rural and peri-urban areas, thereby impacting their health and nutrition; and are dependent on fragile water, energy, and health services (Ahmadalipour, Moradkhani, and Kumar 2019; Gough et al. 2019; Jones 2012). Poor women are disproportionately impacted due to their limited adaptive capacity.

As cities grow, it is important to scale up pro-poor investments to deal with heat stress. This requires a comprehensive understanding of heat stress and its impacts at different scales—individual, household, community, and city—and pursuing a suite of climate adaptation measures to deal with such risk. It also requires an understanding of wider structural transformations that countries are undergoing in the context of the labor market, including the expected increase in the share of construction workers and high rates of informality in the urban economy. Such an understanding can help in identifying measures to limit the exposure of the urban poor to heat stress through improved land use planning and public spaces; promoting solutions that reduce vulnerabilities through improved living and working conditions, including access to housing and workspaces that are more climate resilient; improved access to urban basic services that adopt green and blue solutions; and improved access to public health facilities and heat health alerts. Adopting and scaling up such measures will likely require changes to policies, additional investments, and adoption of people-centered and integrated approaches for urban resilience. Climate adaptation measures will also need to go hand in hand with efforts on climate mitigation and with the wider sustainability agenda.

1.2 Objectives and Structure of the Report

Identifying solutions for supporting the urban poor to adapt to extreme heat. Despite having such widespread impacts on economies and the delivery of basic services, especially for the health and productivity of the urban poor, pro-poor urban policies and investments to deal with urban heat stress remain limited. Within this context, this report has the following objectives:

- To assess the present extent and future character of extreme heat faced by the urban poor and vulnerable populations.
- To communicate the urgency of scaling up pro-poor climate adaptation measures that deal explicitly with the impacts of urban heat stress.
- To recommend pro-poor policies and investments to address such impacts.

This report has been developed by the Asian Development Bank (ADB) as part of its regional technical assistance (TA) project "Advancing Inclusive and Resilient Urban Development Targeted at the Urban Poor," financed by the ADB-administered Urban Climate Change Resilience Trust Fund. The TA recognizes that strengthening the resilience of the urban poor to climate shocks and stresses will require cross-sectoral and integrated solutions at different scales. A key objective of the TA is to increase awareness among ADB's developing member countries on emerging climate-related risks, such as extreme heat, and their impact on urban development, especially for the urban poor.

Structure of the report. In addition to the introduction and conclusion, the report has five key chapters:

- Chapter 2 describes the present and expected risks from extreme heat.
- Chapter 3 discusses the impacts of extreme heat on the urban poor and the local economy, as well as the drivers of socioeconomic vulnerabilities.
- Chapter 4 introduces various pro-poor climate adaptation measures that can be undertaken at different scales: individual and household, neighborhood, and citywide.
- Chapter 5 presents recommendations for strengthening policies and increasing investments for pro-poor adaptation measures to extreme heat.

1.3 Approach

This report focuses on secondary cities in Bangladesh, India, Indonesia, the Lao People's Democratic Republic (Lao PDR), Pakistan, the Philippines, Thailand, and Viet Nam. Secondary cities were chosen because they are experiencing the most rapid population growth but have less capacity to plan or manage it. They are also regarded as catalysts for future economic development. This report selected cities in the range of 0.5 million–5 million people based on their United Nations Population Division estimate for 2020 (UN DESA 2018). This definition yields a list of 183 urban areas with a combined population of 134 million in 2000; 229 million in 2020; and projected total of 289 million people by 2030 (Appendix 1). The mean annual population growth rate of these cities between 2000 and 2020 was 3.6%, compared with a global average of 2.8% per annum for all secondary cities over the same period. Only Khulna, Bangladesh had a smaller recorded metropolitan population in 2011 than in 2000, attributed to declining fertility rates and strong outmigration (Szabo, Ahmad, and Adger 2018). However, the United Nations models expect growth to resume beyond 2020 in line with the wider trend of urbanization in Bangladesh.

A baseline assessment of extreme heat and impacts was undertaken for these secondary cities using peer-reviewed scientific literature. Augmenting this were new analyses of population and urban growth, historic weather data, and climate model projections of extreme humid heat for the chosen countries. The results show so-called hot spots of present and emerging exposure to heat waves. The report provides cautionary remarks about how to interpret climate model information for urban landscapes.

Evidence was gathered to understand the implications of extreme heat on various sectors, including public health, housing, urban planning, urban design, urban basic services, sustainable livelihoods, and worker productivity. In line with latest thinking, the approach adopted is human centric to evaluate "when, where, and to what extent people are exposed to urban heat and further assess the impact of heat exposure on their comfort, performance, well-being, and health" (Nazarian and Lee 2021:1). This receptor-oriented perspective is helpful for identifying climate adaptation options at human, building, neighborhood, and city scales.

Physical Science and Projections of Extreme Heat in Urban Areas

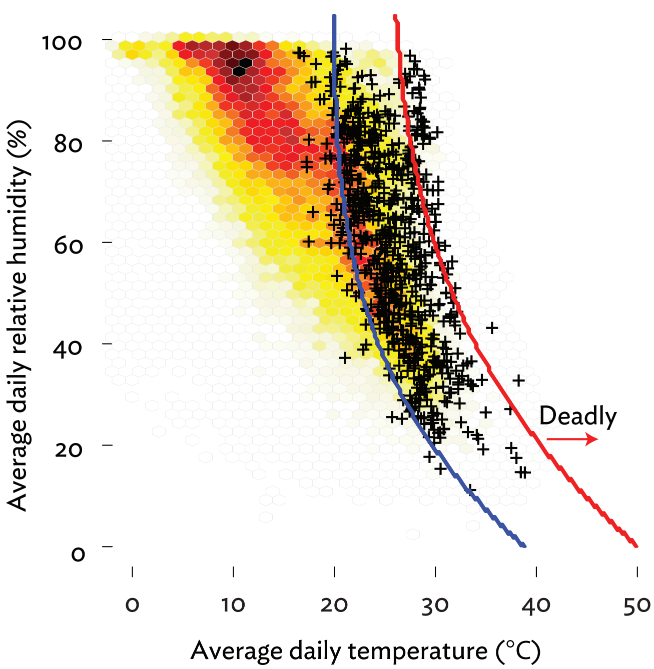
This chapter discusses the physical drivers of heat waves in urban areas, including the factors that contribute to urban heat islands in Asian cities. It further looks at present and future hot spots in the region for extreme heat and analyzes the heat index for the 183 secondary cities studied.

2.1 Measuring Extreme Air Temperatures and Humid Heat

There are many indicators of high air temperatures and humid heat (Anderson, Bell, and Peng 2013; Khan et al. 2019; Nissan et al. 2017; Perkins 2015; Qui and Yan 2020; Schwingshackl et al. 2021). Most incorporate daily maximum and minimum temperature, sometimes combined with relative humidity, and/or thresholds associated with harmful impacts. These metrics are used to calculate, then evaluate, trends in "normal" conditions as well as changes in heat wave frequency, duration, and intensity (e.g., Zahid and Rasul 2012). Other studies recognize compound hazards involving extreme temperatures such as concurrent drought and heat waves (Sharma and Mujumdar 2017); particulates, ozone, and heat (Azhar et al. 2014); drought, heat, wildfire, and air pollution (Zscheischler et al. 2018); heat and pandemic (Phillips et al. 2020); or cyclone followed by heat (Matthews, Wilby, and Murphy 2019).

The United States National Weather Service (NWS) Heat Index (HI) and the WetBulb Globe Temperature (WBGT) are commonly used to analyze historical and projected humid heat. Both indices are used in this report. The NWS HI specifies the "likelihood of heat disorder with prolonged exposure or strenuous activity"[1] based on the apparent temperature (calculated from dry bulb air temperature and relative humidity)[2] (Appendix 2). The NWS defines the following operational thresholds: Caution (26°C–32°C), Extreme Caution (32°C–41°C), Danger (41°C–54°C), and Extreme Danger (>54°C). During *Danger* conditions, heat cramps and exhaustion are likely, and heatstroke is probable with continued activity. Under *Extreme Danger* conditions, heatstroke is impending. Similarly, the WBGT specifies thresholds at which there are growing health risks and/or impacts on labor capacity (e.g., Dunne, Stouffer, and John 2013), incorporating air temperature, humidity, air movement, and heat radiation in one calculated number. The WBGT results can be used to calculate likely economic output loss at the population level (Watts et al. 2020; Kjellstrom et al. 2018) (Appendix 3).

Figure 2.1: Average Daily Air Temperature and Relative Humidity during Lethal Heat Waves



Note: Mean daily surface air temperature and relative humidity recorded during lethal heat waves (black crosses) compared with periods of equal duration but from randomly selected dates (i.e., nonlethal heat events; red to yellow gradient indicates the density of such nonlethal events). The blue line is the threshold that statistically separates lethal and nonlethal heat events, and the red line is the 95% probability threshold; areas to the right of the thresholds are classified as deadly and those to the left as non-deadly.
Source: Mora et al. (2017).

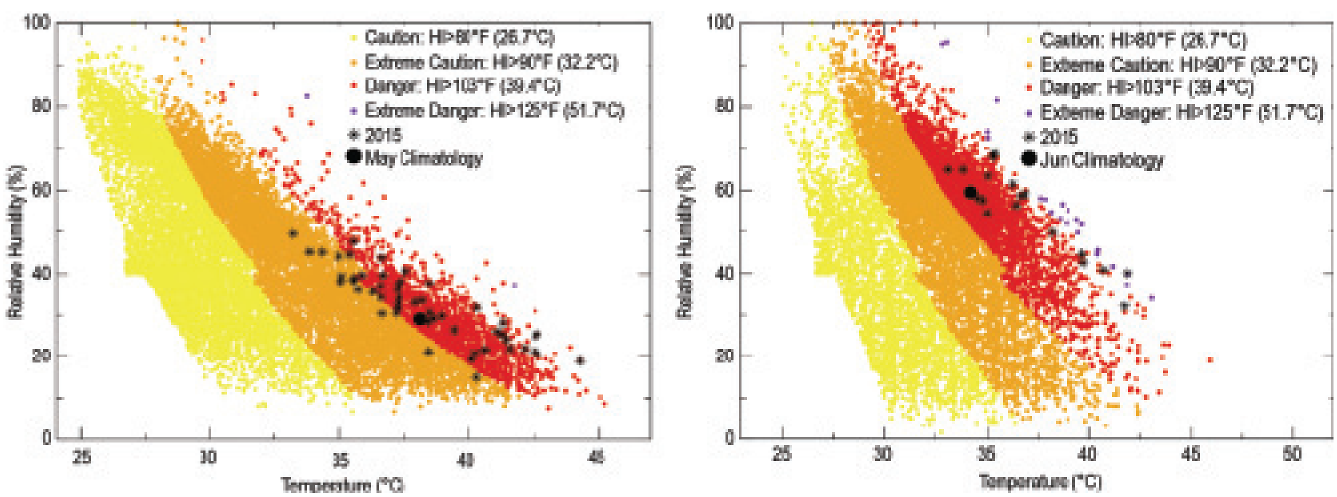
Globally, the highest ever reliably measured air temperature (above ground) was 54.4°C in Death Valley National Park, California, on 16 August 2020 (Masters 2020). However, to describe the temperature felt by people ("heat"), other factors such as air humidity, radiant heat and ventilation, plus individuals' metabolic rate and clothing matter too (Holmes, Phillips, and Wilson 2016). Mortality statistics suggest that an average daily air temperature of 30°C is hazardous at 30% relative humidity but nearly always deadly at 60% relative humidity (Figure 2.1). This is because high humidity reduces the effectiveness of sweating, the natural mechanism for keeping cool. Hence, indicators of humid heat (extreme temperature with high humidity) are especially useful when interpreting excess mortality during heat waves (Desai et al. 2015; Matthews 2018, 2020).

The May–June 2015 deadly heat waves in India and Pakistan were noteworthy for their high humid heat. Maximum HI values of 46.9°C and 53.5°C were reached in Hyderabad, India and Karachi, Pakistan respectively (Figure 2.2). In Hyderabad, India, the maximum temperature was 44°C with relative humidity about 20% (i.e., extreme dry heat). In Karachi, Pakistan the maximum temperature was 42°C with relative humidity up to about 40% (i.e., extreme humid heat).

[1] See NWS Heat Forecast Tools at https://www.weather.gov/safety/heat-index.
[2] See the NWS Heat Index Calculator at https://www.wpc.ncep.noaa.gov/html/heatindex.shtml.

Figure 2.2: Observed Temperature and Relative Humidity from 1973 to 2015 at the Time of the Daily Maximum Heat Index

a. Hyderabad, India **b. Karachi, Pakistan**



HI = heat index.
Note: The 2015 heat wave days are shown by the asterisks. Other observations are colored according to NWS HI advisory levels. The large black dots are the May/June climatological averages.
Source: Wehner et al. (2016).

2.2 Physical Drivers of Extreme Temperature

Analyses of observed temperatures and heat wave indices show that the land area and number of people exposed to deadly heat are rising globally. However, there are some notable hot spots. The number of heat wave days as well as maximum heat wave duration and intensity are all increasing in the region. The likelihood of humid heat peaks around the time of the local climatological monsoon onset. Nights appear to be warming more rapidly than days, and there is also evidence that drier soil conditions are exacerbating heat waves across India.

Heat waves in urban areas are a consequence of physical drivers operating at global, regional, and local scales (Box 2.1). It has long been recognized that even small changes in the mean and/or variability of air temperatures can produce larger increases in the frequency and intensity of extreme temperatures (Mearns, Katz, and Schneider 1984; Griffiths et al. 2005). It has been estimated that with 1.5°C global warming, 14% of the world population could be exposed to severe heat waves at least once every 5 years, whereas this figure might rise to 37% under 2°C warming (Dosio et al. 2018). Whether global warming is 1.5°C, 2°C, or more, this will not translate into the same change in heat waves for everyone. Southeast Asia in general—and Indonesia in particular—is a recognized hot spot (Russo et al. 2014). One analysis of the Coupled Model Intercomparison Project (CMIP5) climate model ensemble found that for every

Box 2.1: The 2015 Heat Waves in India and Pakistan

Heat waves typically last about 7–10 days and are associated with high-pressure systems located over or adjacent to affected regions. This causes hot air to be trapped over, or advected toward, an area. The heat waves in India on 23–26 May 2015 were attributed to hot northwesterly winds flowing from regions of high pressure over southern Russian Federation and Kazakhstan meeting hot westerly winds emanating from a high-pressure zone over North Africa and the Middle East (Dodla, Satyanarayana, and Desamsetti 2017). The two airflows converged on a low-pressure region over the Indian subcontinent decreasing the land–sea breeze on the east coast and raising maximum surface air temperatures above 45°C in Andhra Pradesh and Telangana.

In Pakistan, heat waves separately occurred on 18–24 June 2015 (Masood et al. 2015). During the week before, a subsiding and warming air parcel was brought from the Indian Ocean toward the coastline by the pressure gradient between a high near the Horn of Africa and the low over the Arabian Sea. At the onset of the heat waves, windspeeds dropped and shifted from westerly to east–southeasterly, then at the peak to northeasterly, drawing in hot continental air. The stagnating air mass produced exceptional and unseasonably hot conditions in Sindh state (where temperatures normally peak in April).

The risk of extreme heat is particularly high for coastal cities like Karachi due to their proximity to both continental heat and exposure to marine air masses passing over the warm waters of the Persian Gulf and Gulf of Oman. In fact, humid heat in the southern Persian Gulf shoreline and northern South Asia regions may be approaching the limit of human habitability (Pal and Eltahir 2016; Raymond, Matthews, and Horton 2020).

Source: Authors.

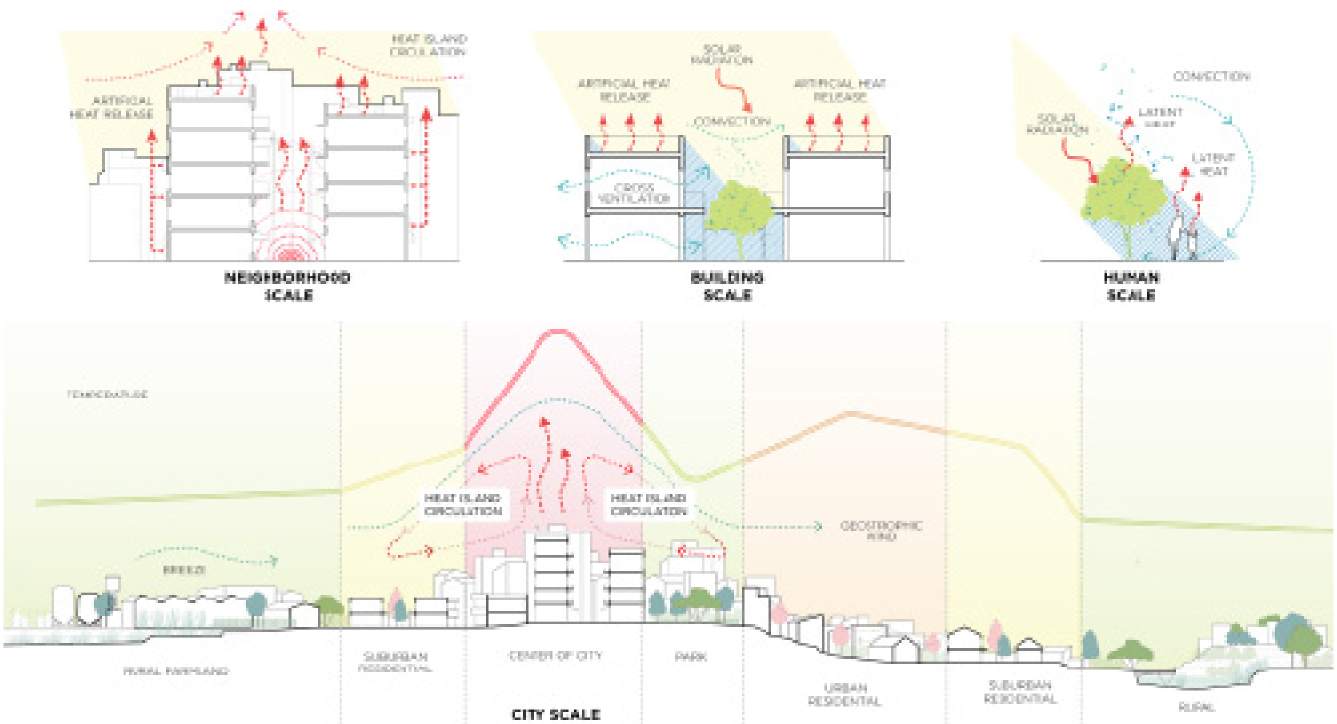
1°C of global warming, the number of heat wave days in South Asia, Southeast Asia, and the Pacific could increase by 20–26 days per season, heat wave intensity by 1.3°C–1.4°C, and maximum heat wave duration by about 8 days (Perkins-Kirkpatrick and Gibson 2017).

Various climatic factors influence heat wave characteristics at regional scales. Severe heat waves across South Asia, Southeast Asia, and the Pacific are, in part, associated with anomalously warm sea surface temperatures in the central Pacific region (Thirumalai et al. 2017)—El Niño episodes—and tropical Indian Ocean (Li 2020). High concentrations of summer aerosols over Pakistan added to maximum net heating rates by 0.44°C per day (Peshawar) to 1.23°C per day (Lahore) during 2005–2018 (Ahmad et al. 2020). Local sea breezes may oppose offshore heat from hot inland regions, thereby adding to heat accumulation during the day at coastal sites, such as in central and southeast India (Dodla, Satyanarayana, and Desamsetti 2017). Temperatures are also expected to be higher for sites at (or below) sea level than at greater altitudes because of the environmental lapse rate, which changes ambient air temperature by about 6.5°C per kilometer.

Cities create their own microclimates because of replacement of natural or agricultural surface with impervious, built areas. Urban heat islands (UHIs) manifest the temperature difference between city centers and cooler, outlying rural areas (Kotharkar, Ramesh, and Bagade 2018). A study of 10 cities in India found multiple UHIs, some with intensities up to +10.3°C in winter (Sultana and Satyanarayana 2018). Others report UHIs in the dry season of +8°C at night in Jaipur (Matthews, Wilby, and Murphy 2017), or +7°C in the day in Bangkok (Arifwidodo and Tanaka 2015) and Manila (Tran et al. 2006). Urban areas also typically have lower humidity and wind speeds, depending on the pattern of land use, width, and orientation of streets. This means that there are likely compensatory effects between higher temperatures yet lower humidity, so the net outcome for urban heat indices is uncertain.

Evidence is growing that rapid urban expansion and loss of green space are contributing to more intense heat waves in tropical cities. Data from Asian megacities suggest that the UHI effect increases by 0.47°C in the day and by 0.30°C at night for every million people (Hung et al. 2006). Conversely, protection of green areas and water bodies can create a cool "oasis effect," especially for cities in arid and semiarid climate zones (Rahul, Mukherjee, and Sood 2020; Borthakur, Saikia, and Sharma 2020). In Bangkok, Jakarta, and Manila, the mean land surface temperature of green space is approximately 3°C cooler than impervious areas (Estoque, Murayama, and Myint 2017). Unfortunately, people residing in high-density, informal neighborhoods are more exposed to higher ambient temperatures than those residing in affluent neighborhoods (Jacobs et al. 2019). Moreover, the research literature is largely silent about temperatures experienced *inside* the homes and workspaces of low-income communities (Wilby et al. 2021) (Figure 2.3).

Figure 2.3: Urban Heat Island Effect at the City Scale and Urban Microclimate Processes at Various Scales (Neighborhood, Building, and Human)

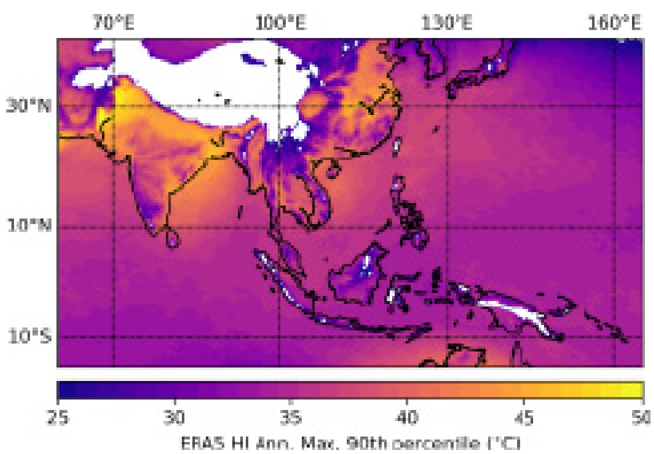


Source: Authors.

2.3 Present and Projected Patterns of Humid Heat for the Study Region

Historic data and climate model simulations over land show that humid heat has increased faster than air temperature (Li et al. 2018). Daily information from the ERA5 reanalysis was used to calculate the NWS HI for the study area at 0.25° resolution over the 1985–2014 period.[3] The Steadman (1979) formula was adapted to calculate humid heat (Appendix 2), then used to derive annual maximum heat for each grid point. The resulting map of extreme humid heat reveals the most exposed areas of the region under present climate conditions (Figure 2.4). Hot spots of dangerous heat (HI > 40.6°C) are already evident over Pakistan, the Ganges–Brahmaputra basin, northern Philippines, and Lower Mekong area.

Figure 2.4: The Near-Maximum NWS Heat Index Observed during 1985–2014



HI = heat index, NWS = National Weather Service (United States).
Note: The 1 in 10-year (90th percentile) maximum observed (ERA5) NWS HI across the study area during 1985–2014. Humid heat is potentially lethal where HI > 40.6°C; white areas denote regions with HI < 27°C (below which there is no need to signal "caution" about heat stress).
Source: Tom Matthews, with permission.

Future heat waves in the cities will depend on the projected emissions and development pathway, the amount of climate variability and change, marine temperatures, city growth, relative extent of green space, water bodies, and impervious cover. Other factors such as changes in aerosols, sea breezes, and soil moisture feedbacks may be locally significant. Climate model projections provide useful information about some of these expected global and regional changes but should be interpreted with care because of deep uncertainties, especially at the city and street scale (Box 2.2). However, climate models consistently show that without significant cuts in emissions, most of the region could be experiencing lethal heat at least once per decade by the end of the 21st century (Figure 2.5).

Anthropogenic climate change has already increased the likelihood of extreme heat across Asia (Imada et al. 2018). Climate model experiments suggest that future heat waves could become more intense, frequent, and persistent in South Asia and Southeast Asia, especially during the pre-monsoon period (e.g., Chen et al. 2020; Li, Yuan, and Kopp 2020; Khan et al. 2020; Rohini, Rajeevan, and Mukhopadhay 2019; Zhu et al. 2020). Future heat wave properties will depend on future emissions and the amount of global warming (Perkins-Kirkpatrick and Gibson 2017;

[3] ERA5 refers to the fifth generation atmospheric reanalysis of the global climate covering the period January 1950 to present, produced by the European Centre for Medium-Range Weather Forecasts.

Box 2.2: Interpreting Climate Model Projections of Heat Waves at City Scales

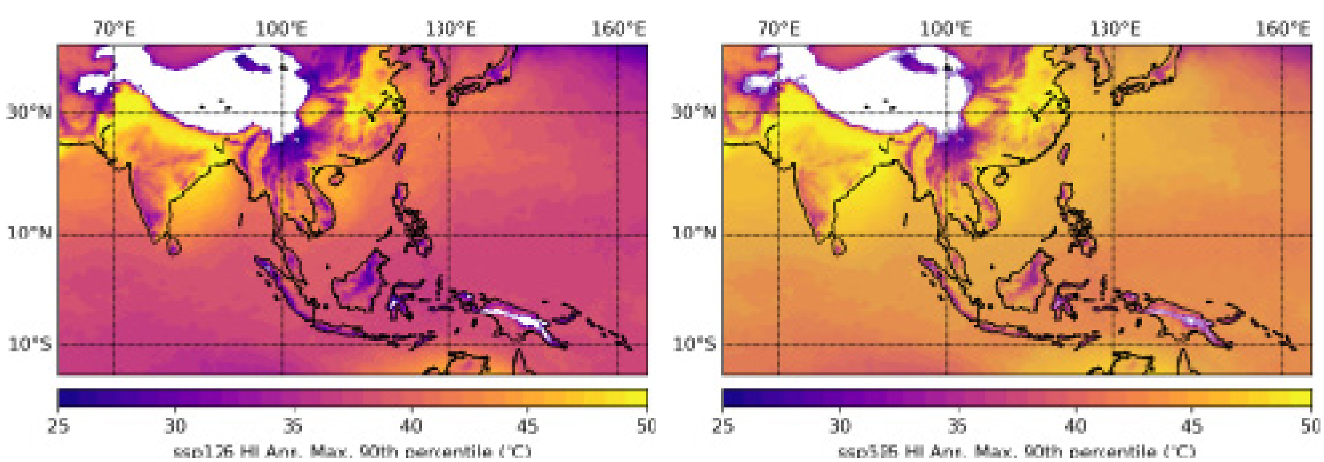
Even advanced climate models likely underrate the true severity of future urban warming encountered at community, household, and human scales. This is because models typically

1. simulate air temperature and humidity for very large idealized land cover types rather than at street scales;
2. provide climate scenarios for natural or agricultural landscapes—only a few models explicitly represent urban surfaces and, even then, in highly idealized ways (e.g., Zhao et al. 2021);
3. ignore local climate changes due to future urbanization and adaptation measures, such as incorporating more green space or reflective roofs (e.g., Oleson, Bonan, and Feddema 2010);
4. correct biases using data from grass covered areas of meteorological compounds (Switanek et al. 2017)—whereas asphalt pavements and highly dense urban areas are already warmer and behave differently to rural weather stations;
5. represent climate conditions outdoors rather than inside homes, workplaces, and public spaces (Wilby et al. 2021); and
6. neglect potentially harmful synergistic effects such as joint occurrence of heat waves with air pollution episodes (Xu et al. 2020).

With these caveats in mind, climate model projections are best viewed as indicators of the future likelihood of exposure to extreme temperatures, persistent heat waves, and attendant impacts at regional scales. Other information is needed to evaluate human vulnerability to heat, such as preexisting illness, population and building density, education, and building materials and house design (Zuhra, Tabinda, and Yasar 2019), as well as the adaptation strategies used by residents (Bakhsh, Rauf, and Zulfiqar 2018). There is evidence that the risk of heat-related mortality has been declining as temperature gradually increases in some high-income countries due to adaptations. Unfortunately, no such trend studies are available for low-income countries or low-income communities, where technology-based heat-adaptation measures (such as air-conditioning) may not be largely available, and/or rapid urbanization may be placing more people at risk (Kinney 2018: 8).

Source: Authors.

Figure 2.5: The Near-Maximum NWS Heat Index Projected for 2071–2100 under Two Emissions Scenarios



HI = heat index, NWS = National Weather Service (United States), SSP = Shared Socioeconomic Pathway.
Notes: The 1 in 10-year maximum future (CMIP6) NWS HI across the study area by 2071–2100 under SSP1 RCP2.6 (left panel) compared with SSP5 RCP8.5 (right panel). The SSPs shown are for sustainable growth and inclusive development with low emissions (ssp126, left panel) versus fossil-fueled development, global markets, and technological development with high emissions (ssp585, right panel).
Source: Tom Matthews, with permission.

Zhang, Held, and Fueglistaler 2021) as well as on the future (uncertain) behavior and interactions between important heat wave drivers such sea surface temperatures in the Pacific Ocean and Indian Ocean (Cai et al. 2015; Le and Bae 2019; McKenna et al. 2020; Yeh et al. 2018; Zheng et al. 2013).

City-level heat indices help to identify most at-risk urban areas under different emissions pathways for selected decades. Humid heat indices were also derived for the 183 secondary cities (Appendix 1) using the occupational heat stress index WBGT (Kjellstrom et al. 2018) for consistency with later analysis of annual work hours lost due to heat (Chapter 3). This could help to focus climate finance and adaptation actions on those cities where the need is most urgent, accepting that there are spatial variations in vulnerability to heat *within* cities (Park et al. 2021).

The WBGT index shows that light labor capacity is already being impacted in many cities across South Asia and Southeast Asia. Even by 1985, the WBGT exceeded 30°C (the threshold for light labor) in 54 of the metropolitan areas covered. Under SSP 370, 90 cities could pass this threshold by 2025 and 146 cities by 2055. Table 2.1 shows the 10 most at-risk cities based on the projected mean daily maximum WBGT: all in Pakistan, India, and Thailand. Most notably, heat in Larkana, Surkur, and Multan in Pakistan by 2055 could be so severe during the

Table 2.1: The 10 Hottest Secondary Cities in the Region in 1985, and by 2025, 2055, and 2085

Rank	1985 (SSP 126)		2025 (SSP 126)		2055 (SSP 370)		2085 (SSP 370)	
	City	°C	City	°C	City	°C	City	°C
1	Larkana, PAK	32.5	Larkana, PAK	33.7	Larkana, PAK	34.3	Larkana, PAK	35.7
2	Sukkur, PAK	32.3	Sukkur, PAK	33.5	Sukkur, PAK	34.1	Multan, PAK	35.5
3	Nellore, IND	31.6	Multan, PAK	33.1	Multan, PAK	33.9	Sukkur, PAK	35.4
4	Ludhiana, IND	31.4	Nellore, IND	32.5	Nellore, IND	33.7	Nellore, IND	35.0
5	Kakinada, IND	31.4	Sargodha, PAK	32.3	Peshawar, PAK	33.2	Peshawar, PAK	34.9
6	Multan, PAK	31.3	Ludhiana, IND	32.2	Kakinada, IND	33.2	Sargodha, PAK	34.8
7	Hyderabad, PAK	31.3	Kakinada, IND	32.2	Pathum Thani, THA	33.1	Ludhiana, IND	34.5
8	Kannur, IND	31.0	Bahawalpur, PAK	32.1	Sargodha, PAK	33.0	Pathum Thani, THA	34.3
9	Patiala, IND	31.0	Peshawar, PAK	32.1	Ludhiana, IND	32.9	Kakinada, IND	34.3
10	Bahawalpur, PAK	30.9	Faisalabad, PAK	31.8	Chon Buri, THA	32.7	Faisalabad, PAK	34.2

GFDL = Geophysical Fluid Dynamics Laboratory, IND = India, PAK = Pakistan, SSP = Shared Socioeconomic Pathway, THA = Thailand, WBGT = WetBulb Globe Temperature.
Note: Mean daily maximum WBGT (°C) in the locally hottest month for the 10 hottest secondary cities in 1985, 2025, 2055, and 2085. The SSP is given in each case. The scenarios are based on output from the closest 0.25° grid cell from three climate models (GFDL-ESM4, MRI-ESM2-0, UKESM1-0-LL).
Data Source: Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b), Potsdam Institute, Germany.

hottest month that less than 25% light labor is possible.

The cities with highest WBGT in each country are also given (Table 2.2). This information could inform decisions when formulating policies and prioritizing adaptation investments. By 2055, all countries in the study region are expected to have at least one city where WBGT exceeds 30°C. Above this threshold, heat-related hospital admissions and emergency visits can rise exponentially (Cheng, Lung, and Hwang 2019).

Projected heat indices are uncertain because they do not reflect future city growth, associated intensification of the UHI effect, and their interplay with climate change, or any adaptation measures. The projections are also based on a small number of climate models. Moreover, changes in the amount of urban green space, irrigated surfaces, or area of water bodies could affect humid heat in uncertain ways, depending on the regional climate context (Krakauer, Cook, and Puma 2020; Fan et al. 2017). However, even modest increases in the UHI effect can have marked impacts on heat stress indices (e.g., Sharma et al. 2019).

Future changes in UHI intensity are partly dependent on the size of the future urban population. Using United Nations population projections for the 183 secondary cities, the mean daytime UHI intensity is estimated at 3.2°C (range 2.8°C–5.5°C) by 2030 (Figure 2.6a). At the same time, the mean nighttime UHI intensity could be 1.1°C (range 0.8°C–2.5°C) (Figure 2.6b). For rapidly growing cities such as Ha Noi in Viet Nam, a modelled intensification of the daytime UHI effect by +1.7°C between 2000 and 2030 is more than the projected rate of regional climate warming.

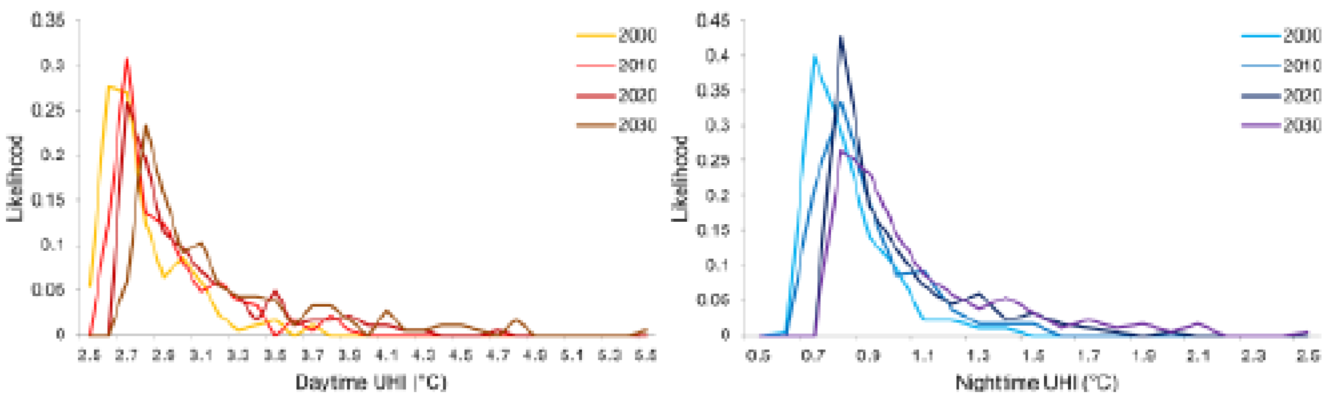
Table 2.2: The Hottest Secondary City in Each Country Studied in 1985, and by 2025, 2055, and 2085 (°C)

Country	City	SSP 126	SSP 126	SSP 370	SSP370
		1985	2025	2055	2085
Bangladesh	Rajshahi	29.7	30.3	31.2	32.5
India	Nellore	31.6	32.5	33.7	35.0
Indonesia	Samarinda	29.4	30.3	31.4	32.6
Lao PDR	Vientiane	29.5	30.3	31.8	32.9
Pakistan	Larkana	32.5	33.7	34.3	35.7
Philippines[a]	Dasmariñas	29.2	30.0	31.0	32.1
Thailand	Pathum Thani	30.8	31.6	33.1	34.3
Viet Nam	Ha Noi	30.1	31.4	32.4	33.9

Lao PDR = Lao People's Democratic Republic, SSP=shared socioeconomic pathway
[a] Bacoor, Dasmariñas, and Imus lie in the same climate model cell, so the largest by population in 2025 was selected.
Data Source: Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b), Potsdam Institute, Germany.

Figure 2.6: Changes in the Distributions of UHI Intensity for 183 Secondary Cities Due to Population Growth by 2000, 2010, 2020, and 2030

a. Day **b. Night**



UHI = urban heat island.
Note: Secondary cities with population of 0.5 million to 5 million. These distributions are based on the empirical equation given by Hung et al. (2006).
Source: Authors.

Chapter 3

Extreme Heat, the Urban Poor, and the Local Economy

This chapter describes the factors that contribute to the impacts faced by urban poor populations during extreme heat. These interrelated factors include (i) limited access to health-care services, (ii) low-quality housing, (iii) urban design and land use planning that do not factor extreme heat considerations, (iv) limited choice for sustainable livelihoods, and (v) overdependence on gray infrastructure for basic services. Other socioeconomic factors, such as gendered vulnerabilities and wider social norms, also contribute. The impacts are felt in the health, livelihoods, and well-being of the urban poor households, as well as in the wider economy of the urban area.

3.1 Health

Climate variability and change pose significant threats to public and occupational health, especially for the urban poor. Recognized direct effects of weather and climate on physical health include heat stress; respiratory conditions linked to heat combined with air pollution and aeroallergens; injury from floods, landslides, and windstorms; plus illnesses from vector-borne and infectious disease, as well as water- and food-related pathogens (Kovats and Akhtar 2008; Kovats and Hajat 2008; Kim, Kabir, and Ara Jahan 2014). There is also growing evidence of "unseen" impacts of extreme weather events on mental health such as post-traumatic stress disorder, anxiety, depression, complicated grief, survivor guilt, recovery fatigue, substance abuse, and even suicide (Hayes et al. 2018; Trang et al. 2016). Added to these are the indirect health impacts of malnutrition due to reduced labor capacities or affected livelihoods, or the consequences of loss of homes, forced migration, increased incidence of conflict, gender-based violence, civil unrest, crime, and unintentional injuries

(Plante, Allen, and Anderson 2017; Sanz-Barbero et al. 2018; Evans 2019). Hence, some claim that the international response to climate change could be "the greatest global health opportunity of the 21st century" (Watts et al. 2015). Moreover, the coronavirus disease (COVID-19) pandemic has shown how the urban poor have been disproportionately impacted by economic shutdowns and social restrictions forcing families to remain indoors, which are typically small spaces lacking ventilation.

The impacts of heat waves and related threats to public health and well-being are recognized—and increasing in some cases. Floods and storms have historically been the leading weather-related causes of loss of life and economic damage in Asia. However, heat waves are an emerging public and occupational health problem in the region. The physiological responses to excessive heat exposure are well-known—ranging from heat rash, edema, dizziness, dehydration, and cramps to heat exhaustion, heatstroke, and death (WMO and WHO 2015). Existing pulmonary, cardiac, kidney, and psychiatric illnesses also may be aggravated by heat. Although there is evidence of decreasing heat vulnerability linked to the advent of heat warning systems, raised awareness, and improved quality of life, this trend broadly reflects experiences in North America and Europe rather than in low- and middle-income countries in other regions (Sheridan and Allan 2018). During 1970–2012, extreme temperatures in Asia accounted for 5% of all weather-related disasters, 2% of deaths, and 3% of economic damage (WMO 2014). Nonetheless, heat-related mortality and morbidity are expected to rise in Asia over the coming decades, driven by a combination of climate change, rapid population and urban growth, and demographic change (Saeed, Schleussner, and Ashfaq 2021). One assessment determined that excess mortality attributed to heat could reach 16.7% in Southeast Asia by the end of the century (Gasparrini et al. 2017).

Heat waves impact critical infrastructure, health facilities, and hospital staff. In addition to their impacts on human health and well-being, heat waves may also contribute to water and energy outages, as well as to overheating of public facilities such as transport systems, hospitals, and clinics (Codjoe et al. 2020). Carmichael et al. (2013:1) note that "patients, visitors, equipment, medication and information technology systems have all been affected or compromised during episodes of extreme heat. High indoor temperatures are also of concern for the comfort, efficiency, and occupational health of staff." Factors such as building design, ward layout, occupancy levels, and ventilation can all affect internal temperatures experienced by patients and health professionals (Lomas and Giridharan 2012). Passive cooling systems may be insufficient to maintain thermal comfort whereas air-conditioning is vulnerable to failure at high operating temperatures and/or when the electricity grid is under strain or damaged by extreme weather (Matthews, Wilby, and Murphy 2019).

Vulnerability to heat hazards is socially, economically, and spatially differentiated. All sectors of society are at risk from extreme heat, but some groups are more vulnerable than others. Such inequalities arise from variations in population heat exposure, sensitivity to heat, capacity to adapt, and access to basic services. Those most at risk during and after heat waves are the urban poor; older persons (over 65 years of age); children (under 5 years); people with existing chronic health conditions, disabilities, or taking certain medications; those working outdoors or in hot and/or poorly ventilated environments; those living alone or with mental health issues; marginalized and indigenous communities; and the homeless.

With a global trend of aging population, the vulnerabilities of older persons are expected to increase. Research also highlights the particular risks faced by pregnant women and neonates (Roos et al. 2021). People living in large cities are exposed to the additional burden of UHIs, which can elevate local ambient (nocturnal) temperatures by more than 10°C. These conditions are most likely in high-density, urban communities lacking the moderating effects of open, green, or blue spaces. Even healthy individuals and those who do not fit into any of the above groups are at risk because they may overestimate their heat tolerance (Hanna et al. 2016). In addition to behavior, other non-climatic factors that shape health outcomes during heat waves include socioeconomic status (as a determinant of underlying healthiness, housing quality, education, and ability to access treatment or adapt); household size (as an indicator of crowding, or social support and caring networks); and gender (which may mark divisions of labor, clothing materials and design, and amount of time spent outdoors) (WMO and WHO 2015; Evans 2019).

3.2 Housing

Houses in lower-income settlements are often overcrowded and not adequately designed for extreme hot climates, leading to either thermal discomfort and/or reduced affordability due to high energy bills. Many lower-income households live in small spaces and low-quality dwellings that may be legal or formal but otherwise substandard. Particularly those on higher floors closer to the roof are not well-suited to hot climates in terms of material or design and can become extremely hot during the peak of summer. Most households living in these units cannot afford air-conditioning. Research suggests that indoor fan use is beneficial up to about 45°C and 10% relative humidity or about 40°C and 60% relative humidity; beyond these limits, there is increased risk of dehydration (Jay et al. 2015). Air coolers (water-based) can be somewhat effective when humidity levels are low. Thermal stress inside homes can be compounded by high humidity, which reduces evaporation and effectiveness of perspiration for cooling and lack of effective ventilation (Head et al. 2018). Even without air-conditioning, energy bills (for relatively less-expensive mechanical cooling methods such as air coolers and fans) can strain the already limited budgets of lower-income households.

Houses in many informal settlements are made of heat-trapping materials. A large proportion of the urban poor live in non-engineered, temporary, or self-built housing that does not meet mandated building or planning standards, and is often poorly located. In the context of heat waves and extreme heat, these houses are typically made of heat-trapping building materials (tin, asbestos, plastic, cardboard, plywood scraps, polyvinyl chloride or PVC tarps, etc.) that increase indoor temperatures and decrease the ability of residents to cool down (NRDC 2013). A host of other local factors increase their vulnerability to extreme heat, including the prevalence of cooking stoves inside the home, overcrowding, poor ventilation, the absence of greenery and tree shade around the houses, and running businesses in the home (Wilby et al. 2021; Martin and Mathema 2009). Many households lack reliable water and electricity supplies—

two essential items for keeping cool and hydrated during heat waves. Indoor heat can thus be persistent not just during the day but also at night. In some cases, heat avoidance behaviors, including outdoor sleeping and other nighttime activities, can lead to other problems—for example, exposure to malaria-causing mosquitoes or poor air quality (Wilby et al. 2021). Moreover, COVID-19 lockdown restrictions and social distancing have reduced the opportunity of the urban poor in dense settlements to spend time outside of their houses.

The materials and techniques used for house construction are strong determinants of indoor heat stress. A significant proportion of the formal (lower income) housing in Asia has roofs made of concrete or cinder blocks, topped with black tar for waterproofing. These dark surfaces absorb heat and transfer it inside, making the spaces unbearably hot, not only during daytime but also at night. Within informal settlements, many roofs are made of tin sheets, which transfer the heat inside quickly. With poor ventilation, the heat is trapped, making the interior space as hot as—or hotter than—outside.

Some studies have attempted to analyze indoor temperatures. For example, Jacobs et al. (2019) characterize intra-urban differences in exposure to heat in three major cities: New Delhi (India), Dhaka (Bangladesh), and Faisalabad (Pakistan). They found that for housing in informal settlements, a reasonably strong relationship between indoor and outdoor temperatures may be expected. In other words, indoor temperatures are likely to be higher in informal neighborhoods when the outdoor environment is warmer, and vice versa. During nighttime, exposure tends to be enhanced in densely built informal neighborhoods. This is an important consideration because of a significant fraction of the night people spend indoors and its possible health effects from quality of sleep (Jacobs et al. 2019). According to Mahadevia et al. (2020), more open space and green cover assists in reducing indoor temperatures; however, open space has a greater impact than tree cover. They found that the informal housing dwellers in Ahmedabad, India—particularly pavement dwellers—experience significantly higher temperatures in their homes compared to residents of formal housing, or by an average 7.6°C difference in household temperature.[4] This highlights that low-income residents of informal housing are much worse off in their thermal comfort during the peak summer.

Population groups that are the most vulnerable to heat exposure include lower-income women, the older persons, young children, people with disability, and people with underlying medical conditions. For those who spend much time at home, especially in households with large numbers of people living in small spaces, an overheated house can put them in a state of constant heat stress. In particular, lower-income women tend to spend more time inside their homes doing household chores, operating home-based businesses, or caring for children—making them disproportionately impacted by the internal environment of the house. Especially when the house is a one-room dwelling made of heat-trapping material, without ventilation, and without open space outside to cool off, the heat can become overbearing. In some cultures, women's movement outside the house may be restricted. Other vulnerable groups include outdoor workers with high exposure to heat, and marginalized groups including homeless people, migrants, refugees, women, and girls, as they may have less access to and awareness of cooling options (C40 2021).

[4] During the peak summer months, the indoor and outdoor temperatures of 860 low-income residences in three different housing typologies in 26 settlements (formal and informal) in Ahmedabad, India were measured.

Modern building materials tend to exacerbate urban temperatures. In most urban areas, traditionally used materials (clay, mud, adobe, and wood or bamboo) and vernacular climate-responsive architecture (based largely on passive cooling techniques) for residential buildings have been replaced by modern materials (concrete, steel, and glass) and rely on intensive mechanical cooling methods. Typically, urban surfaces are constituted by pavements (40%) and roofs (20%–25%) (Akbari and Kololotsa 2016; Hendel 2020). The bulk of cooling energy demands in the tropics is directly related to building materials, particularly the roofing area (Akbari, Menon, and Rosenfeld 2008; Al-Obaidi, Ismail, and Rahman 2014).

3.3 Livelihoods

Sustainable livelihoods require the ability to cope with shocks and stresses. Urban poor households rarely rely on a single income-generating activity. Instead, they typically engage in multiple activities to maximize income and minimize risk. The concept of "livelihoods" encompasses the range of capabilities, assets, and activities required to make a living (Chambers and Conway 1992). Households draw on assets, consisting of capitals, to build their livelihoods (Table 3.1). The central claim of the widely adopted Sustainable Livelihoods Framework is that a livelihood is sustainable when it can cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets. One factor exacerbating this vulnerability in urban Asia is the increased exposure to extreme weather, including very high temperatures and humid heat, which impact most livelihood assets (Table 3.1).

Exposure to extreme heat impacts the livelihoods of the urban poor. Knowledge of when and where people work, how they travel to work, and what type of work they engage in are key to understanding the impacts of rising humid heat on the urban livelihoods of the poor.

Most nonagricultural employment in Asia is informal. The extent of informal employment is 82% in South Asia and 65% in East Asia and Southeast Asia (Chen, Roever, and Skinner 2016). Exposure to extreme heat varies depending on the type of work conducted (Moench et al. 2017) and the intensity of that work. Heat is especially a threat for people who perform manual labor outdoors—such occupations may include construction work, rickshaw pulling, bicycle taxi driving, street vending, and urban agriculture labor. Another group at high risk are those who work close to heat sources, such as bakers, welders, blacksmiths, and people cooking food for sale over an open fire (Gough et al. 2019). These activities not only expose those employed to extreme heat but can also pose a fire hazard. An additional risk to livelihoods is from loss of perishable goods, such as fruit and vegetables, due to extreme heat.

Exposure to extreme heat varies significantly according to the spaces and places where the work is undertaken. For many informal settlement residents, the home is not just a place to live but also a place of work: 30% of nonagricultural workers were reported to be home-based in Nepal, 15% in India, 7% in Bangladesh, and 5% in Pakistan (Chen and Sinha 2016). As documented in the previous paragraphs on housing, homes in informal settlements typically have high exposure, high sensitivity, and low adaptive capacity to heat (Pasquini et al. 2020). Participating

Table 3.1: Household Livelihood Assets and Impacts of Extreme Heat

Capitals	Definition	Impacts of Extreme Heat on Household Livelihood Assets
Human	Labor resources available to households, both quantity and quality (e.g., education, skills, health)	Health and productivity seriously affected
Social	Social resources drawn on for livelihoods (e.g., networks, group membership, trust)	Reduced mobility limiting ability to draw on social capital
Physical	Basic infrastructure, equipment and tools required to pursue livelihoods (e.g., shelter, water, energy, transport, equipment)	Work safety issues Reduced infrastructure capacity (e.g., electricity supplies)
Financial	Financial resources used to pursue livelihoods (e.g., savings, credit, remittances, pensions)	Loss of financial capital due to reduced productivity Increased household expenditure when responding to heat
Natural	Natural resources used in pursuit of livelihoods (e.g., land, water)	Lack of or unreliable water supplies

Sources: Based on Carney (1998) and authors.

in income-generating activities within or close to the home in such settlements not only results in extreme heat exposure but contributes to increasing heat experienced by other residents due to the high population density of low-income settlements. Many from the urban poor are also involved in the informal economy, operating from open public spaces, such as streets, sidewalks, and public squares—making them highly exposed to extreme heat.

Extreme heat exposure also occurs in formally constructed workplaces. Factory employees working in unventilated conditions are particularly vulnerable (Khan, Ahmad, and Khan 2011). The colloquial term "sweatshop" reflects conditions, especially within the clothing industry, where manual workers are employed for long hours at low wages in poor conditions with associated health risks, which are exacerbated by extreme heat. In Dhaka, Bangladesh, production spaces for ready-made garments were found to be too hot. Thousands of workers, primarily women, toiling in these workspaces experience indoor temperatures higher than their body temperatures, which negatively impacts their physiological conditions, resulting in health risks (Chowdhury, Hamada, and Ahmed 2017).

Workers may be exposed to extreme heat while traveling to workplaces outside the home. While some low-income households manage to live close to their places of work, others live far away in less accessible peripheral locations to reduce housing costs (Ahmed, Lu, and Ye 2008), or perhaps due to lack of choice.[5] Rarely able to afford a car, such workers may travel long distances on foot, by bicycle, or on crowded public transport, which is often privately run and managed. Partaking in such journeys can be one of the key periods of exposure to extreme heat for urban residents, particular for the poorest population segments who use the cheapest—and least comfortable—modes of transport. Even where people work from or close to their home, they often still must move around the city. Many travel substantial

[5] To reduce costs, many government-funded housing schemes are located in far-off locations. The beneficiaries of these projects typically have low income and often have little choice in the matter.

distances to buy goods required in their businesses, such as to central marketplaces, or travel into the center of the city to sell goods they have produced at home (Esson et al. 2016). A study of Ahmedabad, Bangkok, and Lahore found that on average home-based workers spend 30% of total work-related expenses on transport, with about a quarter operating at a loss (Chen and Sinha 2016).

Exposure to extreme heat varies depending on the degree to which individuals can influence the number of hours worked and the timing of when they work. Formal employees, such as factory and construction workers, are more likely to be constrained by having to work fixed hours, increasing the risk of experiencing heat-related illness. Self-employed and informally employed workers, however, have greater agency, resulting in some being able to avoid working during the hottest times of the day. Some workers do not have this option due to poverty and the need to generate an income on a daily basis.

The ability to effectively engage in urban livelihoods is greatly influenced by being able to sleep at night. As discussed in the housing section, hot homes can negatively impact sleep patterns and people's ability to rest. Urban residents who have hot homes report disrupted sleep, or an inability to sleep, which impacts their efficiency and concentration, and hence safety while at work (Gough et al. 2019).

The economic implications of high and rising temperatures can be severe for urban poor households. Heat-related losses to incomes can increase food insecurity (Patel 2018). Additional household expenditure in response to heat recorded in Rawalpindi, Faisalabad, and Multan (Pakistan) included cost of treating heat-related illnesses; cost of treating other diseases and conditions worsened by heat; purchasing ice and clothing to protect against heat; increased electricity costs; and investments to reduce heat in homes, such as installing double roofs, painting rooftops white, and increasing ventilation (Moench et al. 2017). Increased domestic conflict has also been related to high temperature events (Deng et al. 2020).

Other factors increase socioeconomic vulnerability of urban livelihoods to extreme heat. Livelihood activities are not neutral, but are influenced by processes of inclusion and exclusion shaped by class, ethnicity, gender, age, and disability (de Haan and Zoomers 2005). Lower income and higher inequality contribute to populations being more exposed and more susceptible to heat, as well as having lower adaptive capacity. Household income inequality in urban areas of the People's Republic of China, for example, has been shown to aggravate high-temperature exposure inequality (Deng et al. 2020). Daily wage earners in particular face high risks as they have no option but to work outdoors regardless of the temperature.

Ethnicity and social norms can influence vulnerability to extreme heat, since some occupations are primarily conducted by certain ethnic groups. In Makassar on Sulawesi, Eastern Indonesia, for example, there is a high degree of ethnic specialization regarding the production of "traditional" goods in small-scale enterprises (Turner 2007). Certain occupations are closed to newcomers, with recent migrants forced to take the most precarious employment, such as working as laborers producing drinks, metal window frames, and car parts. In addition, sociocultural norms can increase vulnerability of certain population. For example, prescribed clothing for workers and/or women and gender-assigned roles can increase vulnerability.

Box 3.1: Gendered Vulnerability to Extreme Heat

Gender dynamics and vulnerability to extreme heat are highly context specific. Khulna, the third-largest city in Bangladesh, is experiencing rising temperatures and humidity. A study of informal settlements in Khulna highlights the gendered vulnerabilities of exposure to extreme heat over long periods of time. In accordance with the patriarchal social structure, men are expected to undertake productive roles, while women are principally responsible for reproductive roles. Female household members, however, are increasingly also engaged in income-generating activities. This might include working as temporary labor in nearby fish-processing factories, in adjacent neighborhoods within walking distance, or as household help. Alternatively, women may operate home-based enterprises, such as cooking food for sale, tailoring, running small shops, or working as subcontractors. As mentioned in the housing section, most low-income households occupy one-room dwelling units, often without windows, within which everyday productive and reproductive activities are performed. Women and children confined to these overcrowded spaces, constructed of heat-absorbing and emitting materials with inadequate ventilation, are exposed to the risks of high temperatures on a daily basis.

Women may also conduct economic activities in open and semi-open spaces in or near their homes, such as verandas, corridors, courtyards, streets, and roadsides, but finding or creating this type of working space in the densest settlements is difficult. Even where it is feasible, few of these spaces offer women any protection from direct sunlight (or rain) while they are working. Men and boys are primarily engaged in labor-intensive economic activities, such as loading and unloading goods from ships, trucks, or trains, and carrying items to and from building materials depots, timber mills, and factories. When and where these men work is entirely at the discretion of their employers, and, as obtaining employment is highly competitive, they often have no option but to work in adverse weather conditions. Other work opportunities include pulling carts with goods or driving rickshaws, which also increase men's exposure to extreme heat. Male household members have much greater access to open spaces by the river and in the semi-open spaces of tea stalls, however, which provide some relief from the heat after sunset.

Source: Jabeen (2019).

A larger proportion of female workers, compared with male, are informally employed (Chen, Roever, and Skinner 2016). The gendered nature of work affects heat exposure and overall individual and household well-being (Masuda et al. 2019). In northern Pakistan, while men go to work, women have limited mobility remaining in poorly ventilated homes (Moench et al. 2017). Consequently, women ranked heat as a greater problem than men, who can access shade and ventilation outdoors. The proportion of female nonagricultural workers who are home based is 48% in Nepal, 40% in Pakistan, 32% in India, and 12% in Bangladesh (Chen and Sinha 2016). For details of gendered vulnerability to extreme heat in Khulna, Bangladesh, see Box 3.1.

Age and disability affect livelihood opportunities and activities. Children and older people from poor households typically form part of the informal urban labor force out of necessity (Lucas and Porter 2016), as do persons with disability. They often work from the home and hence are highly vulnerable to the adverse effects of extreme indoor heat.

Livelihood vulnerability to extreme heat is exacerbated by poor infrastructure. In particular, access to drinking water—that is reliable both in terms of quality and flow—is crucial for all household members, especially those engaging in physical income-generating activities. Interruptions to the electricity supply, which is often already irregular, are increased during periods of extreme heat, having a detrimental impact on many livelihood activities, such as garment makers (Chen and Sinha 2016; Kayaga et al. 2021).

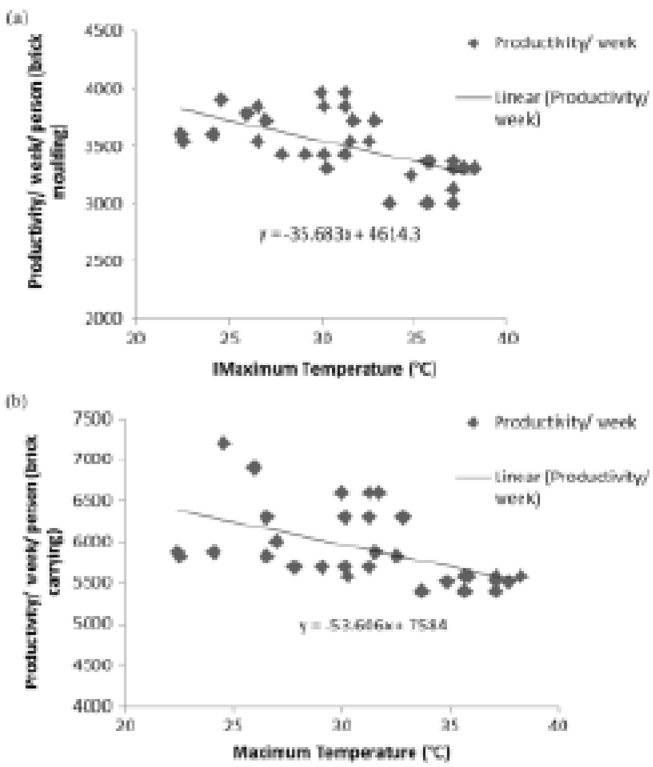
3.4 Worker Productivity and Local Economy

There is a physiological basis for heat effects on working people. When human bodies use muscles for physical work, only 20% of the energy consumed from nutritious food intake (the metabolic rate) actually goes into physical work. The rest ends up as internal heat (Parsons 2014), which keeps our bodies warm in cold working environments, but creates internal waste heat and heat stress in hot working environments. The normal core body temperature at rest is close to 37°C, and this temperature is maintained by physiological mechanisms in the body and the interaction with the external environment—basically, the air around our bodies. When the air temperature around us exceeds 37°C, energy (heat) will transfer from the environment to the body, and to this external heat flow is added the waste heat from physical work, so the body temperature rises. One physiological reaction of the body is to emit sweat, which will take energy (heat) from the skin as it evaporates. However, the effectiveness of this evaporation of sweat depends on the humidity of the air around the skin. If humidity is high, evaporation is reduced, and the cooling is less effective. This is why humid heat is more uncomfortable than dry heat. People carrying out heavy physical labor risk experiencing increased body temperature or dehydration from excessive sweating. The heart rate rises with labor and heat. These changes create not only discomfort but also clinical illness (such as heat exhaustion and heatstroke) in the heat-exposed workers, and even death from heatstroke (e.g., CDC 2008; Pradhan et al. 2019). An individual exposed to excessive heat will naturally slow down work, take more rest periods, and try to avoid the worst heat exposure (Parsons 2014). In many situations, this can reduce hourly work output and labor productivity (Appendix 3).

Excessive heat exposure in workplaces reduces hourly and daily productivity and can have strongly negative effects on the economic performance of individuals, enterprises, communities, and nations (Kjellstrom, Holmer, and Lemke 2009; Kjellstrom et al. 2009; Smith et al. 2014). Due to the interlinkages between climate change, heat exposure, health and physiology impacts, and economic output, there is a need to evaluate projections of climate change in Asian cities and the likely heat exposure impacts on working people, along with different ways to protect them. Risks of occupational health problems, lost production output, or reduced product quality (due to increased error frequency during hot hours) are key reasons for more attention to cooling and worktime management. These risks can occur at all stages of an investment: during building construction and building material provision, at the start-up of new industrial activities or updating of existing ones, or during the process of marketing of products due to potential criticism of lack of worker protection against heat. The latter concern has arisen, for instance, from poor occupational health practices in garment industries in Southeast Asia (ILO 2019) and from increased mortality of construction workers in the hot parts of West Asia (e.g., Pradhan et al. 2019).

Reduced productivity is a key impact of extreme heat. A quantitative example of the reduced productivity in construction materials comes from India (Sett and Sahu 2014). Work intensity was assessed as heavy (about 400 watts [W] metabolic rate). Fitted regression lines for two indicators of productivity (Figure 3.1) show a decrease of approximately 20% output per 10°C increase in maximum temperature (or a reduction of

Figure 3.1: Productivity of Bricks in Relation to Mean Daily Maximum Temperatures in West Bengal, India



Source: Sett and Sahu (2014).

2% per degree Celsius). The indicators were “brick molding” (the process of preparing the clay as a brick) and “brick carrying” (the speed of moving bricks). Similarly, a study of moderate work intensity (300 W metabolic rate) in the construction trade of the People’s Republic of China (Li et al. 2016), quantified activities of “rebar workers” on construction sites as “direct work,” “indirect work,” and “idle time.” Excessive heat exposure reduced the direct work time by 0.57% per degree Celsius per unit increase of heat stress as measured by the WBGT (Appendix 3).

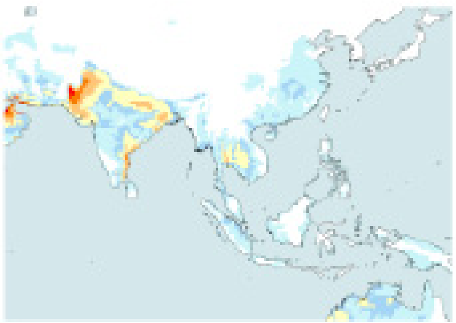
Climate model information can be analyzed for present and future trends in heat exposure and effects. Here, climate model data for present and projected conditions were used to estimate WBGT heat stress levels outdoors in-shade and in-sun. Global grid cell data over land (67,420 grid cells; cell size = 0.5 x 0.5 degrees) from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) database at the Potsdam Institute, Germany were used. These estimates include temperature and humidity, making it possible to calculate WBGT with the assumption that air movement over skin is 1 meter per second and that heat radiation is nil or typical levels from sun radiation. The report compares RCP2.6 and RCP6.0 using the midpoint of the Geophysical Fluid Dynamics Laboratory (GFDL) and Hadley Centre Global Environment Model (HadGEM) climate models. A risk function (in this case the Kjellstrom curve in Appendix 3) is needed to calculate the heat-related work capacity loss for each grid cell.

Already hot tropical areas in Asia are expected to be worst affected in terms of productivity loss due to heat. Analysis was undertaken for this report to compare the current heat impacts on work productivity in Asia with those expected by the end of the 21st century depending on the maximum mitigation possible (RCP2.6) and the one achieved by current plans for all countries (RCP6.0). As shown in Figure 3.2, hot tropical areas in Asia are expected to be worst affected.

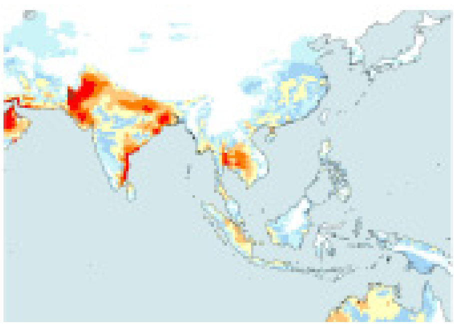
Potential losses of current and future work–hour outputs can be estimated for the study countries. The trends of heat impacts on hourly work output were calculated for eight countries (Bangladesh, India, Indonesia, the Lao PDR, Pakistan, the Philippines, Thailand, and Viet Nam). Figure 3.3 shows the projected heat impacts on annual work–hour potential outputs using ISIMIP data for a modified global greenhouse

Figure 3.2: Lost Productive Hours for a Labor Intensity of 300 W Due to Heat (%)

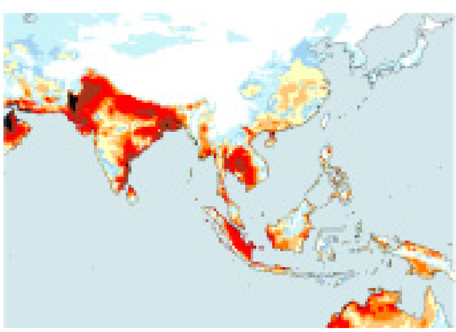
Work hours lost for 300 W work, in-shade, 1981–2010, CRU

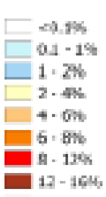


Work hours lost for 300 W work, in-shade, 2071–2099, GFDL-HadGEM2 average, RCP2.6



Work hours lost for 300 W work, in-shade, 2071–2099, GFDL-HadGEM2 average, RCP6.0





CRU = Climate Research Unit, GFDL = Geophysical Fluid Dynamics Laboratory, HadGEM2 = Hadley Centre Global Environment Model version 2, RCP = Representative Concentration Pathway, W= watts.
Note: Results are shown for the baseline climate (1981–2010) and by 2071–2099 depending on two emissions pathways (RCP2.6, RCP6.0) and output from two climate models (GFDL, HadGEM2).
Source: Kjellstrom et al. (2018).

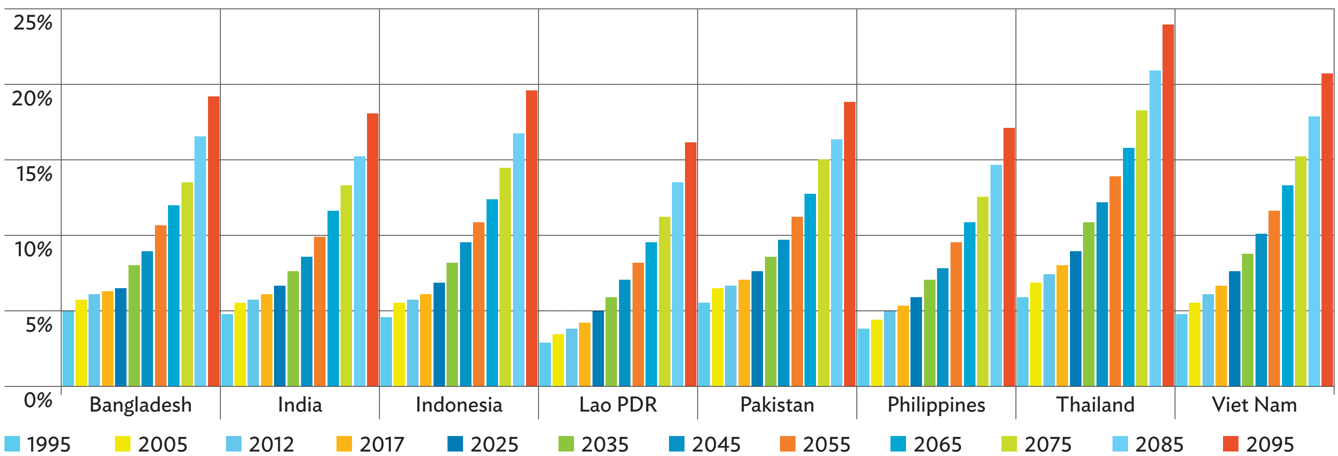
gas emission scenario labeled SSP370 and the mean of two climate models (UKesm and GFDL). Trends of percent of lost productive work hours are very similar for the selected countries. Impacts up to the 2050s are only significantly affected by local adaptation measures, whereas trends beyond that depend very much on the scale of mitigation efforts.

Labor capacity loss for India. The impacts at different work intensity levels (200 W, 300 W, and 400 W) were analyzed and whether the most intensive work is carried out in the sun (Figure 3.4). Under projected changes of heat (WBGT) for India, there is a doubling of labor capacity loss in each work category. Heavy labor in the sun during the middle of the day could be very restricted, and a third of the annual work hours in such jobs may be lost by the end of the century.

City-level analysis of heat trends are also daunting. Heat trends were studied for specific cities under different climate mitigation scenarios (SSP126 is maximum mitigation and SSP370 current national plans). The database for 183 secondary cities was analyzed. For each city, the grid cell containing the center of the city was used for the climate trend estimates. Most of the city populations were contained inside the chosen cell. Figure 3.5 illustrates estimates for Nellore, India. Here, the projected WBGT in the chosen months (January, April, July, October) increases by about 3°C for SSP370 (Figure 3.5a) and by 1°C for SSP126 (Figure 3.5b) between 1995 and 2095. The impacts of heat on work capacity over a year are shown for three work intensities in-shade or indoors without air cooling (Figure 3.5c) and for heavy labor (400 W) in-shade and in-sun (Figure 3.5d). The usual heat situation now reduces work capacity in the shade by 7%–20% depending on labor intensity; working in the sun adds 10% to this loss for heavy labor jobs. The important role of shade to protect workers' health and productivity is clear.

Figure 3.3: Estimated Losses of Current and Future Work–Hour Outputs Based on In-Shade Work at 300 W Metabolic Rate

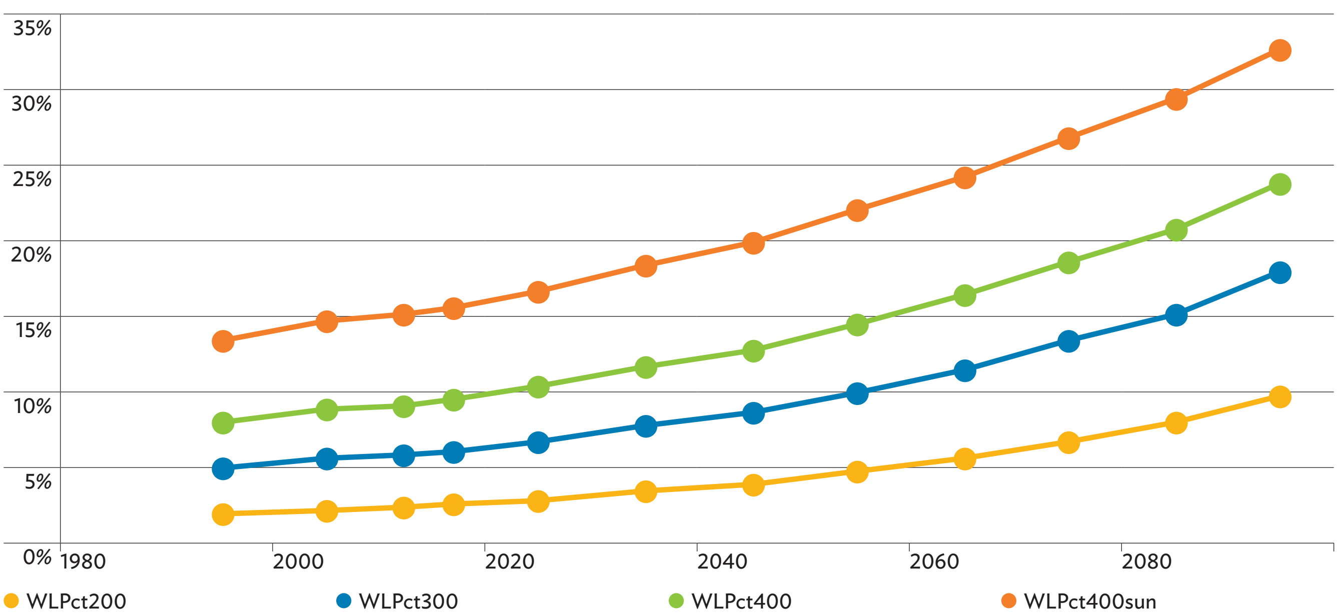
Percent of annual work output lost due to heat; 300W work intensity; RCP 6.0



Lao PDR = Lao People's Democratic Republic, RCP = Representative Concentration Pathway, W = watts.
Note: The country average is based on population distribution and estimated heat levels in each grid cell.
Source: Authors.

Figure 3.4: Projected Annual Work Hours Lost Due to Workplace Heat In-Shade for Three Work Intensity Levels and for Most Intense Work in Sun (%)

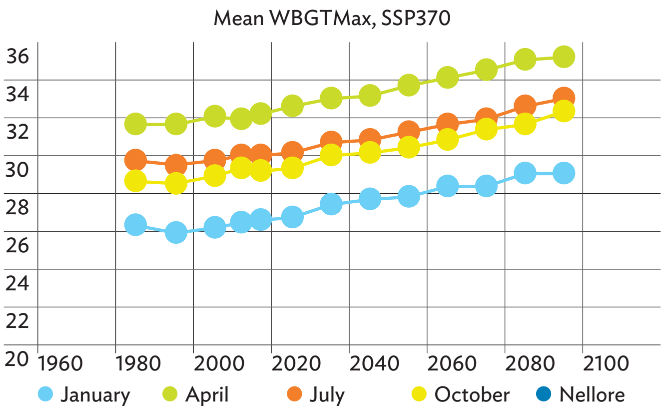
India: 300 W; RCP 6.0; mean of GFDL and HadGEM



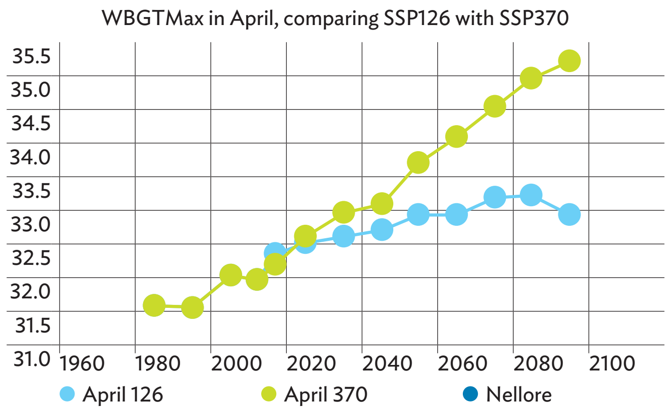
GFDL = Geophysical Fluid Dynamics Laboratory, HadGEM = Hadley Centre Global Environment Model, RCP = Representative Concentration Pathway, W= watt, WLPct = percent of work hours lost.
Source: Authors.

Figure 3.5: Projected WBGT and Work Hours Lost for Nellore, India, One of the Most Heat Affected Cities in the Region

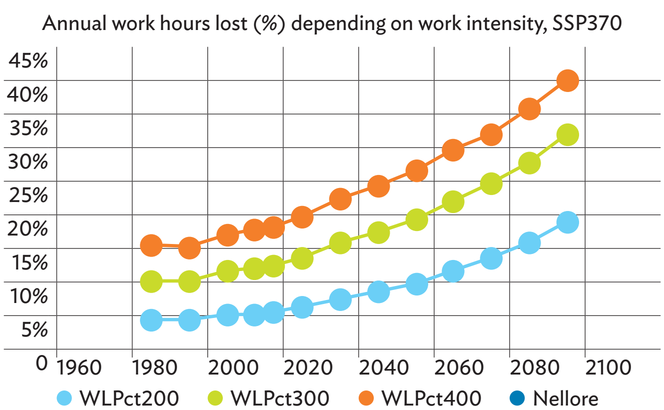
a. Four monthly means of daily maximum heat levels



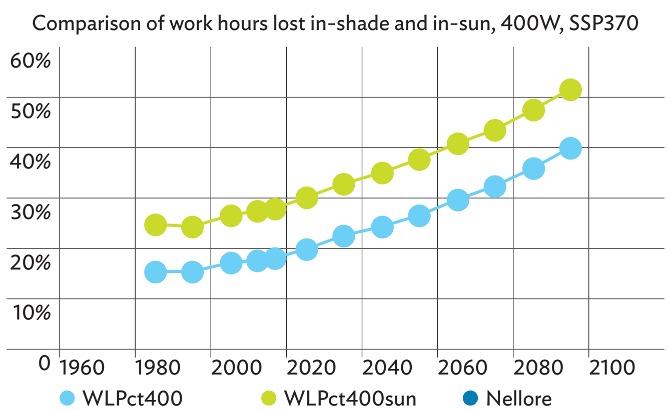
b. Difference of April levels of heat between SSP126 (most protective pathway) and SSP370 (similar to current national policies)



c. Estimated annual work hours lost due to heat (in shade) based on SSP370 for three different work intensities



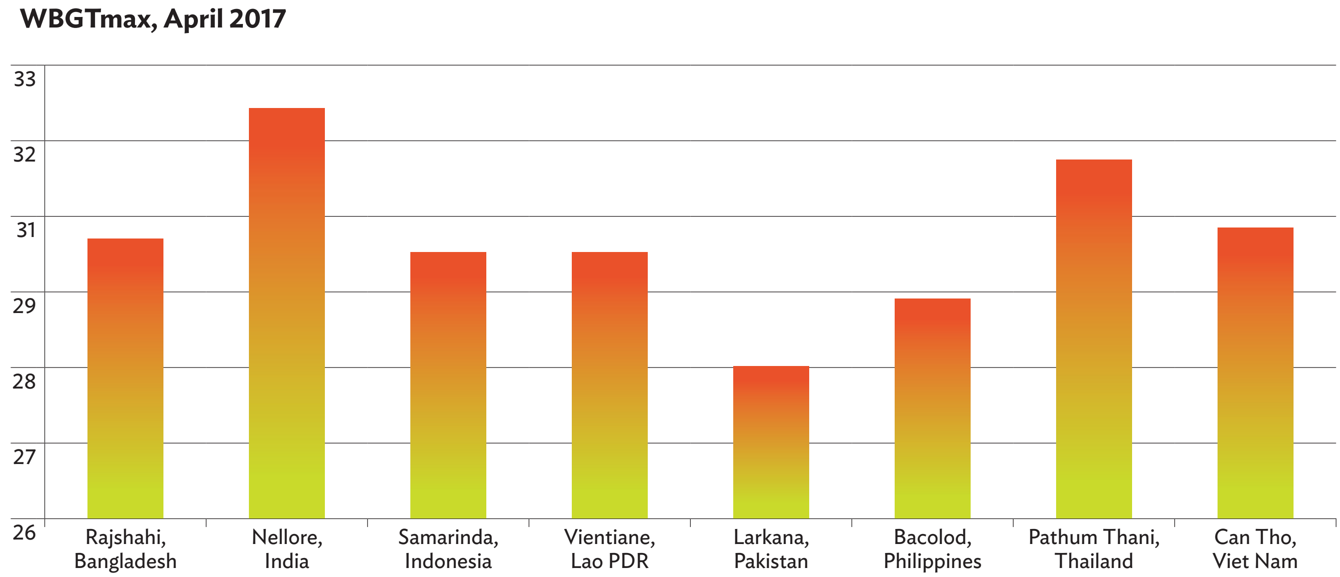
d. Difference of work hours lost in shade and in sun for heavy labor work (400W)



SSP = Shared Socioeconomic Pathway, W= watt, WBGT = WetBulb Globe Temperature, WLPct = percent of work hours lost.
Source: Authors.

The amount of lost labor can be calculated for the hottest cities in the study countries. Mean WBGTmax values (afternoon heat) for April 2017 in the hottest cities in each of the study countries are shown in Figure 3.6. The cities are Rajshahi, Bangladesh; Nellore, India; Samarinda, Indonesia; Vientiane, Lao PDR; Larkana, Pakistan; Bacolod, Philippines; Pathum Thani, Thailand; and Can Tho, Viet Nam. The value of WBGT varies between 28°C and 32°C. This may seem modest, but the risk function applied to such WBGT levels (Kjellstrom et al., 2018) in Figure 3.6 indicates that the hourly work capacity loss increases from approximately 10% to 50% in this WBGT range. All eight cities are

Figure 3.6: Mean April 2017 Heat Levels in the Hottest Cities of the Eight Study Countries (°C)



WBGT = WetBulb Globe Temperature.
Source: Authors.

experiencing heat stress challenges in 2017, and these are likely to rise substantially in the future.

The effects of heat on human physiology that lead to health and productivity risks occur in the whole community. People at major risk will include rickshaw pullers, bicycle delivery people, car mechanics, slum workshop laborer, street vendors, and all people working from home in small self-employment activities. Associated health impacts and economic losses may not be seen in national or local statistics but are a part of the overall impacts of heat.

Measures to Support the Urban Poor Adapt to Extreme Heat

Climate adaptation measures are critical for supporting the urban poor to reduce heat exposure, and hence adverse impacts on their health, livelihoods, and well-being. It is also important to reduce productivity losses due to rising heat and thereby protect local economic development. However, since the adverse impacts of extreme heat are observed at different scales, a combination of climate adaptation measures is needed across all scales. This chapter discusses potential measures that can be implemented at (i) individual or household level, (ii) neighborhood or community level, and (iii) city level (refer to the figure on page ix).

4.1 Individual and Household-Level Adaptation Measures

4.1.1 Health

Assessments are needed to identify vulnerable groups and reduce the health burdens of those at greatest risk from heat waves. Most efforts to assess and manage heat wave impacts are focused at national and building levels, with less attention on household and individual scales (Kotharkar and Ghosh 2021). Indicator-based vulnerability assessment is a powerful way of discerning those characteristics of city systems and communities that best describe variations in sensitivity and adaptive capacity of people to climate hazards such as heat waves (e.g., Tapia et al. 2017). Indicators of sensitivity include proportion of single-person households, percentage of households headed by women, population density, unemployment rate, number of days with high particulate or ozone concentrations, and cost of water. Indicators of adaptive capacity are reflected by the proportion of green and/or blue open space, household income, education level, and climate-resilient urban governance. The latter is more likely where there is decentralization and autonomy, accountability and transparency, responsiveness and flexibility, participation and inclusion of poor or marginalized groups, and experience and support (Tanner et al. 2009:3). It is acknowledged that information scarcity and/or low granularity present considerable obstacles to heat–health vulnerability mapping. However, once vulnerable groups are identified, city authorities and planners are better equipped to target resources for upgrading basic services (i.e., water, sanitation, drainage, waste collection); improving access to public health and affordable housing; strengthening land tenure to incentivize home improvements; and increasing awareness among households on possible fatal effects of heat waves. City authorities can partner with local women's group in many of these activities.

4.1.2.Housing

Housing-related adaptation measures require a combination of technical and people-led solutions. Adaptation to extreme heat in the context of housing includes a range of solutions, including cool roofs, greenery, and cool pavements. However, recognizing that the urban poor typically reside in temporary or self-built housing that does not meet mandated building standards or in "formal" but low-quality housing, adaptation measures need to be simple, practical, and cost-efficient. Moreover, while technical solutions are important, it is equally important to ensure such solutions are identified and implemented in close collaboration with local communities, especially women, to ensure the solutions are locally and culturally appropriate and can be maintained by the poor households.

A "home" is the sum total of the house and its surroundings. While some rudimentary improvements can be made to reduce heat stress in low-quality or informal housing, there is a limit to how much can be done to make the houses truly heat responsive. This is often because of the lack of access to utilities and mechanical cooling, poor ventilation due to dense layout or poor air quality, and inability to build better due to poverty or insecure tenure. Here, the surrounding environment becomes critically important. This includes communal spaces and facilities that can provide relief outside the house—both immediately outside, as well as within walking distance (within 400 meters), such as child-friendly spaces, parks with shaded trees, benches in the shade, public baths, and public drinking fountains. These communal amenities are important aspects of the house in the context of its surrounding environment (see interventions discussed in section 4.2). Such measures will most effectively be implemented at the neighborhood level—through nongovernment and community-based organizations and the lowest level of government.

Measures to reduce heat transfer into buildings include roof insulation, cool roofs, and radiant barriers. Although roof insulation is quite commonly used, cool roofs and radiant barriers are relatively new solutions. Cool or high-albedo roofs refer to the outer layer or exterior roof surface that acts as the key reflective surface. Radiant barriers are a way of increasing the thermal performance of a roof by introducing a new layer with low emissivity below the roof surface (Arumugam et al. 2015). Based on the literature, cool roofs appear to offer the most viable solution for the urban poor: they are more cost-effective than insulation, and feasible for new buildings as well as in retrofitting.

Various types of cool roof are available (Environmental and Energy Studies Institute 2012). These include

- *naturally cool roofs:* By using white vinyl or other white surface materials, a building's albedo can increase to 60%, compared to 10%–20% on a traditional asphalt roof. This reduces heat absorption and cools the building interior;

- *coated roofs:* Buildings with traditional roofs can receive a solar reflective coating that helps reflect sunlight. Once retrofitted, these roofs function in much the same way as naturally cool roofs; and

- *insulated cool roofs:* A roofing system that pairs thermally resistant insulation with a white or reflective roof coating makes an effective thermal barrier, keeping heat out on hot days and in on cold days. This enables building air-conditioning systems to work more efficiently.

White painted "cool roofs" can be an effective solution for helping urban poor households reduce the impacts of extreme heat. While many commercially available white paints reflect between 80% and 90% of sunlight, tests carried out by researchers at Purdue University on their "ultra-white" paint showed that more than 98% reflected sunlight can be achieved (Gill 2021). Roofs can be painted white or with other highly reflective paint, or covered with sheet covering, highly reflective tiles, or shingles, to reflect more sunlight and absorb less heat than a standard roof. This could cut building energy use by up to 20%. Even in cooler climates, the gains in summer appear to outweigh the small heat use increases in winter (C40 2021).

Selection of cool roof solutions should keep in mind its limitation, especially in the context of urban poor households. First, given that cool roofs tend to be varying shades of white, they make dirt and grime more visible. Second, their reflectivity—and hence, their performance and effectiveness—depends on their maintenance (removing dirt, repainting, etc.). Accumulation of dirt and soot and other natural deposits over time can lead to decreased performance in reflectivity (Roof Knowledge n.d.). Wind, rain, dust, and dirt contribute in diminishing effectiveness of cool roofs. Data from the Cool Roofs Rating Council, tiles and shingles last longer than paint, coatings, or membranes over a 3-year period (NRDC 2018). Third, cool roofs may also cause unwanted glare that can be a nuisance to neighbors or passers-by.

Cool roofs offer affordable solutions to high temperatures for lower-income urban households. According to NRDC (2018), cool roof techniques in the context of lower-income communities can be broadly divided into three categories:

- *Tiled/painted cool roofs:* These involve the application of high albedo, mosaic tiles, or shingles on top of an existing roof or to a new roof. For example, under the Ahmedabad Cool Roofs Program (Jaiswal 2019), locally available white lime paint that costs INR1.50 ($0.02) per square foot (Denchak 2019).

- *Membrane cool roofs:* These use prefabricated materials such as membranes or sheeting to cover an existing roof in order to increase the roof surface's reflectivity. For example, under the Hyderabad Cool Roofs Program, a high-density polyethylene (HDPE) cool roof membrane, Tyvek, is being used. This material retails in Hyderabad for INR13 ($0.2) per square foot (Goldstein, Kaur, and Kwatra 2017).

- *Special cool roof materials such as ModRoof:* These roofs, made of coconut husk and paper waste, have been installed in households around Gujarat and Delhi and can serve as an alternative to reinforced cement concrete (RCC) roofs. Made of packaging waste and coconut fiber held together by a natural binder and covered in a waterproofing material, the ModRoof panels are made to be strong, waterproof, fireproof, and long-lasting, which improves safety and decreases maintenance.[6]

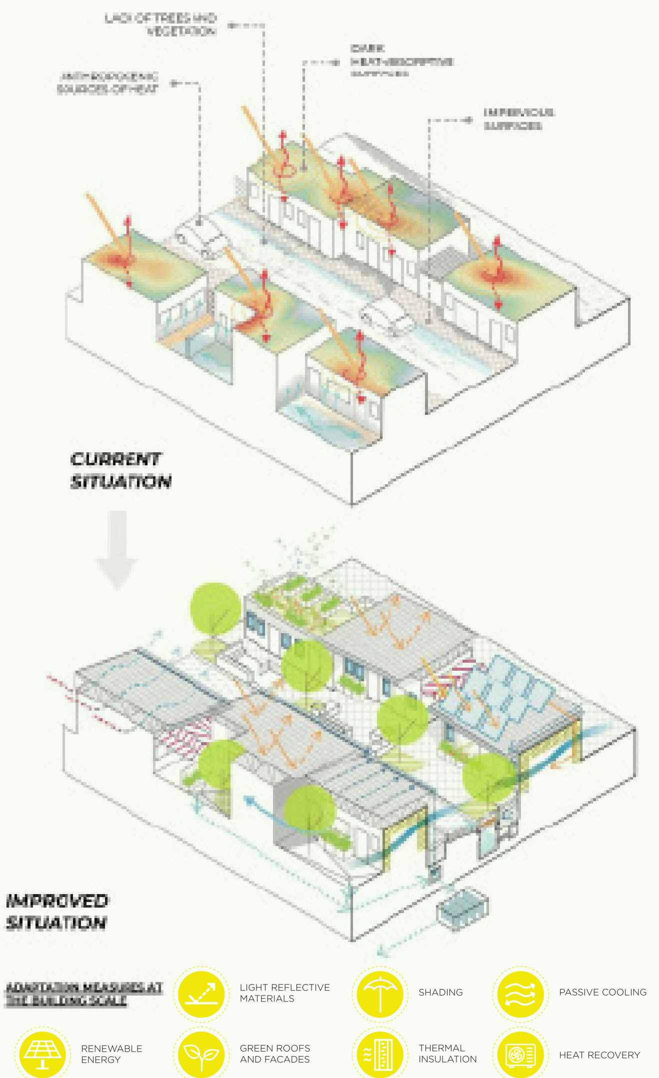
Although there is limited research, all cool roofs reduce indoor temperatures to some extent. Vellingiri et al. (2020) carried out a study to evaluate the performance of cool roof interventions: Thermocol insulation, solar reflective white paint on the outer surface of the roof, and Modroof. They compared these with the nonintervention conventional roof types: tin, asbestos or cement sheet, and concrete. The results revealed that all interventions effectively reduce the indoor temperature relative to the nonintervention roofing: (i) Modroof was found to be 4.5°C cooler than conventional roof types, but requires a complete removal of the existing roof and bigger financial investment than the other options, which is a disadvantage; (ii) the solar reflective painted tin roof performed better than a noncoated one; and (iii) lower indoor temperature in Thermocol-insulated asbestos houses than those with roofs that do not have coating or insulation. However, the difference in average indoor temperature of Thermocol-insulated houses and RCC or concrete houses is minimal, but this research was based on a relatively small sample, and it appears from the methodology that nighttime temperature was not recorded.

Green roofs, while generally not included among cool materials, can provide lower surface temperatures compared with their standard counterparts (Hendel 2020). Green roofs are categorized into two major types of intensive roofs (soil depth of 150 millimeters [mm] or deeper, which may include small trees and shrubs) and extensive roofs (soil depth of 50 mm to 75 mm, covered by a thin layer of vegetation). The key disadvantage of green roofs is that they tend to be very heavy; some up to 125 kilograms per square meter when full of water (McKellar 2016). Also, green roofs are unlikely to be cost-effective for reducing heat in urban poor communities because of significantly bigger costs and requirement for water (NRDC 2018).

Adoption of passive design approaches for buildings can help reduce impacts of extreme heat. Passive design responds to local climate and site conditions to maximize the comfort and health of building users while minimizing energy use. The key to passive design is to take advantage of the local climate (Taleb 2014). In tropical climates, passive buildings should focus on shading, natural ventilation, and appropriate building materials to exploit the cool breeze at night and sunlight during the day (Dinkel et al. 2017). According to Zhao et al. (2015), rooftop characteristics can explain over 30% of the variation in daytime rooftop surface temperatures and slightly more than 17% of the nighttime temperatures. The study found that daytime rooftop temperatures are positively correlated to southeast and south exposure of roof surfaces, and that larger roof areas are warmer because they provide more homogeneity and therefore continuity of insolation. Tree canopy coverage within 1.5 meters of the structure can reduce rooftop temperatures by 0.64°C–0.84°C. The study recommended reducing roof area and southern exposures, using rooftop materials that have high reflectivity, and planting trees to reduce daytime rooftop temperatures (Figure 4.1).

[6] See Design Management Institute (n.d.) and Modroof (n.d.) webpages.

Figure 4.1: Heat Adaptation Measures at Building Scale



Source: Authors.

Basic guidelines for passive design (northern hemisphere, hot climates) include (World Bank 2012):

- A north–south orientation wherein most of the fenestration faces north (or south for countries or parts of countries in the southern hemisphere) is a very effective passive strategy for reducing solar gains.
- Shading reduces solar gains and gives better thermal performance. Providing horizontal shades can reduce the operational energy substantially.
- Natural ventilation is very effective for preserving indoor comfort conditions when the outside temperature is lower than the inside temperature. Natural ventilation is highly effective for coastal locations because of the relatively mild ambient conditions coupled with high humidity. Openings should be designed and oriented to take advantage of the prevailing sea breeze. For hot and dry climates, nighttime ventilation is efficient for precooling the thermal mass as there is a substantial daily range for dry-bulb temperature. That said, ventilation can only help when the air quality is acceptable. If air quality is poor, natural ventilation can cause more harm than good.
- Along with natural ventilation, additional mechanical ventilation (fans) is helpful when the outside temperature is lower than inside.
- Higher thermal mass limits the indoor environment from reaching extreme conditions. However, higher thermal mass also increases nighttime indoor temperatures unless other cooling mechanisms are used.

For further reading and technical detail, refer to Singh et al. (2021).

Cooling solutions for formal sector housing may not necessarily be viable in informal settlements. Lack of secure land tenure and threats of eviction deter informal settlers from spending on improvements to their houses with permanent materials. This complexity, together with their poverty, often limits use of materials to second-hand tin sheets and asbestos (cement) sheets, which are economical. It is also important to note that housing in informal settlements is extremely heterogenous and largely antithetical to the norms of planning that define formal settlements. Accordingly, solutions to address heat need to factor in a level of practicality and flexibility that takes these realities into account.

4.1.3 Livelihoods and Workplaces

Adaptation measures for livelihoods are closely related to the various assets available to urban poor households. Table 4.1 describes some of the ways in which urban poor households may draw on their assets to adapt their livelihoods to extreme heat. It is important to recognize that adaptation strategies carry an economic cost. Poorer households are less able to adapt as they are already resource constrained and can end up falling into or being trapped in poverty. For instance, financial constraints may result in workers being unable to reduce the number of hours they work, even on hot days (Barrett et al. 2016, cited in Masuda et al. 2019). Moreover, given the limited household assets of the urban poor, most of the measures they adopt are essentially coping mechanisms. Investment by public and private entities is needed to enable more transformational mechanisms that will enable low-income urban households and their livelihoods to better cope with extreme heat.

Increasing access to shade to protect workers and output. For outdoor construction work, adaptation to current and increasing future heat exposures begins with providing shelter from direct sun radiation. Time management is another approach commonly used, which means that the hottest hours of the day become rest hours. One example is construction workers in India who rest during the entire afternoon during hot seasons (Kjellstrom and Meng 2016). Reducing work intensity and/or increasing the frequency of short breaks are additional strategies. This may mean that workers have to be close to the site for more than 12 hours each day, which creates difficulties in normal social and family life. Hourly productivity can also be affected. Another time management

Table 4.1: Household Assets to Adapt Livelihoods to Extreme Heat

Capitals	Adaptation
Human	Increasing knowledge on how to adapt to impact of extreme heat Gaining new skills to switch into more heat-resilient livelihoods
Social	Establishing better community relations with local government to influence policies regarding urban heat management
Physical	Wearing heat-reducing clothing Improving homes and workplaces to make them more resilient to extreme heat Increasing access to public cooling spaces Adequate potable water for hydration in workplaces
Financial	Generating capital to retrofit homes and workplaces Accessing enterprise loans to adapt to extreme heat and switch to livelihoods less impacted by heat
Natural	Gaining access to natural sources of water Planting trees by homes and workplaces to increase shade

Source: Authors.

approach is to schedule intensive work activities for cooler seasons and days. Clothing matters, and special cooling jackets with heat-absorbing material inside the jackets have been designed and used in particularly affected jobs. Seeking out public cooling spaces, such as parks, shaded areas, and air-conditioned public facilities, is another strategy used to cool down. The ability to adopt this behavior depends on the availability of such cooling spaces close by, or transport links and household resources for transportation if located further afield, as well as the nature of the livelihoods and hence type of work being undertaken (Pasquini et al. 2020). Retrofitting workspaces to become more heat resilient is another adaptation strategy. For example, in Ahmedabad, the installation of white mosaic "cool roofs" in hospitals has helped reduce heat stress (Singh et al. 2021).

4.2 Neighborhood-Scale Adaptation Measures

Climate-sensitive urban planning and design involves the creation of thermally comfortable, attractive, and sustainable urban environments. This is achieved by enhancing positive natural and human-made features through planning, architecture, landscape, and urban design critical for adaptation to extreme heat. Also, design and delivery of climate-resilient infrastructure and basic services are critical adaptation measures to extreme heat. While there are a range of potential urban design and infrastructure-related adaptation measures (description follows), their effectiveness often depends on adopting a combination of such measures through integrated approaches. While these measures may not always be explicitly targeted at the urban poor, if designed in close collaboration with the urban poor, they can support building resilience of poor households and communities.

4.2.1 Climate-Sensitive Urban Design and Urban Planning

Decongesting spaces by removal of redundant structures. Removing redundant and non-useful structures in the neighborhood allows opening space to facilitate air circulation and helps the wind flow. This can create cross-ventilation between buildings and blocks in the neighborhood, effectively reducing heat. Removing excess structures also helps reduce the heating of materials and the subsequent heat radiation.

Using cool pavements. Similar to cool roofs, the widespread application of cool pavements can help mitigate summer urban heat islands, thereby further reducing the overall air-conditioning load, and improving outdoor air quality and comfort (Akbari and Matthews 2012). Conventional paving materials, which typically cover around 40% of a city, can reach peak summertime temperatures of up to 65°C and heat the air above them. Cities can use lighter-colored paving options to create more reflective paved surfaces that reduce heat risk (C40 2021). To increase the albedo of a pavement, solutions are being tested in some developed countries. These range from the use of light-colored binders or aggregates to deploying a reflective coating or thin surface layer for asphalt pavement structures. The added layer can be composed of concrete, in which case the process is known as "white-topping." Light-colored aggregate chip seals can also be used. Alternative designs can use a resin-based binder and alternative aggregates. For concrete, white cement can be used, although its production is significantly more energy-intensive than regular gray cement. Alternatively, concrete doped with titanium dioxide or slag cement can also be used. The surface layer of both asphalt and concrete pavements can also be painted over with a reflective coating (Hendel 2020). However, less information is available on how readily these can be adopted or adapted in the context of poor communities—in upgrading projects, for example.

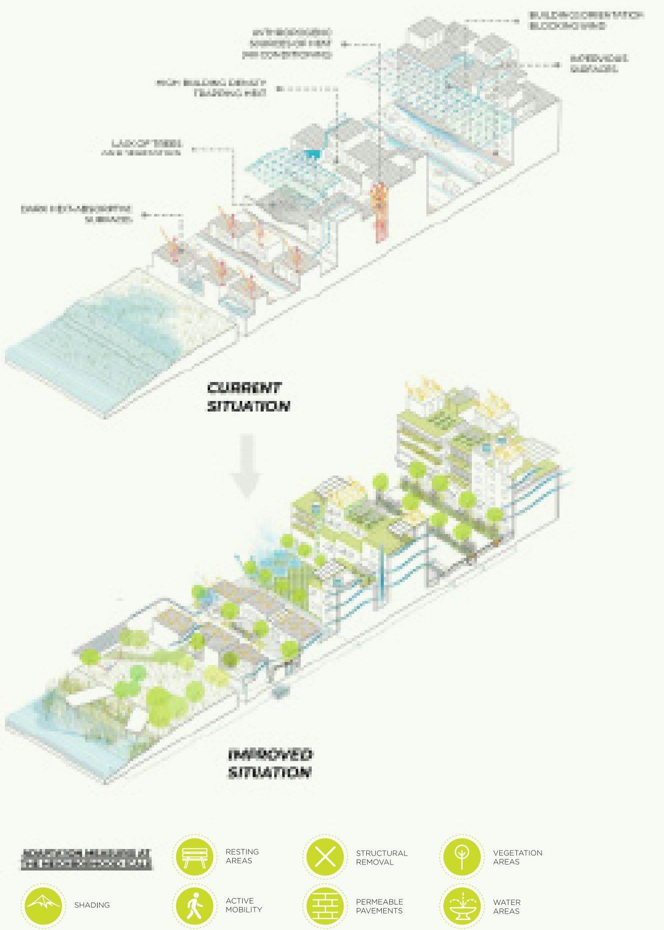
Using permeable pavements. Permeable pavements often rely on pervious materials, with or without water retention. Porous pavements are usually obtained by increasing the proportion of large aggregates while reducing the proportion of fine aggregates in the pavement mix. The binder can be cement, asphalt, or resin based. The void content is typically in the 15%–25% range. Few green pavements are available, though structures known as grid pavements can be found with grass-planted soil in the interstices or reinforced turf. Grass lawns, which could be considered to represent an extreme of the spectrum of green pavement materials, generally offer the best performance with up to 20°C reduction in surface temperature compared to standard pavements. However, this performance is entirely canceled out once the grass is dry or has died (Hendel 2020). Like cool pavements and surfaces, limited research is available on the applicability of "green" pavements in the context of poor communities.

Providing shading to urban spaces (streets, buildings, open spaces, parking areas, etc.). Shading devices are canopies located above the streets and public places. They can be made of fabric or tent-like structures. Trees and vegetation cover act as shading devices as well. They prevent the sunrays from reaching and heating up the surfaces and materials below it, and directly protect the people under it. Shade in public space enhances pedestrian thermal comfort and permits outdoor activities safe from sunrays.

Installing vegetation areas (parklets, green corridors, green plazas, etc.). Vegetation areas formed by trees or vegetation cover have many benefits. Through evapotranspiration, they cool the air in their direct environment. They reduce air pollution and sequester carbon. Trees and canopies shade people from harmful exposure to ultraviolet sunrays. Shade from vegetation also decreases the demand for air-conditioning and the consequent heat production from buildings; it also keeps sidewalks cool and walkable for people to commute to work, run errands, go to school, and so on, protecting them from outdoor heat. Planting endemic species that are adapted to the local climatic conditions helps reduce the irrigation and maintenance costs. Green areas can also be transformed into planted gardens to grow food and generate income for the local community, all while cooling the environment. Finally, vegetation adds social and aesthetic value to a place, compensating for other neglected aspects of the built environment (Figure 4.2).

Installing water features to provide evaporation. Where appropriate, water areas such as ponds, canals, and fountains help significantly decrease the ambient heat by reducing air temperature in their direct surroundings through evapotranspiration. This improves the conditions of informal workers in public spaces, allowing them to safely undertake economic activities. Water can also be used for direct refreshment on the skin. If the water is clean and potable, it can be used for drinking through water dispensers, helping prevent dehydration and increasing physical comfort. Access to drinking water is particularly important for children playing outdoors, allowing them to stay hydrated and safe.

Figure 4.2: Heat Adaptation Measures at Neighborhood Scale



Source: Authors.

Adding cool, safe, and accessible resting spaces for all users in public spaces. Resting spaces such as benches and seating areas are an important element in spaces. They ensure physical rest and comfort and contribute to prevent health issues linked to heat and exhaustion. They also ensure the accessibility of spaces for all types of users, in particular older persons, children, pregnant women, and people with disability. Since domestic spaces are often small and badly equipped against the heat, providing cool public spaces ensures that people can have at least some spaces in their direct neighborhood where they can socialize and feel comfortable.

Providing comfortable and accessible sidewalks and bicycle lanes. Active mobility is a nonmotorized transportation means based on human activity, such as walking and cycling. Relying on active mobility helps reduce greenhouse gas emissions and pollution caused by cars and fuel-based transportation. Active mobility is more accessible for people when circulation spaces (sidewalks and bicycle lanes) are combined with heat-reducing measures such as shade, vegetation, water, and resting spaces. Given that a large part of the poorer population relies on walking and cycling instead of owning private motorized vehicles, providing cool circulation spaces is important to allow them to go to work and leisure locations even in extreme heat situations.

4.2.2 Urban Infrastructure: Gray, Green, and Blue

Reducing the proportion of gray infrastructure should be an important target for urban heat mitigation. This can be achieved by converting components to green infrastructure, such as sewage treatment utilizing plant-based approaches. Introducing blue infrastructure and converting some of the gray infrastructure to serve the city as a whole would contribute to reducing the impact of heat such as stormwater collection and storage in reservoirs, and natural or artificial water bodies. Heat contribution of buildings and hard urban surfaces are to be mitigated by covering as much as possible of their surfaces in vegetation. An important challenge is that gray infrastructure is usually underground (pipes for sewerage, for example), whereas green and blue infrastructures—that would replace them—require dedicated areas of land to accommodate them. The costs of allocating urban areas for these nature-, water-, and plant-based infrastructures, however, could be offset by appreciating their impacts on urban heat reduction, provision of economic opportunities (urban agriculture), environmental improvement, carbon sequestration, and overall climate change mitigation. Table 4.2 provides examples of how conventional gray infrastructure elements can be replaced by

Table 4.2: Green and Blue Infrastructure Alternatives for Adapting to Extreme Heat

Infrastructure Categories/Elements		Gray Urban Infrastructure	Green Urban Infrastructure	Blue Urban Infrastructure
Roads	Vehicular circulation	Heat radiating materials (street width)	Cool pavement materials (increased albedo)	
	Pathways	Hard exposed surfaces (height-to-width ratio)	Shade with trees, building overhangs	
	Public squares	Hard exposed surfaces	Vegetation	Water bodies
Storm Drainage	Roof collection	Drainage to drainage system	Irrigate green roof agriculture	Rain harvesting for water supply (reduce runoff)
	Urban collection	Drainage grills	Filter through vegetation, retain/reduce runoff	Water bodies do not receive pollution from untreated runoff
	Disposal	Drainage pipe system to water bodies	Irrigate urban agriculture and other urban uses	Collect and store in cisterns, reservoirs for use in irrigation
Water Supply	Source	Rivers, wells, or rain		Harvested rainwater
	Treatment	Chlorination of all urban water	Plant-based treatment for harvested rainwater	Harvested rainwater for urban agriculture
	Reticulation	Citywide system, one system for all uses	Localized to cluster (citywide for backup)	Separate potable water from water for agricultural use
Wastewater	Collection	From buildings to sewage system	From buildings to local treatment	Natural systems reduce chemicals from water systems
	Transport/ Treatment	Long distances to treatment; requires pumps	Localized plant-based treatment	Treated water can be stored for urban use
Solid Waste	Collection, transportation	Collection of all garbage and transport to dumps	Composting food remains for urban agriculture	
	Transport/ disposal	All to municipal waste dumps	Minimal to waste dumps	
Power Lighting	Generation	Use of fossil fuels (heat generating)	Renewable energies: solar, wind, sea	
	Distribution	Networks with transmission losses	Localized to neighborhood or building	
	Type of light fixtures	Power-hungry incandescent, halogen, etc.	LED and other low-power consuming fixtures	

continued on next page

Table 4.2, continued

Infrastructure Categories/Elements		Gray Urban Infrastructure	Green Urban Infrastructure	Blue Urban Infrastructure
Transportation	Bus systems	Gas-driven vehicles	Electric vehicles	Hydrogen driven
	Tramways and trolley buses	Few and if existing depend on fossil fuel-produced electricity	Introduce electric-driven mass transit systems	Hydrogen driven
Urban Agriculture	Plant nurseries	Not considered	Plant nurseries for urban agriculture	
	Urban irrigation system	Not considered		Water for urban agriculture from harvested rain
Water Cooling	Water bodies	Seldom used in low-income areas		For water cooling and stormwater storage for agriculture
	Fountains	Seldom used in low-income areas		Introduce in hot dry climates to humidify air to reduce heat
	Drinking fountains	Seldom in low-income areas		Could be on mobile units during hot weather
Housing and Social Facilities	Type of construction	Energy-dependent production of materials	Green passive architecture	
	Earth air heat exchanger	Not considered; using power-consuming cooling systems	Low energy fan used to move air (could be solar power run)	
	Construction materials	Heat-reflecting, absorbing, and radiating roofs and walls	Green roofs and walls: urban agriculture	
	Landscaping	Decorative vegetation	Urban agriculture areas	Water cooling bodies-dry areas
	Landscaping of perimeter	Not always considered	Shading via buildings (arcades), shading trees outdoors	
	Drinking fountains	Not usually provided for free		Drinking fountains for passers-by during hot weather
	Shading spaces	Not always considered	Trees on sidewalks as possible	

Source: Authors.

green and blue infrastructure alternatives. Such approaches are easier to implement when designing new urban areas. In more restricted conditions in urban renewal and area upgrading, where the majority of lower-income groups reside, there are innovative ways of introducing green infrastructure, as discussed in Box 4.1. Infrastructure categories discussed in Table 4.2 include roads, storm drainage, water supply, wastewater, solid waste, power, lighting, transportation, urban agriculture, water cooling, and buildings (housing and social services).

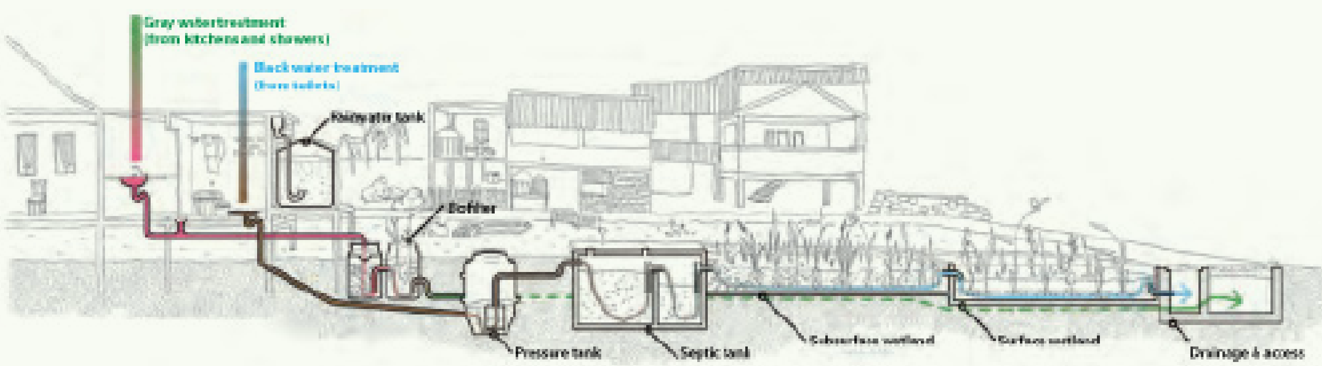
Box 4.1: Revitalizing Informal Settlements and Their Environments

Revitalizing Informal Settlements and their Environments (RISE) is an applied research program implemented by Monash University with funding from the Wellcome Trust, the Asian Development Bank, and the governments of Australia and New Zealand. To assess the viability of utilizing the water-sensitive cities (WSC) approach in retrofitting urban areas, RISE adapted it in 24 informal settlements (12 in Indonesia and 12 in Fiji) with different physical morphologies (ADB and Monash 2021). It is an example of utilizing nature-based methods of eco-friendly biofiltration and plant-based sewage treatment.

The RISE approach improves the microclimate and mitigates heat impact. This is achieved by using vegetation for sewage treatment through subsurface and surface wetlands. The cross-section in the Box figure shows the “treatment train” using natural systems and biofiltration elements: rainwater harvesting for domestic use (flushing toilets, etc.); gray-water treatment (from kitchens and showers) through a biofilter; and black water (from toilets) collected by gravity to a pressure tank where it is macerated—and, if not possible by gravity, it is pumped to a communal septic tank for primary treatment. It then flows for secondary treatment in a subsurface wetland followed by a surface wetland. It could then be safely discharged to the soil to be soaked away or to be conveyed to nearby water bodies.

Access to land in built informal environments. The most prominent challenge was land scarcity in densely built-up areas. This was addressed through a variety of approaches, including land contribution from the residents where possible, allocation of public land along abutting roads or canals through negotiations with local and national authorities, and contributions from neighboring formal developments in the form of corporate social responsibility. A variety of legal instruments was used, including land readjustment, land consolidation, compensations, and contributions.

Water-Sensitive Cities Approach “Treatment Train” Using Natural Systems and Biofiltration



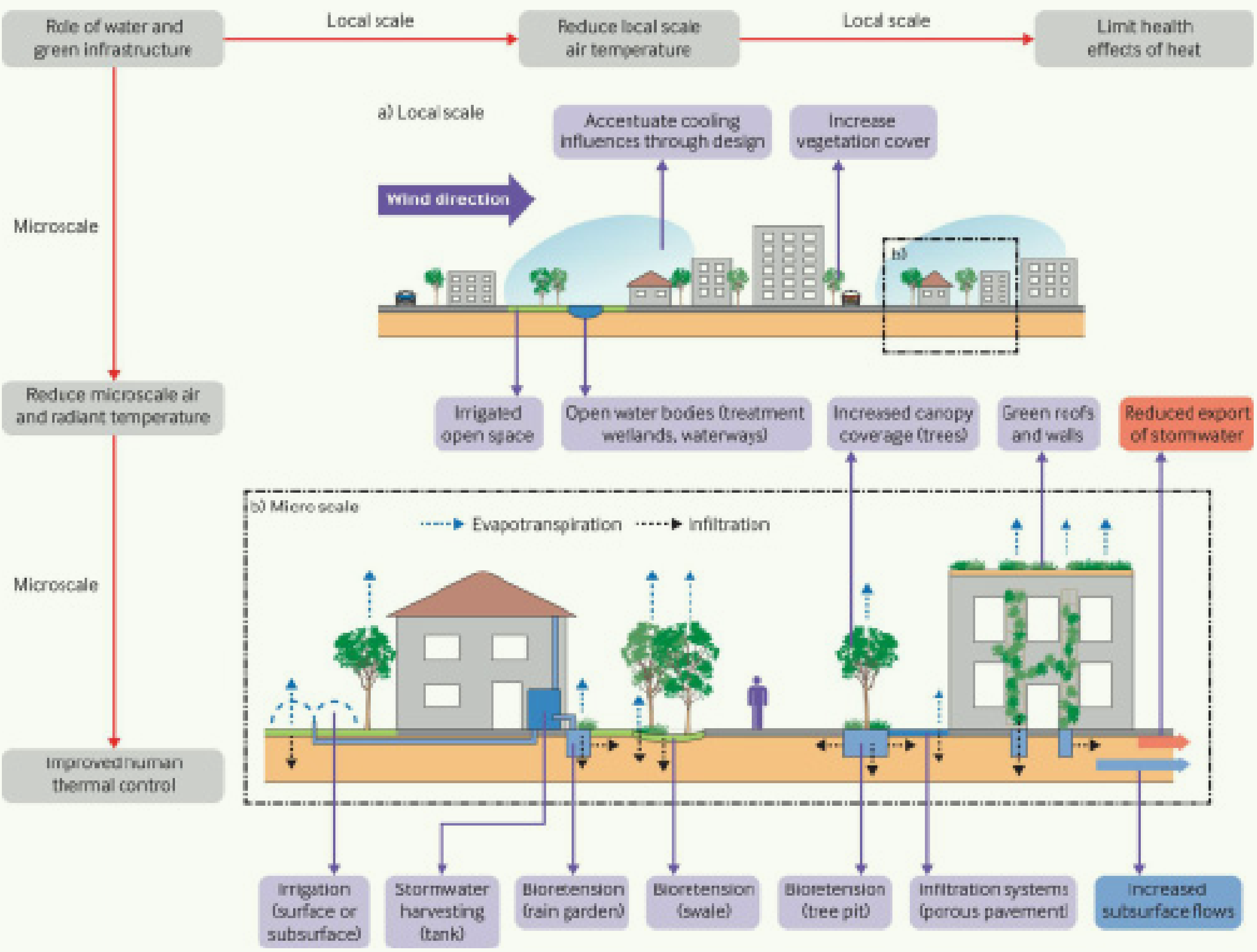
Source: ADB and Monash University (2021).

Images below show the stages of the physical implementation of the WSC approach by the RISE program. Narrow, linear wetlands were developed along pathways; the residents on either side agreed to contribute a meter of land from their plots along the road to allow for the construction of the wetlands. The approach provides flood-free, contamination-free access to dwellings with a communal sewage and wetland technology for safe sanitation services.

Water-sensitive slum upgrading interventions in Makassar, Indonesia (Wong, Tapper, and Luby 2020)
Source: Compiled by authors.

Water-sensitive city cooling technologies contribute to reducing deaths and illnesses from urban heat. Strategies to reduce temperatures by 1°C–2°C at the critical heat thresholds could lower heat-related deaths and illnesses. For example, installing fountains and misting systems increases direct evaporative cooling; creating lakes and ponds provides surfaces that stay relatively cool in daytime. Urban greening such as forests, parks, vertical gardens, and other nature-based features contribute to cooling through evapotranspiration and shading (Figure 4.3) (Wong, Tapper, and Luby 2020). This demonstrates that measures to reduce urban heat should not be invoked in isolation but be integrated with measures to address other climate hazards such as flooding. But all these strategies increase water demand. The principle that cities are water supply catchments indicates that recycled water and stormwater could be used.

Figure 4.3: Water-Sensitive City Cooling Technologies

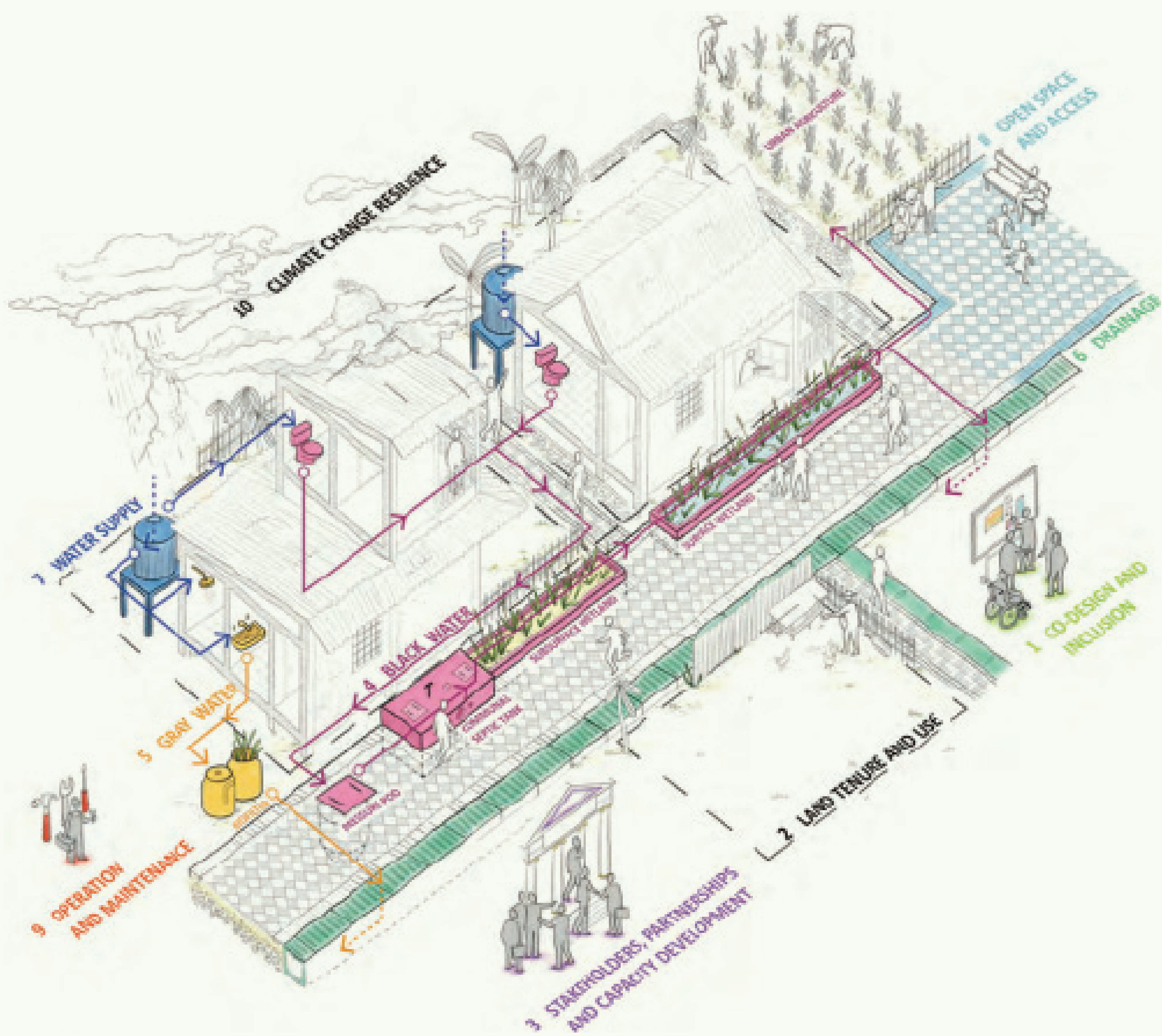


Source: Wong, Tapper, and Luby (2020).

Water-sensitive cities approach adapted to upgrading informal areas. The water-sensitive cities (WSC) approach aims to address management of the urban water cycle in a holistic way. Broadly, the approach is framed around three pillars and can be applied across both developed and developing cities (RISE and ADB 2021):

- cities as water supply catchments: access to water through a diversity of sources at a diversity of supply scales;

Figure 4.4: The 10 Components of the Water-Sensitive Cities Upgrading Approach



Source: RISE and ADB (2021).

- cities providing ecosystem services: the built environment functions to supplement and support the function of the natural environment; and

- cities comprising water-sensitive communities: sociopolitical capital for sustainability exists, and citizens' decision-making and behavior are water-sensitive.

The 10 components of the WSC upgrading approach (see Figure 4.4) include (1) community co-design and inclusion; (2) regularization of land tenure and use; (3) engaging a wide range of stakeholders toward partnerships and through capacity development; (4) nature-based solutions for black water treatment; (5) gray water treatment through biofiltration; (6) stormwater drainage; (7) water supply through rainwater harvesting; (8) provision of open space and adequate access; (9) operation and maintenance; and (10) climate change resilience (RISE and ADB 2021).

4.3 City-Scale Adaptation Measures

4.3.1 Urban Planning and Development

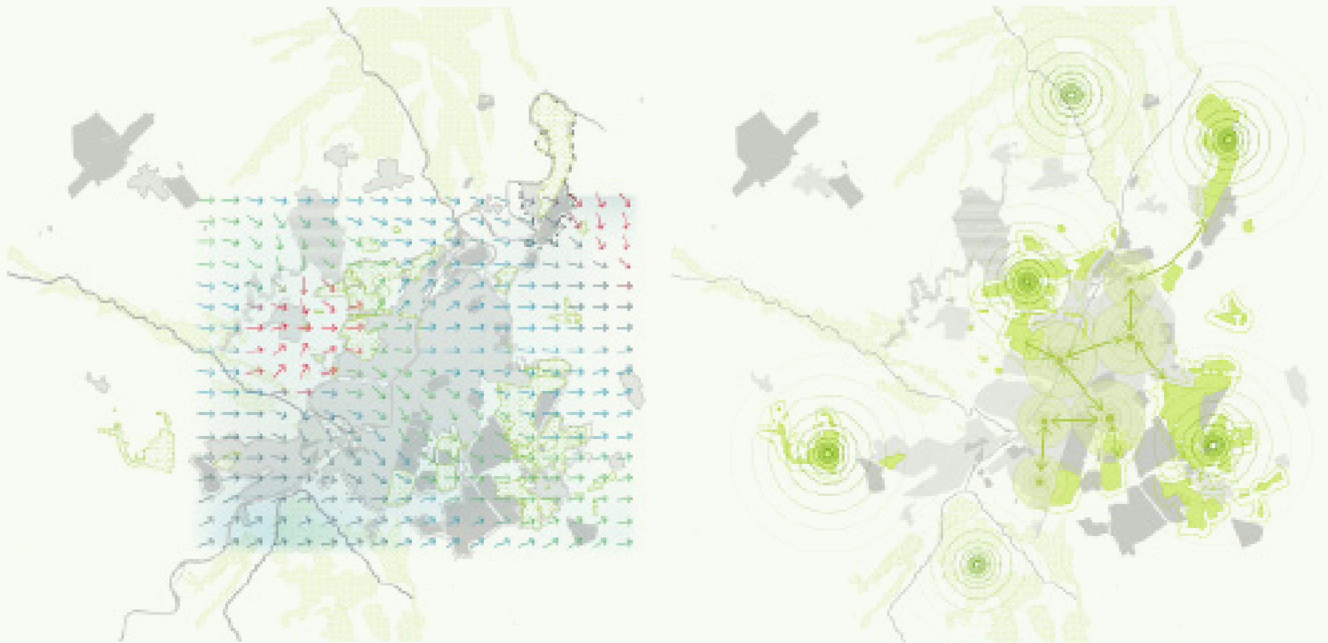
Preserving and creating wind corridors. Urban wind corridors are linear passages within a territory which enable air to flow freely. They facilitate air exchange between the city center and surrounding rural areas, helping to reduce heat and disperse pollutants. Major ventilation corridors can be planned around existing large open areas such as main roads, river channels, landscaped areas, areas of low-rise buildings, ground areas of high-voltage power lines, and so on (Figure 4.5).

Preserving, creating, and connecting large-scale green areas. Large-scale green spaces are areas concentrating vegetation such as parks, urban forests, and wetlands. These green areas act as sinks for carbon sequestration and absorb certain pollutants from the air. The soil also increases stormwater infiltration rates and facilitates evapotranspiration, which helps cool the urban environment. In hot dry climates, connecting these areas supports mobility and provides shaded walkable corridors (Figure 4.5) while contributing to biodiversity. The benefits of introducing water should be evaluated according to the climatic conditions of the context; for example, introducing water into an already very wet environment would be counterproductive.

Preserving and creating water areas. Water areas are natural or human-made bodies such as rivers, lakes, ponds, wetlands, canals, and reservoirs. The evaporation of water helps decrease the ambient heat, and the body of water itself can act as a heat sink in hot dry climates. The presence of a water body creates heterogeneous conditions of humidity and temperature, which in turn generates vertical and horizontal convection that will accelerate wind speed and lower the temperature within the area. In humid climates, water reservoirs for future use would be best located away from urban areas such as in the rural hinterland where the water could be used during dry spells.

Implementing and improving public transportation systems. Public transportation systems available for use by the general public for a fee include networks of buses, trams, trains, and rapid transit (metro or subway). These systems contribute to the reduction of greenhouse gases and pollution that is caused by the

Figure 4.5: Heat Adaptation Measure at City Scale



Source: Authors.

individual use of cars. Public transit is also accessible for lower-income populations, providing safe alternative modes of transportation without having to own private vehicles.

Urban agriculture as an important urban cooling mechanism. A large body of literature cites vegetation as an important urban cooling mechanism.[7] Vegetation contributes to managing stormwater, treating gray and black water, shading, etc. In the context of poverty, to offset the costs of conventional vegetation, including tree planting and the use of decorative vegetation, the introduction of urban agriculture should be considered as an option. Some of the heat mitigation aspects of urban agriculture include (i) microclimate improvement, reducing the impacts of heat island effect and acting as a carbon sink; (ii) shade to alleviate the impact of direct sun on people; (iii) when planted on roofs and walls, reducing building temperatures and the UHI effect; (iv) urban agriculture spaces between buildings improve ventilation of dwellings, reducing heat and humidity impacts; and (v) stormwater absorption due to soil porosity in rainy zones, reducing evaporation and relative humidity. However, challenges to introducing urban agriculture include land tenure security that would allow the use of land for urban agriculture purposes. In the case of social housing, for example, in many cases open spaces are dedicated to "green areas" and are mostly neglected due to lack of funding for operation and maintenance. A land use change through community consultations could be made to allow residents to utilize some of these areas for urban agriculture while maintaining

7 See, for example, Grimmond (2007); Hebbert (2014); Kotharkar and Ghosh (2021); Singh et al. (2021); Sun et al. (2017); Theeuwes, Solcerova, and Steeneveld (2013); US-EPA websites; Wang (2016); and Wong, Tapper, and Luby (2020).

the areas used for recreational purposes. Also, public works should consider planting fruit-bearing trees for the benefit of the residents rather than decorative ones to produce multiple benefits, as discussed. To render urban agriculture bankable, it should be considered as a holistic approach from various angles, such as contributing to job creation and income generation, as well as to food security and poverty alleviation—in addition to the cooling benefits.

Establishing cooling centers across the city. Cooling centers are public or private spaces such as schools or markets, which cities set up temporarily to provide cooling shelter for citizens. They serve as emergency shelters during heat waves. Cooling centers provide shade, water, and restrooms; they can also provide medical and social services. The location of these centers must be clearly marked through signage and billboards, and communicated with the community through apps, text messages, or door-to-door information. Schools can extend their opening hours for children to spend more time in the shade during heat waves. Similarly, since markets are often social and economic hubs for the communities, especially the poorer ones, they can be better equipped to be an extension of the public spaces and provide a safe refuge during extended heat waves.

Creating a citywide heat risk map. A heat risk map—or Heat Vulnerability Index—combines data on climatic data within the city (surface temperature and air temperature measurements, tree cover, heat sources) with socioeconomic data (age, income levels). By overlaying the vulnerable areas with the heat islands, local governments can target most vulnerable residents and improve energy efficiency in these areas. A city's heat map can be made publicly available (online) alongside mapped information about the location of cooling centers. The heat map can also support training in the most vulnerable communities, by raising awareness and equipping them with the necessary information and materials to improve their direct built environment. This action makes communities more resilient.

4.3.2 Health

Establishing a heat action plan to prepare communities to emergency situations. Heat action plans are beginning to be developed at national and city levels across Asia (Kotharkar and Ghosh 2021). They require strong interagency coordination between meteorological agencies, city authorities, and stakeholders, with a clear focus on high-risk groups. Typical features of heat action plans are (1) a road map for strategic capacity development of heat-related health services (infrastructure and skills); (2) (near) real-time heat morbidity–mortality surveillance systems; (3) heat wave forecasting and effective dissemination of alerts; (4) city infrastructure improvements (such as cool roofs); and (5) community-level action plans for raising awareness and coping with high temperatures (such as increasing access to drinking water and cool spaces during extreme heat). Following a deadly heat wave in 2010, Ahmedabad was the first city in the region to develop a heat action plan (Box 5.1) (Knowlton et al. 2014); this approach has now been scaled up to other cities across India (Singh et al. 2021). Unfortunately, beyond Ahmedabad, there are not many examples of cities in the region with operational early warning systems for heat waves. Most are at the prototype stage of development, delivering forecasts at national scales (such as Nissan et al. 2017; Pattanaik et al. 2017; Khan et al. 2019). Ideally, such an early warning system would reflect locally relevant morbidity–mortality thresholds and integrate heat wave forecasts with outlooks of poor air quality at the community scale.

Climate change adaptation should be integrated within public health policies and planning processes at national to city scales. Public health has lagged behind other sectors in developing adaptation initiatives (Ford et al. 2015), but they should be a priority for urban planners (Neira 2018). One international review of progress in developing core functions and essential services of public health found that the "response to climate change has been promising in the area of assessment (monitoring climate hazards, diagnosing health status, assessing vulnerability); mixed in the area of policy development (mobilizing partnerships, mitigation and adaptation activities); and relatively weak in assurance (communication, workforce development and evaluation)" (Fox et al. 2019:1). However, the authors acknowledged the lack of studies outside of North America, Europe, and the People's Republic of China. More specifically, there have been very few intervention evaluations (as discussed later). Although health projects are widely regarded by countries in the region as one of the priorities in their national adaptation plans, details are often thin on implementation processes, timing, responsibilities, and financing (Bowen and Ebi 2017). There is considerable scope for alignment of efforts to manage the health impacts of climate change in concert with the Sustainable Development Goals. There are also opportunities to embed climate change within national public health policies and city plans. Conceptual, technical, and operational synergies between climate change adaptation in health and disaster risk reduction could be developed too (such as early warning systems and risk communication to most vulnerable individuals) (Banwell et al. 2018). This will require "genuine collaboration, within and between health and related ministries, as well as across levels of governance (local to national) and types of organizations" (Bowen and Ebi 2017:7).

Monitoring, evaluation, and learning are needed to track health systems' ability to reduce heat wave and associated health risks to the urban poor. Indicators and surveillance systems are needed to detect emerging hot spots and changing patterns of vulnerability to heat waves. Information is also required to evaluate the health benefits and dynamically adjust heat wave interventions based on lessons learned (Fox et al. 2019). Information on global hazards is now available courtesy of the weekly bulletins issued by UK Health Security Agency.[8] The Lancet Countdown[9] reports annually on 41 indicators covering progress on health and climate change (Watts et al. 2017). Four indicators relate to health and heat exposure, with seven more tracking adaptation planning and resilience for health (Table 4.3). Other indicator domains (and metrics) are given for mitigation actions and health co-benefits (such as number of premature deaths caused by air pollution from individual economic sectors); the economic impact of climate change and its mitigation (such as cost of heat-related mortality as a proportion of gross domestic product); and public and political engagement (such as level of information-seeking behavior on Wikipedia). Most of these indicators are necessarily aggregated to national or regional scales in line with available data. However, a few studies have evaluated adaptation measures at city scales. For example, temperature versus all-cause mortality relationships before and after the Ahmedabad heat action plan was implemented reveal a decrease in summer mortality rates, especially for the highest temperatures (Hess et al. 2018). Others have provided typologies for the systematic appraisal and comparison of city health adaptation activities based on indicators for governance, information,

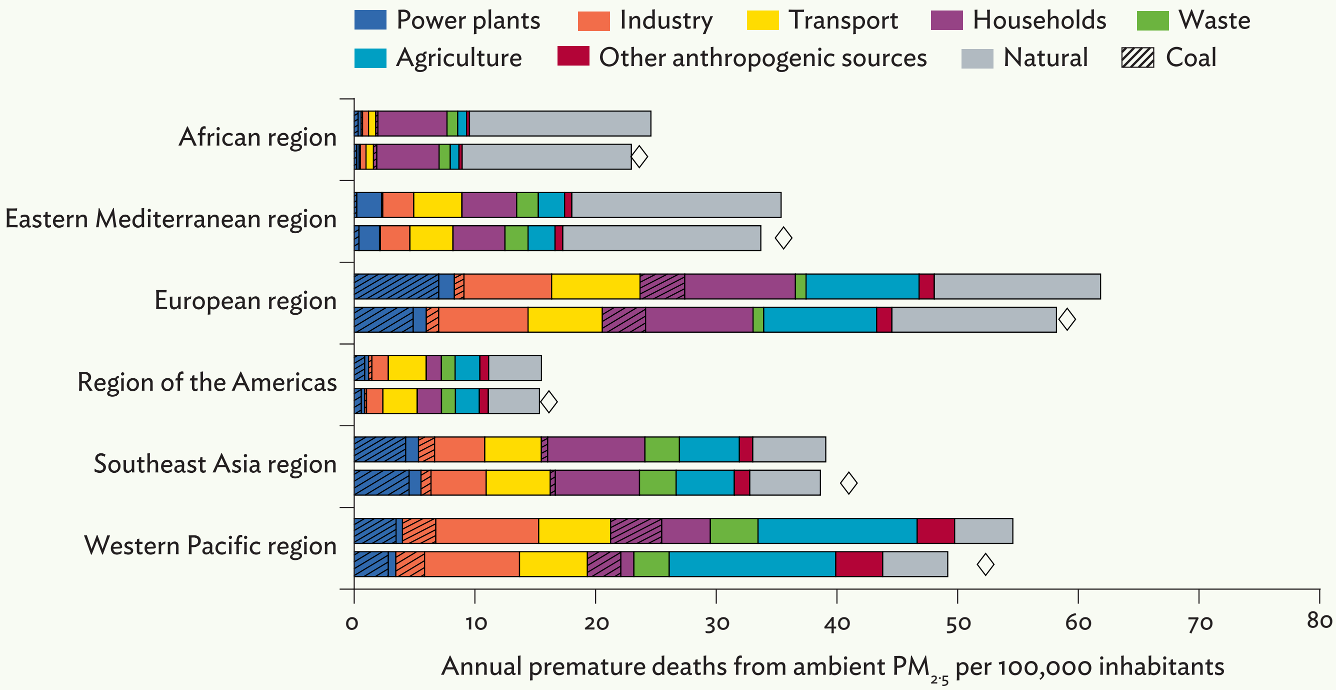
[8] See the Global Hazards Weekly Bulletin (United Kingdom Health Security Agency n.d.).
[9] Available on their website (Lancet Countdown n.d.).

Table 4.3: Heat-Related Vulnerability and Adaptation Indicators from the Lancet Countdown on Health and Climate Change

Indicators	Description
	Vulnerability Indicators
Population vulnerability to extremes of heat	A composite index ranging from 0 to 100, which combines data on the proportion of the population older than 65; the prevalence of chronic respiratory disease, cardiovascular disease, and diabetes in this population; and the proportion of the total population living in urban areas.
Exposure of vulnerable populations to heat waves	The change in the number of heat wave exposure events (with one exposure event being one heat wave experienced by one person aged over 65 or child from birth to 1 year old) and days of heat wave exposure in this population compared with the average number of events in the reference period (1986–2005). A heat wave was defined as a period at least two days at a given location where the minimum daily temperature was greater than the 95th percentile of the distribution of minimum daily temperature at that location over the 1986–2005 reference period for the entire year.
Heat-related mortality	Global heat-related mortality in populations older than 65 years. It applies an exposure-response function and optimum temperature to the daily maximum temperature exposure of the population older than 65 years to estimate the attributable fraction and thus the deaths attributable to heat exposure.
Potential hours of labor lost due to exposure to heat	Hours of work lost by linking WetBulb Globe Temperature (Appendix 3) with the amount of energy typically expended by workers in four sectors: agriculture, construction, service, and industry. It then combines this calculation with the proportion of people working in each of these four sectors within each country to estimate the potential work hours lost per year.
	Adaptation Indicators
National adaptation planning and assessment	Countries that have a national health and climate change plan or strategy, current levels of their implementation and the commitment of national health funds toward their implementation. It also tracks countries that have conducted national assessments of vulnerability, impacts, and adaptation for health, and whether the results from these assessments have influenced policy prioritization or financial resources.
City-level climate change risk assessments	The number of global cities that have undertaken a citywide climate change risk or vulnerability assessment and the reported climate-related health impacts and vulnerabilities of these cities.
Climate information services for health	The number of countries reporting that their meteorological and hydrological services provide climate information to the health sector.
Detection, preparedness and response to health emergencies	Monitors implementation of capacity C8 (the existence of a national health emergency framework), as tracked by the International Health Regulations of the World Health Organization.
Air-conditioning benefits and harms	For selected countries and regions, the proportion of households using air-conditioning and estimated ultra-fine particulate matter ($PM_{2.5}$) attributable premature mortality due to air-conditioning use and the number of deaths averted by air-conditioning use in the 65-and-older population.
Urban green space	Quantifies exposure to urban green space for 2020 in the 1,029 urban centers with more than 500,000 inhabitants. Green space is detected through remote sensing of green vegetation, making use of the satellite-based Normalized Difference Vegetation Index (NDVI).
Spending on adaptation for health and health-related activities	Annual per capita spending on climate change adaptation in the health-care sector. It monitors two elements of spending that could provide adaptation for health: (i) global funding approved for health-related adaptation projects through multilateral funds, and (ii) global financial transactions with the potential to deliver adaptation in the health-care sector and other sectors that are relevant to the determinants of health (e.g., waste and water management, built environment, or agriculture sectors).

Source: Lancet Countdown on Health and Climate Change data explorer (n.d.).

Figure 4.6: Premature Deaths Attributable to Exposure to $PM_{2.5}$ in 2015 and 2018 by Key Sources of Pollution in WHO Regions



$PM_{2.5}$ = fine particulate matter, WHO = World Health Organization.
Note: The colored bars represent the attributable deaths if there were a constant 2015 population structure. The diamonds represent the total attributable deaths for 2018 when considering demographic changes.
Source: Watts et al. (2021).

services, risks, and capacities (e.g., Sheehan, Freire, and Martinez 2021). Further studies and frameworks of this kind are needed for cities in Asia.

Multiple co-benefits to health of reducing greenhouse gas emissions should be realized. The case for reducing greenhouse gas emissions can be framed as a human health issue (Limaye 2021). The reasoning is that weather-related threats to health can localize the urgency of climate change in the minds of the public and policy makers. While this connection may resonate with some citizens in high-income nations, for many urban poor on the front line of climate change, exposure to climate hazards is already a lived experience. However, the health benefits of mitigating emissions—expressed as reduced mortality from air pollution—may be greatest for communities of low socioeconomic status who are generally exposed to the poorest ambient air quality (Gao et al. 2018). Globally, premature deaths attributed to burning coal are rapidly declining, but there are regional variations in sector contributions to mortality. In Southeast Asia, the leading non-natural sources of ultra-fine particles ($PM_{2.5}$) are from households, agriculture, and transport (Figure 4.6). Here, there are opportunities to reduce the future risk of joint occurrence and human exposure to heat waves and poor air quality episodes (Xu et al. 2020).

Recommendations

The threat of extreme heat is significant and rising. The drivers of present and future heat and its impact on the urban poor are described in previous chapters. Due to their high exposure, high sensitivity, and limited capacity to adapt, the urban poor are especially vulnerable to high temperatures in their homes, workplaces, and neighborhoods. Local heat impacts may be exacerbated where there is low-quality housing, high-density urban development, poor air quality, unreliable water and energy supplies, lack of access to heat warnings, or few cool spaces for respite. Moreover, the heat affects people differently according to their age, health, gender, livelihoods, and environment. Thus, a range of targeted policies and investments across different scales—individual, household, neighborhood, city, and national—and involving the public and private sectors are needed to support the urban poor adapt to extreme heat (Section 5.2). This chapter describes key policies and investments that can be adopted by cities and countries in the region. In addition, recognizing the systemic nature of risk, importance of local characteristics, and the scale of resources needed to meet the challenge, the chapter introduces key principles that should guide the adoption of the recommended policies and investments.

Regional risk assessment can help focus resources on most exposed cities. The primary analyses of humid heat in Chapter 2 identified present climate "hot spots" in Pakistan, the Ganges–Brahmaputra basin, northern Philippines, and Lower Mekong area (Figure 2.4). These areas are projected to expand by varying amounts under climate change, depending on future greenhouse gas emissions (Figure 2.5). Without significant reductions in global emissions, most of the region could be experiencing lethal heat at least once per decade by the end of the 21st century. The WBGT index already shows that light labor capacity is impacted in more than 50 secondary cities across South Asia and Southeast Asia. According to the WBGT, the most at-risk secondary cities are in Pakistan, India, and Thailand (Table 2.1), with Larkana, Sukkur, and Multan in Pakistan most exposed by 2055. Other highly exposed cities are Nellore, Kakinada, and Ludhiana in India; Peshawar and Sargodha in Pakistan; and Pathum Thani and Chon Buri in Thailand. These cities, together with those most at risk of humid heat in Bangladesh (Rajshahi), Indonesia (Samarinda), the Lao People's Democratic Republic (Vientiane), the Philippines (Dasmariñas), and Viet Nam (Ha Noi), provide focal points for discussions about climate adaptations with national governments, municipalities, city authorities, and community groups (Table 2.2). These cities could be used to pilot and scale up some of the initiatives described in following sections.

5.1 Principles for Enhancing Policies and Investments That Support the Urban Poor Adapt to Extreme Heat

Adopt people-centered approaches. The starting point is a good understanding of who or what is most vulnerable to extreme heat (and other climate hazards). Critical for this is engaging with the urban poor communities in understanding risk and in identifying and implementing adaptation measures to extreme heat. This is because, the urban poor are not homogenous with some living in formal low-income housing and others in informal settlements; some involved in casual work and others engaged in informal economy; many have home-based livelihoods and others may work outdoors or in formal workplaces. Thus, various solutions are needed. Adopting people-centered approaches will help to prioritize the concerns of urban poor households, capture their local knowledge and daily experiences in facing and dealing with heat stress, and understand how they use their homes and public spaces. It will be important to collaborate with grassroots organizations that can provide support in organizing communities and ensuring their needs are reflected in policies and investments. People-centered approaches also promote empowerment, such that the urban poor households, especially the women, can meaningfully participate and have a voice in decision-making. Countries in Asia and the Pacific have well-established grassroot networks of informal settlers, informal workers, and home workers, such as the Shack/Slum Dwellers International, Asian Coalition for Housing Rights, and Self-Employed Women's Association. Establishing long-term partnerships with such organizations will be critical for the successful implementation of adaptation measures to deal with extreme heat.

Adopt integrated solutions (multisector and cross-scale). Adaptation measures, which span sectors and spatial scales ranging from individual houses to city plans, are required. Meta-analysis of heat wave studies and related urban policies in South Asia suggests that most interest has focused on building-level measures and national adaptation planning, with relatively little attention to neighborhood efforts (Kotharkar and Ghosh 2021). The investment considerations of interest in this project may focus on the productivity aspects and adaptation(s) needed to deal with heat in the short term, but each investment in adaptation can also include analysis of the potential mitigation value of different adaptation decisions. Measures that combine adaptation and mitigation elements are of greatest value for climate change protection (see paragraph that follows on co-benefits).

Adopt a mix of adaptation measures involving coping measures, incremental adjustments, and transformational changes. Coping measures are typically short-lived behavioral changes such as wearing different clothing, increasing water consumption, caring for older persons in the family, or avoiding strenuous (outdoor) activities and unnecessary travel during heat waves. Communities and other actors may also adapt incrementally, for instance, by retrofitting insulation or installing cool roofs, upgrading heat forecasting systems, developing heat evacuation plans or educational materials, revising occupational guidelines, or restoring natural blue-green spaces. Transformational adaptations may be invoked where risks and vulnerabilities are so extreme that neither coping nor incremental measures are sufficient (Kates, Travis, and Wilbanks 2012). Put simply, transformative adaptation goes beyond "more of the same." Examples of transformational adaptations to extreme heat include relocating populations away from hazardous areas (i.e., extreme hot spots), new building programs with designs and blue or green spaces that are novel to a region, radical changes in land tenure to incentivize household investment, or major anticipatory capacity building of surveillance systems and health-care facilities. Such measures are typically costly to implement and may have to overcome the inertia of existing institutional structures and procedures. Supportive social contexts and/or collective action, acceptability of options, and local leadership are also needed to sustain transformational change.

Implement adaptation measures that are contextually appropriate to maximize co-benefits and avoid potential maladaptation. Co-benefits from adaptations to heat include reduced energy costs and emissions from passive cooling systems, more open space, and cool roofs; improved air quality, habitat, and amenity value of blue or green spaces; carbon sequestration by blue or green infrastructure; and less surface runoff from green spaces. Adaptations may also be aligned with the Sustainable Development Goals (such as sustainable cities, good health, clean energy, water and sanitation, decent work). However, measures should be screened to ensure they do not increase or shift vulnerability or undermine sustainable development (Table 5.1). For example, more water bodies may create a beneficial "oasis effect" in semiarid landscapes but could increase the risk of vector-borne disease, drowning, toxic algae blooms, and aeroallergens. Blue spaces can also elevate humidity and cause more oppressive conditions at night (Gunawardena, Wells, and Kershaw 2017).

Table 5.1: Examples of Maladaptation to Extreme Heat

Outcome	Effect	Examples
Rebounding vulnerability (for implementing targeted actor(s))	Increased exposure	Trees planted to increase shade damage buildings during a storm; building insulation reduces peak temperatures during the day but raise them at night; improved ventilation increases exposure to poor air quality and pests; creation of water features for cooling increases exposure to vector-borne diseases
	Increased sensitivity	Tree species planted to increase shade and/or restore green spaces are stressed by new climate conditions; creation of blue spaces raises humidity during heat waves
	Decreased adaptive capacity	Relocation of inhabitants leads to lower adaptive capacity due to unemployment, homelessness, landlessness, food insecurity, social marginalization, reduced access to common-property resources, and increased morbidity
Shifting vulnerability (to external actor(s))	Increased exposure	Upgrading drainage in one neighborhood increases the rate of surface runoff into another neighborhood with less effective drainage
	Increased sensitivity	Development within floodplains leading to reduced storage capacity for river water
	Decreased adaptive capacity	Investments to improve reliability of water and energy services lead to increased prices, decreasing adaptive capacity among most vulnerable groups
Eroding sustainable development (common pool problem)	Increased greenhouse gas emissions	Adaptation actions increase emissions and/or environmental degradation; investments in energy services leading to high-carbon technology lock-ins; development of energy-intensive desalination plants to improve drinking-water supplies
	Environmental degradation	Unregulated use of traditional surface or groundwater resources with poorly defined property rights; urban agriculture leads to salinization of groundwater and/or degradation of wetlands
	Negative economic and social externalities	Adaptation actions lead to market failures including market externalities, collective goods problems, and the absence of knowledge for decision-making; resource concentration, land grabbing, aggravated social poverty

Source: Adapted from Juhola et al. (2016).

5.2 Policies and Investments to Support Pro-Poor Adaptation Measures to Extreme Heat

1 **Improve preparedness through heat action plans**.

Cities should institutionalize the process of developing and implementing heat action plans. Such plans should provide details on the standard operating procedures for interagency coordination to be activated in response to heat stress-related early warning to improve preparedness in the health sector. The coordination should include agencies responsible for providing early warning, health-related institutions, utilities involved in providing basic services, education institutions, media, and civil society organizations working closely with the low-income communities. The heat action plan should prioritize outreach activities through media (television, radio, social media, SMS alerts) to improve awareness among communities on actions to be taken at household and community level in response to heat early warnings, plus actions for building capacity among community leaders and health officials for preparedness and response. In cities with high risk of heat stress, the heat action plans should identify specific interventions to reduce exposure of communities by promoting

Box 5.1: Ahmedabad Heat Action Plan, India

Ahmedabad's Heat Action Plan, unveiled in 2013, has been instrumental in reducing the impacts of heat waves. The plan includes components related to (i) raising people's awareness and undertaking community activities to disseminate information on risk of heat waves and implement measures to avert heat-related deaths and illnesses; (ii) early warning system and institutional coordination to establish communication protocols to alert government agencies, health officials, emergency responders, local community groups, and media outlets of extreme temperature forecasts; (iii) capacity building of health-care professionals, such as primary medical officers, paramedics, and community health staff, to respond to heat-related illnesses; and (iv) adaptation measures to reduce heat exposure by launching new initiatives including a citywide cool roof program.

The Ahmedabad Municipal Corporation and development partners have been implementing several cool roof pilots, applying white lime wash to 3,000 low-income homes in the city, with 500 in each city zone, covering almost 2% of the city's low-income households. The citywide cool roof program is a target-based program to increase the percentage of cool roofs in the city. The Cool Roofs program uses three strategies for different building types: (i) mandatory cool roofs for all municipal, commercial and government buildings; (ii) voluntary cool roofing for residential buildings (multi-level apartment complexes and individual houses); and (iii) cool roofing for low-income housing under heat action plans and corporate service responsibility initiatives. The key drivers for adopting cool roofs for the first two types of buildings are thermal comfort, and the cooling load reduction and resulting energy savings. Thus, a payback period of cool roofing material installations is important for these types of buildings. For low-income housing being used by large proportion of households as their place of work, the drivers for using cool roofs are lower indoor temperatures and increased thermal comfort that could lead to enhanced productivity.

Drawing lessons from the Ahmedabad Heat Action Plan, other cities in India and national-level authorities are ramping up efforts to implement extreme heat warning systems and preparedness plans. The national government is working with 23 states and over 100 cities and districts to develop and implement action plans across states (Kotharkar R. and A. Ghosh, 2021).

Source: Government of India, Ahmedabad Municipal Corporation (2018).

adaptive measures described in Chapter 4. It is critical that such plans have access to budgets for implementation, and promote innovative financial products to incentivize and support the low-income population access resources for implementing household- and community-level adaptation measures. Box 5.1 describes the heat action plan of Ahmedabad, India.

2 Adopt heat-responsive design standards.

Housing and urban design can play a critical role in reducing exposure of the urban poor to extreme heat. Thus, it will be critical to revisit standards, construction codes, and guidance available for housing, public buildings, pavement design, street furniture, and so on. Housing design standards can recommend the use of cool roof technology and use of passive design practices. Many countries in Asia and the Pacific have adopted green building standards and rating schemes such as the Green Rating for Integrated Habitat Assessment in India and those of the India Green Building Council. Such standards should include measures to reduce exposure to extreme heat.

3 Design standards for urban design should be upgraded.

Recommend the use of cool pavements, neighborhood-level orientation of transport infrastructure to minimize heat retention, tree planting, preservation of natural features, and incorporation of green spaces. As discussed in Chapter 4, the use of green and blue infrastructure should be promoted. Training programs on heat adaptation measures installation and maintenance should be conducted, in particular for the construction professionals (architects, engineers, commercial and residential developers, and construction companies). Such programs would equip the individuals with the necessary skills to implement and maintain the solutions independently and create new job opportunities.

There might be a need to provide incentives for homeowners, private developers, and businesses to implement measures to adapt to heat stress. Subsidies could be introduced for building materials that promote cool technology. Tax incentives can be provided to the private sector involved in low-income housing to implement heat adaptation measures.

Attention would need to be paid toward enforcement of such standards, by improving regulations and local legislation, strengthening processes to attain housing and development permits, and in some cases providing incentives to encourage households and the private sector to adopt such measures.

4 Involve architects and community members , especially women, in the development of simple guidelines on low-cost materials that can be used with passive design approaches and adopted by households.

Housing in these settlements is extremely heterogeneous: ranging from, say, a simple cardboard shack to a much more substantial concrete-block house. Fundamental to this is acknowledging that people in informal settlements build the way they do because of very basic practical reasons, primarily economic choice. Materials must be affordable, and the skill set for using those materials readily available. Very often, the house plans, however spontaneous, are a direct outcome of the dimensions of the materials, not vice versa (for example, the length of a bamboo pole, the dimensions of a tin sheet, and so on). This should be the starting point for developing user-friendly guidance, in local language and with simple illustrations that is easy to follow by local communities and local construction workers. Moreover, since, in the case of informal settlements, households and communities are themselves involved in constructing housing, it will be important to organize capacity development programs.

5 Undertake risk-sensitive land use management.

Urban land use management processes such as land use planning, development controls, greenfield development, and urban redevelopment provide opportunities for reducing exposure to extreme heat. Urban land use management processes provide opportunities to understand how rising temperatures interact with existing and future urban growth patterns and accordingly propose policy measures. For example, a land use plan for a new city can propose strategies such as air corridors created by distinctive positioning of green and open spaces. Land use plans for existing cities can also introduce percentage targets (for public and private spaces) for maintaining green spaces including, parks, green belts, and city forests and reservoirs in peri-urban areas. Development control regulations such as zoning ordinances can promote bylaws such as green buffers. Such measures not only help in improving the microclimate and thereby reducing heat stress, but also increase overall attractiveness of the city and reduce costs associated with use of energy. Although these measures are not exclusively pro-poor, if implemented in an inclusive manner, they can significantly benefit the health and productivity of the urban poor.

Implementation of such measures requires buy-in from decision-makers, close partnership with private developers, and good understanding of the needs of the urban poor. It may require introducing new legislation and a strong set of incentives to encourage implementation. Updating city land use plans based on future climate projections becomes critical. Using earth observation-related technology can help in routine monitoring of such green spaces.

6 Improve employment and labor market-related regulations to protect workers from extreme heat.

Recognizing the direct links between heat stress, decent work, and worker productivity, it becomes critical to adopt employment and labor market-related policies through regulations, codes, and guidelines that consider the protection of both outdoor and indoor workers from extreme heat. This may include adopting regulations, such as prescribing maximum temperatures to which workers may be exposed or introducing more breaks and flexible working hours during the hottest times of day. Adaptive social protection systems, through social assistance programs and/or social insurance programs, may need to be put in place to compensate for the loss of income of workers exposed to extreme heat, including informal workers. Similarly, labor market programs as part of social protection programs in urban areas could introduce flexible work hours to enable low-skilled workers to continue earning an income by working only at appropriate temperatures. Changes in regulations should also factor future structural economic shifts and workforces in urban areas (and associated skills needed), due to transition toward low-carbon development and rural–urban migration, which are expected to increase due to climate-related shocks and stresses. Equally important is to raise understanding among workers of their rights through awareness programs.

Regulatory interventions can also require businesses to upgrade cooling systems in workplaces during excessively hot periods, improve technology used for buildings that can reduce internal temperature, and allow changes in workwear. If the business provides such cooling systems or occupational health management services, the increasing heat can be an advantage (such as retail shopping may be more extended in hot locations if shops have air-conditioning). It is important to communicate risks of extreme heat and preventive options to supervisors, managers, workers, and owners of enterprises of all sizes. Much construction work takes place outdoors, and heat exposure from air temperature and humidity are added to that from sunlight. The additional heat exposure is substantial, and providing shade for continuous work activities during hot periods would be essential for protecting worker health and productivity. Dialogue and close collaboration between employers and workers' organizations would be needed. Resources would also be needed for government and regulatory institutions to supervise the enforcement of regulations and standards.

However, it should be noted that such approaches may not always benefit the urban poor, since they are often involved in the informal economy (such as street vendors and casual workers). Alternate solutions related to improved infrastructure and awareness raising would be needed in such cases especially to ensure these benefit women involved in informal economy.

7 Implement a large-scale "cool roof" programs.

There is need for a long-term urban housing strategy to address the impact of indoor temperature, particularly for low-income households and residents of informal housing. A conscious and deliberate effort toward heatproofing existing informal housing is required (Mahadevia et al. 2020). Installing cool roofs and cool pavements in cities is a compelling win–win activity that can be undertaken immediately (Hashem Akbari 2012). In parallel, longer-term efforts are needed to minimize operational energy, utilize locally available materials to make housing cost-effective, and incorporate passive techniques to attain a comfortable indoor environment and healthy homes and workspaces (Singh et al. 2021).

A cool infrastructure program could be a quick and effective way to showcase the benefits of cool roofs and pavements, and help poor communities become more resilient to extreme heat. This is envisioned at the city level for lower-income housing developments in the formal sector, as well as informal settlements. Possible elements include (i) support for a menu of "cooling" options such as different types of cool roofs (reflective paint, false ceiling, ModRoof, clay tiles, etc.), green roofs and walls, depending on the type of existing housing, the sourcing and availability of materials, and local climate regime (arid, semiarid, monsoon, or tropical); (ii) subsidies (cash or material) or grants to poor and low-income households to install cool roofs and walls, and plant greenery; (iii) microfinance or housing microfinance for home improvement, linked with technical assistance to make houses more heat resistant through adoption of "cool" technologies, passive design techniques, such as high ventilators, high ceilings, local materials such as adobe, mud plaster painted with white lime, etc.; (iv) community grants or group loans to small community groups to install communal facilities (cool spaces to rest or work, parks, etc.); and (v) community mobilization and awareness generation on the impacts of extreme heat and heat prevention, and the installation and maintenance requirements of cool roofs. This should be complemented with a monitoring and evaluation element to gather data on the relative performance of the various options under field conditions. Based on experiences gained, such programs can be scaled up in other cities or elements related to cool roofs integrated in wider informal settlement upgrade programs.

8 Scale up investments in blue and green solutions as part of urban infrastructure.

Blue and green infrastructure provide opportunities to adapting to extreme heat while contributing to other social, economic, and environmental benefits. Table 5.2 provides a list of blue and green infrastructure options, including cool pavements, restoring natural water bodies, and preserving and restoring vegetated open spaces. As described in the table, most of the examples have initial capital expenditure (CAPEX) and operation and maintenance expenditure (OPEX) costs. The table also indicates the levels of investment from national to city, community, investor, and individual, with the last subcolumn indicating where incentives are suggested such as tax breaks, subsidies, or cross-subsidies. These incentives will serve to entice investors to contribute to the introduction and/or management of such elements. In addition, infrastructure such water fountains and shades for street vendors are also critical for reducing the exposure of the urban poor to extreme heat. These measures contribute to achieving the Sustainable Development Goals: vegetation and urban agriculture (Goal 1 – poverty alleviation, Goal 2 – food security, Goal 3 – human well-being, Goal 13 – carbon sequestration, reduction of global warming); stormwater drainage, harvesting and water body creation (Goal 6 – water security, Goal 13 – conservation of water and biodiversity); provision of drinking water fountains and cooling stations (Goal 3 – well-being, healthy lives); and nature- or plant-based green infrastructure (Goal 9 – resilient infrastructure; Goal 13 – clean environment).

Invest in early warning systems. Strengthening surveillance and warning systems for heat waves is a critical investment for reducing the impact of heat waves on the urban poor and wider urban population. Such investments include improvements in observation and monitoring systems, forecasting, and capacity development. In the context of urban spaces, it would require strengthening collaboration between national hydrometeorological agencies and city governments, including city health administration and utilities to translate the forecast of heat waves into impact scenarios to inform decisions for preparedness measures. There may also be scope for greater use of social media data in heat hazard detection, improved preparedness and coordination of relief, especially where formal surveillance systems are absent (e.g., Cecinati et al. 2019; Kusumasari and Prabowo 2020).

Invest in research and development. Research on understanding the impacts of heat stress at a local level remains limited and should be scaled up. For example,

Table 5.2: Examples of Blue and Green Infrastructure

Category	Green and Blue Infrastructure Components and Outputs	Cooling Mechanisms	Input to Urban Infrastructure	Category Number	Cost		Investors				
					Installation	Maintenance	National/City	Community	Investors	Individual	Incentive
1. Roads, Walkways	Porous for stormwater to infiltrate	Reduced heat absorption			⬢	⬢	⬢				
	Cool paving materials	Reduced heat emission			⬢	⬢	⬢				
	Vegetation interlocking paving	Plant cooling			⬢	⬢	⬢				
2. Storm Drainage	Collection and harvest	Humidity reduction	Water supply	3	⬢	⬢	⬢	⬢	⬢	⬢	⬢
	Channeling to vegetation	Evapotranpiration	Agriculture	8	⬢	⬢	⬢				
	Effluent disposal to water reservoirs	Humidity reduction	Water supply	3	⬢	⬢					
3. Water Supply	Water purification and storage	Drinking water			⬢	⬢	⬢				
	Reticulation in city and to households	Domestic uses			⬢	⬢	⬢	⬢	⬢	⬢	
	Supply for urban agriculture	Urban agriculture	Agriculture	10	⬢	⬢	⬢	⬢	⬢	⬢	
4. Wastewater	Black/gray water plant-based treatment	Vegetation cooling	Agriculture	9	⬢	⬢	⬢				
	Reuse in planting agriculture	Vegetation cooling	Agriculture	10	⬢	⬢	⬢				
	Discharge treated water to nature	Water body cooling	Blue infrastructure	9	⬢	⬢	⬢				
5. Solid Waste	Composting in communities	Through urban agriculture	Agriculture	8	⬢	⬢	⬢		⬢		
	Recycling community jobs	Reduced transportation			⬢	⬢	⬢				⬢
	Anaerobic waste digestion	Reduced heat emission	Energy		⬢	⬢	⬢				
6. Power Lighting	Locally produced/used energy	Reduced gas emission	Housing	7	⬢	⬢	⬢	⬢	⬢	⬢	⬢
	Minimized distribution grids	Reduced energy loss			⬢	⬢	⬢				
	Solar-powered LED lighting	Less heat production	Roads, safety	3	⬢	⬢	⬢	⬢	⬢		⬢

continued on next page

Table 5.2, continued

Category	Green and Blue Infrastructure Components and Outputs	Cooling Mechanisms	Input to Urban Infrastructure	Category Number	Cost		Investors				
					Installation	Maintenance	National/City	Community	Investors	Individual	Incentive
7. Transportation	Increased electric-driven public transit	Reduced temperature			⬢	⬢	⬢				
	Shaded pedestrian lanes	Reduced heat emission			⬢	⬢	⬢				
	Low heat-emitting vehicles	Reduced heat emission			⬢	⬢		⬢	⬢	⬢	⬢
8. Urban Agriculture	Water reservoirs, reticulation for agriculture	Vegetation cooling	Cooling roads	3	⬢	⬢	⬢				
	Nurseries: seedlings, tree production	Shading people, surfaces	Water supply	1	⬢	⬢	⬢				
	Shading, Parks, recreation	Shading buildings	Housing	7	⬢	⬢	⬢	⬢	⬢	⬢	
9. Blue Infrastructure	Natural/artificial water bodies	Water evaporation	Agriculture	9	⬢	⬢	⬢				
	Water fountains for cooling	Evaporation			⬢	⬢	⬢				
	Drinking water fountains	Thirst quenching	Water supply	2	⬢	⬢	⬢				
10. Housing	Renewable energy	Power for cooling		⬢	⬢	⬢	⬢	⬢	⬢	⬢	⬢
	Urban agriculture roofs/walls	Vegetation cooling		⬢	⬢	⬢	⬢	⬢	⬢	⬢	
	Passive cooling < energy	Reduced heat emission		⬢	⬢	⬢	⬢	⬢	⬢	⬢	

Note: The blue and green infrastructure interventions are linked to their cooling mechanisms, their inputs to urban infrastructure, and the levels of investors.
Source: Authors.

previously mentioned meta-analyses identified significant gaps in knowledge around indoor temperatures and thermal comfort, epidemiological data on all-cause mortality during heat waves, and evidence of the relative efficacy of different adaptation measures, within informal and low-income settlements (Laue 2020). Without such data, it becomes difficult to craft targeted policies and investments. There is need for conducting more research and development on building materials and house designs specifically in informal settlements, and for devising rules-of-thumb or guidelines for improving heat performance—using locally available materials to the extent possible. More remotely sensed indicators are needed to track changes in exposure and resilience to heat, linked to interventions (e.g., Estoque et al. 2020). Further applied research is needed to develop forecast systems of *indoor* heat and local hot spots within cities, as well as into the combined impacts of poor air quality, water scarcity, and heat stress to target most vulnerable groups.

5.3 Overcoming Challenges in Scaling Up Pro-Poor Policies and Investments in Support of Adaptation to Extreme Heat

Uptake of adaptation policies and investments may be hindered by various factors. There are many recognized obstacles to adaptation. These include fragmented or siloed governance structures; reactive rather than proactive decision-making cultures; short-term planning horizons; emphasis on quick-win, high-visibility projects rather than transformational change; isolated projects with limited scope for learning and integration; weak institutional coordination at municipal scales; low fiscal autonomy of city governments to act; low household incomes constraining the ability of households to adopt measures; aging and/or inadequate basic infrastructure; limited land and/or water availability; lack of information about climate risks, feasibility, and costs of adaptation; and uneven and/or marginalizing patterns of urban development (Singh et al. 2021). Long-term maintenance costs may deter some adaptations (such as re-whitening of cool pavements and roofs), or some groups may have insufficient resources to both access and/or act on information (such as adjusting work patterns to heat warnings) (Toloo et al. 2013).

More work is needed to monetize adaptation benefits and increase finance for adaptation in cities. A global survey of 800 cities in 2020 found that 43% do not have adaptation plans, and that 41% have yet to undertake a climate risk and vulnerability assessment (Carbon Disclosure Project 2021). A quarter of the surveyed cities were hindered by budgetary issues. Whereas returns on investments in climate mitigation through, for example, lower renewable energy costs, job creation, and improved environmental quality can be demonstrated (now), there is greater uncertainty about (future) cost recovery from anticipatory adaptation projects. However, business cases for upgrading climate services and early warning systems can be made in terms of socioeconomic and other benefits (Vaughan and Dessai 2014). Likewise, methods for valuing goods and services provided by green infrastructure are well-established (e.g., Foster, Lowe, and Winkelman 2011). Some financial flows could be accessed by helping cities to apply for climate finance, or by pooling local and intergovernmental resources where development and climate adaptation co-benefits can be aligned (Cook and Chu 2018). Alternatively, public–private partnerships could fund demonstration projects to showcase returns from investments in adaptation (to heat waves) that improve worker health, well-being, and productivity. City authorities might also use pandemic recovery plans to upgrade basic services or provide tax incentives to encourage “cooler” land uses such as urban agriculture and tree planting. The cost of borrowing might be lower where municipal climate policies enhance creditworthiness in the eyes of rating agencies and investors (Rashidi, Stadelmann, and Patt 2019).

Chapter 6

Conclusion

Pro-poor solutions are needed that build urban resilience to extreme heat and other climate hazards. This report assessed present and expected risks from extreme heat faced by the urban poor in secondary cities of South Asia and Southeast Asia. Heat impacts and pro-poor adaptation opportunities were identified via reviews of literature spanning urban planning and design, basic services, housing, livelihoods, worker productivity, and public health. Where feasible, adaptation measures were identified at household, neighborhood, and city scales—recognizing that actions have to be integrated across scales and sectors to achieve triple wins (for adaptation, mitigation, and development) and avoid maladaptation. Adaptation obstacles, cost-effectiveness, and inclusivity also were considered. The report also discussed guiding principles for identifying and implementing pro-poor adaptation measures, including adopting people-centered approaches, integrated solutions, a suite of solutions that collectively promote coping, incremental and transformational solutions, and contextually appropriate measures to maximize co-benefits and avoid potential maladaptation.

Actions are needed at different levels by a range of stakeholders. As described in Chapter 5, a range of policy actions and investments is needed to scale up pro-poor adaptation investments to deal with extreme heat. All stakeholders, including national governments, urban local bodies, and community organizations, have to work together to advance such actions. Table 6.1 describes key actions that different stakeholders can undertake. The most at-risk cities identified in Chapter 2 could form the basis for helping national and local governments to prioritize interventions.

Ways ADB can provide support. ADB's Strategy 2030 recognizes "resilience" as a key objective for achieving sustainable and inclusive development in Asia and the Pacific. Strategy 2030 identifies seven operational priorities, including on "Tackling climate change, building climate and disaster resilience, and enhancing environmental

Table 6.1: Action Areas for Adapting to Extreme Heat

Action Areas	Stakeholders	Policies and Investments
Community engagement and awareness	National government	Institutionalize the development of city-level heat action plans Develop curriculum and educational resources on heat and other climate hazards
	Municipality	Develop a heat action plan and strengthen collaboration between key stakeholders and communities for undertaking preparedness activities
	Community-based organization	Enable neighborhood committees, especially involving women, to coordinate heat evacuation and cool refuges for most vulnerable groups
Improving access to low-income housing and basic services	National government	Reform or upgrade national building codes with minimum standards/allowances for climate change Create tax incentives or schemes to retrofit workplaces with heat management/ventilation systems Improve the preparedness and surge capacity of health-care facilities for heat waves Support city governments in accessing climate finance to deal with extreme heat
	Municipality	Establish pilot programs on "cool roofs" and urban agriculture Upgrade water, sanitation, energy, and transport systems in low-income and informal communities by integrating green and blue solutions
	Community-based organization	Provide access to microfinance especially to women for building improvements and community facilities (cool spaces) Provide more fountains
Policies and planning	National government	Update labor policies and regulations to integrate extreme heat related considerations
	Municipality	Undertake city climate risk and vulnerability assessments for integrated adaptation planning (including for critical public infrastructure) Improve security of land tenure for informal settlements (to incentivize adaptation measures) Integrate more shaded areas, urban agriculture, open and blue/green space through land use planning and urban design
	Community-based organization	Consult representatives of informal areas through women's groups about appropriate and affordable heat management solutions
Data and information	National government	Strengthen climate services in heat and hazard forecasting at city scales and for critical infrastructure Establish surveillance systems to gather epidemiological data on human heat impacts
	Municipality	Set up early warning and local dissemination systems
	Community-based organization	Install low-cost heat–humidity sensors to gather data on local conditions to verify/improve city forecast systems
Research and technology	National government	Establish programs and grants for research into the climate-urban development nexus
	Municipality	Investigate heat–health–labor stress thresholds Support cool roof campaigns to demonstrate various materials and benefits
	Community-based organization	Support field experiments on affordable adaptations to building design and materials that reduce indoor heat, improve comfort, and increase productivity

Source: Authors.

sustainability" and on "Making cities more livable." In order to achieve its climate objectives, ADB will scale up its climate financing targets to ensure that (i) 75% of the number of its committed operations (on a 3-year rolling average, including sovereign and nonsovereign operations) will be supporting climate change mitigation and adaptation by 2030; and (ii) climate finance from ADB's own resources will reach $80 billion cumulatively from 2019 to 2030 (ADB 2018). Meeting these climate targets will entail expanding investments in climate adaptation and ensuring that the benefits of such investments reach the poorest and vulnerable populations. It will also require strengthening the capacity of ADB's developing member countries to undertake transformational planning and programming that encourages a paradigm shift toward resilient development, in alignment with the priorities of Nationally Determined Contributions and National Adaptation Plans.

The recommendations provided in this report offer a basis for ADB to scale up its extreme heat-related adaptation support in urban areas of Asia and the Pacific. Support could include a range of instruments, such as providing countries with technical assistance to assess risks related to extreme heat; strengthening policies, regulations, guidelines, and standards; and building the capacity of local government units to implement such policies. Support might also involve providing grant resources to help high-risk cities update their land use management processes that integrate extreme heat-related considerations, to undertake pilots on "cool roof" programs and urban agriculture. Investment projects can integrate features to deal with extreme heat through resources for green and blue infrastructure, social housing, and early warning systems. Such support could be provided in the context of urban operations, as well as operations related to social development, health, and finance. Apart from sovereign operations, nonsovereign operations can also be undertaken to promote adaptation to extreme heat in the context of housing finance, small and medium-sized enterprise development, and financial inclusion.

Supporting countries implement such actions would also require facilitating partnerships between urban local governments and community-based organizations, academic establishments to undertake research and development, and local financial institutions.

Adaptation–mitigation–development programs are also needed to manage risks from heat and other extreme weather to the rural poor. Finally, this report focused on investment opportunities for reducing the impact of extreme heat on the urban poor. However, poor households in the densely populated *agricultural* regions of South Asia are also highly vulnerable to deadly heat waves (Im, Pal, and Eltahir 2017). Without access to air-conditioning, nearly a fifth of the global population faces significant risk of illness or death. Hence, an equivalent assessment of adaptation measures for at-risk rural communities is needed. Over the medium to long term, cutting emissions limits changes in the severity of regional extremes and impacts—and ultimately, the amount of adaptation needed to protect both and urban and rural populations from heat waves and other extreme weather (Seneviratne et al. 2016).

Appendixes

Appendix 1: Secondary Cities

The following 183 cities had an estimated population of 0.5 million to 5 million in 2020, according to data from the United Nations Population Division. Climate model information was used to calculate the WetBulb Globe Temperature (WBGT) (Appendix 3) for the grid cell nearest to the city coordinates.

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
Bangladesh	20112	Bogra	24.8500	89.3667	775	1,132
	20117	Comilla	23.4578	91.2044	589	787
	20124	Khulna	22.8098	89.5644	954	1,091
	20131	Rajshahi	24.3667	88.6000	908	1,136
	20136	Sylhet	24.8967	91.8717	852	1,183
India	21150	Agartala	23.8364	91.2750	575	755
	21151	Agra	27.1833	78.0167	2,210	2,774
	21155	Ajmer	26.4500	74.6333	614	740
	21158	Aligarh	27.8833	78.0833	1,211	1,548
	21160	Allahabad	25.4500	81.8500	1,394	1,698
	21163	Amravati	20.9333	77.7500	752	920
	21164	Amritsar	31.6310	74.8755	1,377	1,685
	21170	Asansol	23.6833	86.9833	1,431	1,744
	21171	Aurangabad	19.8766	75.3433	1,558	1,982
	21179	Bareilly	28.3500	79.4167	1,255	1,583
	21184	Belgaum	15.8521	74.5045	725	893
	21185	Bellary	15.1500	76.9333	521	656
	21190	Bhavnagar	21.7667	72.1500	700	855
	21193	Bhiwandi	19.3000	73.0667	859	1,053
	21195	Bhopal	23.2667	77.4000	2,390	3,008

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
	21196	Bhubaneswar	20.2333	85.8333	1,163	1,482
	21203	Bikaner	28.0167	73.3000	772	953
	21204	Bilaspur	22.0783	82.1457	600	766
	21205	Bokaro Steel City	23.6645	86.1478	634	766
	21212	Chandigarh	30.7343	76.7933	1,148	1,413
	21215	Cherthala	9.6835	76.3367	764	1,057
	21219	Coimbatore	10.9925	76.9614	2,787	3,542
	21222	Cuttack	20.4650	85.8793	742	896
	21226	Davanagere	14.4608	75.9199	512	629
	21227	Dehradun	30.3167	78.0333	919	1,167
	21230	Dhanbad	23.8000	86.4500	1,331	1,604
	21235	Durgapur	23.5204	87.3119	675	826
	21234	Durg-Bhilainagar	21.1887	81.2806	1,208	1,465
	21238	Erode	11.3428	77.7274	635	789
	21244	Firozabad	27.1500	78.4167	821	1,058
	21249	Gaya	24.7833	85.0000	565	696
	21253	Gorakhpur	26.7599	83.3714	758	908
	21255	Gulbarga	17.3333	76.8333	673	841
	21258	Guntur	16.3000	80.4500	854	1,078
	21261	Guwahati (Gauhati)	26.1735	91.7503	1,117	1,365
	21262	Gwalior	26.2236	78.1792	1,378	1,727
	21274	Hubli-Dharwad	15.4587	75.0106	1,117	1,374
	21277	Imphal	24.8167	93.9500	576	745
	21278	Indore	22.7179	75.8333	3,017	3,918
	21279	Jabalpur	23.1670	79.9501	1,450	1,763
	21280	Jaipur	26.9167	75.8167	3,909	4,943
	21281	Jalandhar	31.3256	75.5792	1,054	1,304
	21282	Jalgaon	21.0092	75.5644	565	703
	21284	Jamnagar	22.4667	70.0667	645	767

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
	21286	Jamshedpur	22.8000	86.1833	1,599	1,974
	21288	Jhansi	25.4333	78.5833	643	788
	21289	Jodhpur	26.2392	73.0158	1,472	1,866
	21292	Kakinada	16.9333	82.2167	514	629
	21295	Kannur	11.8729	75.3716	2,167	2,766
	21296	Kanpur	26.4667	80.3500	3,124	3,715
	206046	Kayamkulam	9.1666	76.5043	695	951
	21305	Kochi (Cochin)	9.9307	76.2601	3,082	4,064
	21307	Kolhapur	16.6956	74.2317	619	744
	21308	Kollam	8.8806	76.5917	1,852	2,557
	21310	Kota	25.1665	75.8561	1,387	1,799
	21312	Kottayam	9.5833	76.5167	696	1,013
	21313	Kozhikode (Calicut)	11.2567	75.7787	3,555	4,993
	21316	Kurnool	15.8267	78.0352	665	860
	21318	Lucknow	26.8500	80.9167	3,677	4,628
	21319	Ludhiana	30.9000	75.8500	1,857	2,260
	21322	Madurai	9.9333	78.1167	1,734	2,133
	21325	Malappuram	11.0667	76.0667	3,391	4,976
	21326	Malegaon	20.5500	74.5333	716	895
	21328	Mangalore	12.9172	74.8560	713	868
	21329	Mathura	27.5000	77.6833	588	745
	21332	Meerut	28.9716	77.7193	1,696	2,093
	21336	Moradabad	28.8333	78.7833	1,197	1,539
	21341	Muzaffarnagar	29.4667	77.6833	717	943
	21342	Muzaffarpur	26.1167	85.4000	504	635
	21343	Mysore	12.2979	76.6393	1,210	1,504
	21347	Nagpur	21.1500	79.1000	2,893	3,534
	21348	Nanded Waghala	19.1618	77.3137	690	865
	21350	Nashik	19.9833	73.8000	2,066	2,638

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
	21352	Nellore	14.4463	79.9842	751	965
	21359	Panipat	29.3889	76.9681	548	683
	21363	Patiala	30.3267	76.4003	599	769
	21364	Patna	25.6000	85.1167	2,436	3,002
	21368	Puducherry	11.9300	79.8300	836	1,054
	21376	Raipur	21.2333	81.6333	1,642	2,169
	21377	Rajahmundry	17.0038	81.7894	544	661
	21379	Rajkot	22.3000	70.7833	1,878	2,416
	21384	Ranchi	23.3500	85.3333	1,439	1,817
	21387	Raurkela	22.2249	84.8618	623	754
	21391	Saharanpur	29.9667	77.5500	1,054	1,403
	21392	Salem	11.6500	78.1667	1,102	1,363
	204984	Sangli	16.8544	74.5642	584	708
	21405	Siliguri	26.7161	88.4236	1,020	1,343
	21409	Solapur	17.6833	75.9167	1,031	1,231
	21411	Srinagar	34.0837	74.7974	1,586	1,990
	21415	Thiruvananthapuram	8.5069	76.9569	2,585	3,474
	204988	Thoothukkudi (Tuticorin)	8.8090	78.1369	561	724
	21416	Thrissur	10.5167	76.2167	3,068	4,221
	21417	Tiruchirappalli	10.8050	78.6856	1,165	1,415
	21418	Tirunelveli	8.7333	77.7000	566	687
	21419	Tirupati	13.6500	79.4167	679	899
	21420	Tiruppur	11.1154	77.3546	1,496	2,018
	21425	Udaipur	24.5661	73.6911	569	704
	21427	Ujjain	23.1833	75.7667	607	746
	21430	Vadodara	22.3000	73.2000	2,190	2,708
	21433	Varanasi (Benares)	25.3164	82.9822	1,665	2,036
	21434	Vellore	12.9333	79.1333	569	698
	21435	Vijayawada	16.5167	80.6167	2,040	2,644

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
	21436	Visakhapatnam	17.6819	83.2097	2,175	2,732
	21439	Warangal	18.0000	79.5833	960	1,210
Indonesia	21443	Ambon	-3.6954	128.1814	513	668
	21444	Balikpapan	-1.2675	116.8289	682	825
	21446	Bandar Lampung	-5.4254	105.2580	1,092	1,326
	21447	Bandung	-6.9194	107.6085	2,580	3,002
	21448	Banjarmasin	-3.3244	114.5910	732	874
	205695	Batam	1.1191	104.0313	1,546	2,065
	895000051	Bekasi	-6.2383	106.9756	3,394	4,332
	21452	Bogor	-6.6065	106.8019	1,160	1,402
	205696	Denpasar	-8.6500	115.2167	987	1,203
	895000050	Depok	-6.4025	106.7942	2,727	3,564
	21455	Jambi	-1.6000	103.6167	626	749
	21479	Makassar (Ujung Pandang)	-5.1444	119.4236	1,584	1,900
	21459	Malang	-7.9797	112.6304	887	1,033
	206494	Mataram	-8.5833	116.1167	505	616
	21461	Medan	3.5833	98.6667	2,338	2,749
	21462	Padang	-0.9492	100.3543	980	1,172
	21463	Palembang	-2.9167	104.7458	1,723	2,064
	21467	Pekan Baru	0.5333	101.4500	1,205	1,500
	21469	Pontianak	-0.0333	109.3333	668	804
	21471	Samarinda	-0.4948	117.1436	1,010	1,272
	21472	Semarang	-6.9932	110.4203	1,866	2,245
	21474	Surabaya	-7.2888	112.7411	2,944	3,413
	21475	Surakarta	-7.5561	110.8317	527	610
	895000049	Tangerang	-6.2024	106.6527	2,339	2,884
	206493	Tasikmalaya	-7.3506	108.2172	1,056	1,447
Lao PDR	21772	Vientiane	17.9667	102.6000	683	861

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
Pakistan	22035	Bahawalpur	29.4000	71.6833	845	1,101
	22038	Faisalabad	31.4167	73.0833	3,462	4,401
	22039	Gujranwala	32.1500	74.1833	2,229	2,883
	22041	Hyderabad	25.3667	68.3667	1,850	2,323
	22042	Islamabad	33.7035	73.0594	1,129	1,477
	204847	Larkana	27.5500	68.2167	534	691
	22048	Multan	30.1833	71.4833	2,015	2,552
	22051	Peshawar	34.0020	71.5594	2,203	2,896
	22052	Quetta	30.1990	67.0097	1,100	1,420
	22054	Rawalpindi	33.6000	73.0667	2,237	2,805
	22056	Sargodha	32.0833	72.6667	700	874
	22057	Sheikhupura	31.7131	73.9783	517	665
	22058	Sialkot	32.5000	74.5167	705	892
	22059	Sukkur	27.7000	68.8667	534	672
Philippines	22084	Angeles	15.1500	120.5833	510	673
	895000027	Antipolo	14.6235	121.1245	881	1,100
	22085	Bacolod	10.6507	122.9460	613	747
	895000028	Bacoor	14.4130	120.9737	686	861
	22088	Basilan City (including City of Isabela)	6.7041	121.9712	533	675
	22093	Cagayan de Oro	8.4822	124.6472	753	929
	895000026	Calamba	14.1877	121.1251	525	662
	22096	Cebu City	10.3167	123.8907	980	1,172
	895000031	Dasmariñas	14.2990	120.9590	747	932
	22099	Davao City	7.0739	125.6125	1,825	2,256
	22100	General Santos	6.1128	125.1717	653	797
	895000033	Imus	14.4064	120.9405	528	722
	895000034	San Jose del Monte	14.8206	121.1023	608	725
	22125	Zamboanga City	6.9103	122.0750	917	1,099

Country	City Code		Latitude	Longitude	Population ('000)	
					2020	2030
Thailand	22618	Chiang Mai	18.7904	98.9847	1,167	1,318
	205937	Chiang Rai	19.9083	99.8325	550	621
	22619	Chon Buri	13.3611	100.9883	1,399	1,580
	205939	Kalasin	16.4328	103.5066	518	585
	22620	Khon-Kaen	16.4467	102.8330	503	568
	205945	Nakhon Pathom	13.8194	100.0442	503	607
	22621	Nakhon Ratchasima	14.9707	102.1020	774	869
	22624	Nonthaburi	13.8602	100.5218	963	1,088
	205949	Pathum Thani	14.0135	100.5305	914	1,032
	204120	Rayong	12.6810	101.2580	538	608
	204118	Samut Prakan	13.5993	100.5968	1,307	1,477
	205974	Samut Sakhon	13.5475	100.2736	578	653
	22626	Songkhla	7.1988	100.5951	967	1,092
	204119	Udon Thani	17.4157	102.7859	570	640
Viet Nam	22450	Bien Hoa	10.9500	106.8167	1,013	1,327
	23355	Can Tho	10.0333	105.7833	1,618	2,294
	22455	Da Nang	16.0513	108.2124	1,125	1,449
	22457	Hà Noi	21.0245	105.8412	4,678	6,362
	22456	Hai Phòng	20.8648	106.6835	1,300	1,698

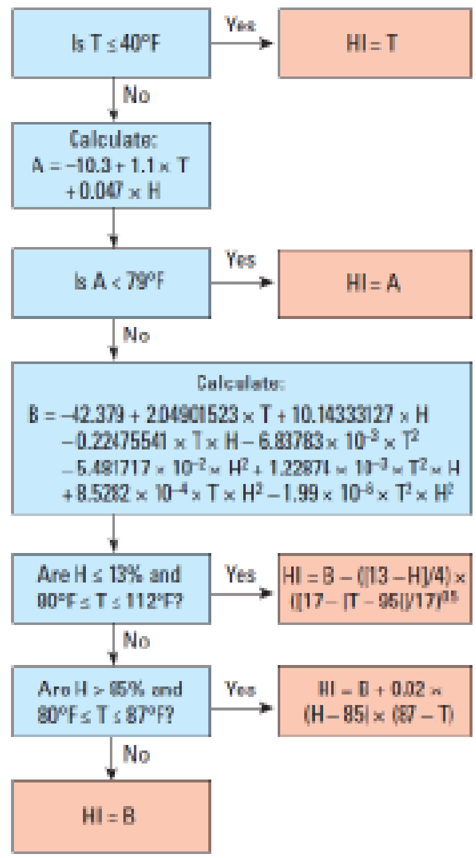
Lao PDR = Lao People's Democratic Republic.
Source: United Nations Population Division.

Appendix 2: United States National Weather Service Heat Index

The National Weather Service (NWS) Heat Index (HI) is a regression model of complex relationships between environmental conditions and the "apparent" temperature felt by people. The original data were gathered and analyzed by Steadman (1979) from extensive biometeorological experiments. Some of the variables involved in the calculation include atmospheric vapor pressure, surface area of humans, clothing cover, core temperature, activity and metabolic output, wind speed, radiative heat transfer from the surface of the skin, sweating rate, and heat lost via exhalation.

The NWS algorithm (see figure) collapses all of the above (and more) into a reduced-form, empirical relationship between dry bulb temperature (at various humidity levels) versus the skin's resistance to heat and moisture transfer (Rothfusz 1990: 2). Only air temperature and relative humidity are needed. Here, daily mean values are used, although it is recognized that a higher instantaneous HI can arise when sub-daily temperature and humidity data are inputted. The NWS issues warnings of "dangerous" heat whenever the forecasted value stays above 105°F (HI > 40.6°C). The same threshold for felt temperature was used in this report to identify regions with potentially lethal heat waves under historic and projected climate conditions.

Algorithm Used by the United States National Weather Service Online Heat Index Calculator



Note: Heat index (HI) based on air temperature (T) in degrees Fahrenheit and relative humidity (H) in percent.
Source: Anderson, Bell, and Peng (2013).

References

Anderson, G.B., M.L. Bell, and R.D. Peng. 2013. Methods to Calculate the Heat Index as an Exposure Metric in Environmental Health Research. *Environmental Health Perspectives* 121: 1111–9.

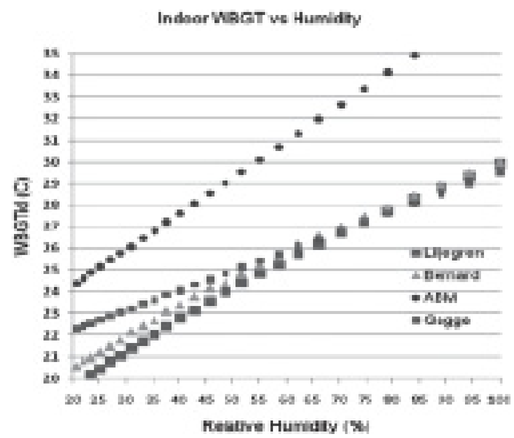
Rothfusz, L.P. 1990. *The Heat Index Equation (Or, More Than You Ever Wanted to Know about Heat Index)*. Fort Worth, Texas: National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology. https://wonder.cdc.gov/wonder/help/Climate/ta_htindx.PDF.

Steadman, R.G. 1979. The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *Journal of Applied Meteorology and Climatology* 18: 861–73.

Appendix 3: WetBulb Globe Temperature and Labor Productivity

It is well known that the effects of environmental heat on human physiology, health, and performance capacity are related not just to air temperature, but also to humidity, air movement over the skin, and heat radiation onto skin (Parsons 2014). The WetBulb Globe Temperature (WBGT) is designed to protect people in a way that fits the physiological heat strain that healthy people experience. The methods and formulas for measuring and calculating this index were developed in studies of exercising soldiers in the United States Army (Yaglou and Minard 1957).

Figure A3.1: Indoor WBGT Calculations by Liljegren, ABM, and Bernard



ABM = Australian Bureau of Meteorology, WBGT = WetBulb Globe Temperature.
Notes: Air temperature is 30°C. Results for Gagge are also included as a comparison with ABM.
Source: Lemke and Kjellstrom (2012).

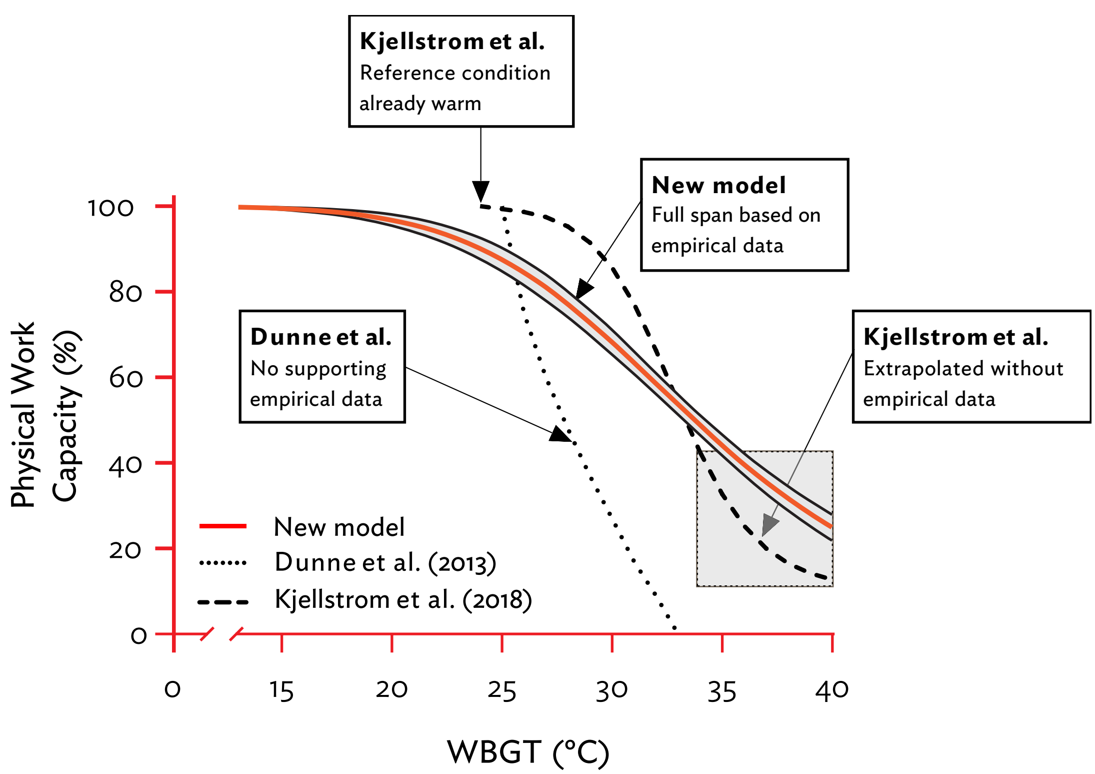
The original measurement method involved three thermometers: one with a 6-inch black globe around the actual thermometer (designed to pick up heat radiation), one with a wet cloth around the thermometer bulb to react to water evaporation, and one common thermometer reading the actual air temperature. With this equipment, three temperatures are recorded: the globe temperature, the wet bulb temperature, and the air temperature. A simple formula brings the three readings into the WBGT, and this is all described in the international standard (ISO 2017). However, few people have access to the equipment from the 1950s, and for future forecasting, some way to calculate the WBGT from common climate variables is more useful. A number of methods have been developed, and a comparison of these (Lemke and Kjellstrom 2012) showed that methods published by Liljegren or Bernard were most valid. Figure A3.1 shows the calculated WBGT at different relative humidity when air temperature is 30°C.

Additional examples of air temperature (Ta) and relative humidity (RH) influencing the calculated WBGT is shown in the following table. When RH is 100%, WBGT in shade = Ta. A convenient and correct formula for air movement of 1 meter per second and no heat radiation can be found on the website: www.ClimateCHIP.org.

Ta (°C)	26	28	28	28	30	30	30	30	32	35
RH (%)	80	40	60	70	40	50	60	80	40	40
WBGT (°C)	24.3	21.6	24.0	25.1	23.3	24.6	25.9	28.0	25.0	27.6

The WBGT was developed to represent the heat stress perceived by a typical human body and is the basis for heat protection guidelines at international (ISO 2017) and national levels (e.g., NIOSH 2016). A WBGT of 26°C marks the onset of reduced productivity due to heat according to these guidelines. (Heat physiological stress and discomfort start in sensitive persons at about 20°C, exhaustion at 26°C, and death can occur beyond 38°C after a few hours of exposure.) For example, Figure A3.2 shows results from physiological experiments, which, according to the middle curve, reduce physiological work capacity as heat increases. The Dunne, Stouffer, and John (2013) curve shows the expected reduction of work if heat standards in the United States are enforced, and the Kjellstrom et al. (2018) curve shows the actual work output reduction in real workplaces in South Africa (gold mining) and India (rice harvesting). The latter curve indicates that people in those job situations actually work beyond the physiological discomfort level. The curves in Figure A3.2 also indicate that in the 20°C–32°C WBGT range, heat-exposed workers can continue working above physiological strain levels. This report uses the Kjellstrom curve as it calculates the productivity losses as actual observed average hourly levels. The Dunne curve is based on standards that protect up to 95% of a working population, whereas the Kjellstrom curve is the effect on an average worker. Hence, the difference in the heat level at which a specific work capacity loss is reached represents the difference between a heat-sensitive worker and the average worker (i.e., the difference between the two curves). The New Model curve (red line; Foster et al. 2021) indicates the extent of physiological exhaustion that an average worker

Figure A3.2: Risk Functions for Reduction of Work Capacity, as Workplace Heat Levels (WBGT) Rise



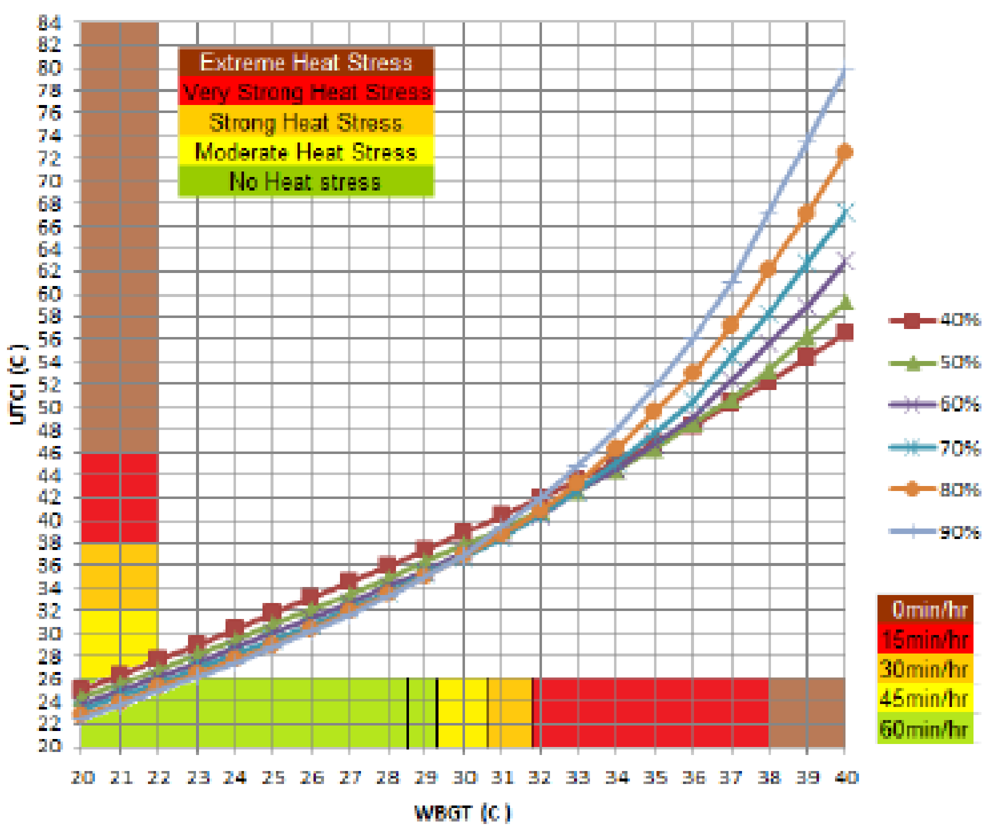
WBGT = WetBulb Globe Temperature.
Source: Foster et al. (2021).

may experience. This curve is based on laboratory experiments with young British volunteers, which may also contribute to the difference to the Kjellstrom curve based on actual work by South African and Indian laborers.

It may be assumed that intensive agricultural or construction work is carried out at a metabolic rate of 400 watts or W (resting level is about 100 W), either in the shade or in the sun. Manufacturing work is assumed to be undertaken at 300 W (in the shade or indoors without cooling) and other work (mainly service occupations) at 200 W (in-shade or indoors). These four occupation categories are the short list favored by the International Labour Organization, as shown in their heat impact report (ILO 2019).

It should be noted that some heat physiologists and ergonomists are unhappy with WBGT or its interpretation. Therefore, the Universal Thermal Climate Index (UTCI) was developed and compared with WBGT (e.g., Havenith and Fiala 2015). The UTCI is designed to include physiological risk of heat as well as cold. Unlike WBGT, it is not designed for different work intensity interpretation. However, as Figure A3.3 shows, from the 20°C–33°C WBGT range onward, there is close agreement between the two indices.

Figure A3.3: Comparison of Calculated WBGT and UTCI at Different Temperature and Humidity Combinations



UTCI = Universal Thermal Climate Index, WBGT = WetBulb Globe Temperature.
Source: Lemke et al., personal communication.

References

Dunne, J.P., R.J. Stouffer, and J.G. John. 2013. Reductions in Labour Capacity from Heat Stress under Climate Warming. *Nature Climate Change*. 3: 563–6.

Foster, J. et al. 2021. An Advanced Empirical Model for Quantifying the Impact of Heat and Climate Change on Human Physical Work Capacity. *International Journal of Biometeorology*. 65(7): 1215–29.

Havenith, G., and D. Fiala. 2011. Thermal Indices and Thermophysiological Modeling for Heat Stress. *Comprehensive Physiology*. 6: 255–302.

International Labour Organization (ILO). 2019. *Working on a Warming Planet: The Impact of Heat Stress on Labour Productivity and Decent Work*. Technical report. Geneva.

International Organization for Standardization (ISO). 2017. Hot Environments – Estimation of the Heat Stress on Working Man, Based on the WBGT-Index (Wet Bulb Globe Temperature). ISO Standard 7243. Update. Geneva.

Kjellstrom, T. et al. 2018. Estimating Population Heat Exposure and Impacts on Working People in Conjunction with Climate Change. *International Journal of Biometeorology*. 62: 291–306.

Lemke, B., and T. Kjellstrom. 2012. Calculating Workplace WBGT from Meteorological Data. *Industrial Health*. 50: 267–78.

National Institute for Occupational Safety and Health (NIOSH). 2016. *NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments*. Cincinnati, OH: United States Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Parsons, K. 2014. *Human Thermal Environment: The Effects of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance*. Third edition. New York, NY: CRC Press.

Yaglou, C.P., and D. Minard. 1957. Control of Heat Casualties at Military Training Centers. *Archives of Industrial Health*. 16(4): 302–16.

References

Ahmad, M. et al. 2020. Long-Term Variation in Aerosol Optical Properties and Their Climatic Implications over Major Cities of Pakistan. *Journal of Atmospheric and Solar-Terrestrial Physics* 210: 105419.

Ahmadalipour, A., H. Moradkhani, and M. Kumar. 2019. Mortality Risk from Heat Stress Expected to Hit Poorest Nations the Hardest. *Climatic Change.* 152: 569–79.

Ahmed, Q.I., H. Lu, and S. Ye. 2008 Urban Transportation and Equity: A Case Study of Beijing and Karachi. *Transportation Research Part A.* 42: 125–39.

Akbari, H., and D. Kolokotsa. 2016. Three Decades of Urban Heat Islands and Mitigation Technologies Research. *Energy and Buildings.* 133: 834–42.

Akbari, H., and H.D. Matthews. 2012. Global Cooling Updates: Reflective Roofs and Pavements, *Energy and Buildings.* 55: 2–6.

Akbari, H., S. Menon, and A. Rosenfeld. 2008. Global Cooling: Increasing World-Wide Urban Albedos to Offset CO_2. https://www.researchgate.net/publication/226722602_Global_Cooling_Increasing_World-Wide_Urban_Albedos_to_Offset_CO2.

Al-Obaidi, K.M., M. Ismail, and A.M.A. Rahman. 2014. *Passive Cooling Techniques through Reflective and Radiative Roofs in Tropical Houses in Southeast Asia: A Literature Review*. Higher Education Press Limited Company, Elsevier B.V.

Anderson, G.B., M.L. Bell, and R.D. Peng. 2013. Methods to Calculate the Heat Index as an Exposure Metric in Environmental Health Research. *Environmental Health Perspectives.* 121: 1111–9.

Arifwidodo, S.D., and T. Tanaka. 2015. The Characteristics of Urban Heat Island in Bangkok, Thailand. *Procedia-Social and Behavioral Sciences.* 195: 423–8.

Arumugam, R.S. et al. 2015. *Optimizing Roof Insulation for Roofs with High Albedo Coating and Radiant Barriers in India.* Elsevier.

Asian Development Bank (ADB) and Monash University. 2021. *Water-Sensitive Informal Settlement Upgrading: Overall Principles and Approach*. https://www.adb.org/publications/water-sensitive-settlement-upgrading.

ADB. 2018. ADB Launches Strategy 2030 to Respond to Changing Needs of Asia and Pacific. News Release, 16 July 2018. https://www.adb.org/news/adb-launches-strategy-2030-respond-changing-needs-asia-and-pacific.

Azhar, G. S. et al. 2014. Heat-Related Mortality in India: Excess All-Cause Mortality Associated with the 2010 Ahmedabad Heat Wave. *PloS One*. 9: e91831.

Bakhsh, K., S. Rauf, and F. Zulfiqar. 2018. Adaptation Strategies for Minimizing Heat Wave Induced Morbidity and Its Determinants. *Sustainable Cities and Society*. 41: 95–103.

Banwell, N., S. Rutherford, B. Mackey, and C. Chu. 2018. Towards Improved Linkage of Disaster Risk Reduction and Climate Change Adaptation in Health: A Review. *International Journal of Environmental Research and Public Health.* 15: 793.

Borthakur, M., A. Saikia, and K. Sharma. 2020. Swelter in the City: Urban Greenery and Its Effects on Temperature in Guwahati, India. *Singapore Journal of Tropical Geography*. 41: 341–66.

Bowen, K.J., and K.L. Ebi. 2017. Health Risks of Climate Change in the World Health Organization South-East Asia Region. *WHO South-East Asia Journal of Public Health.* 6 3-8.

C40. 2021. *How to Adapt Your City to Extreme Heat*. https://www.c40knowledgehub.org/s/article/How-to-adapt-your-city-to-extreme-heat?language=en_US.

Cai, W. et al. 2015. ENSO and Greenhouse Warming. *Nature Climate Change* 5: 849–59.

Carbon Disclosure Project. 2021. *Cities on the Route to 2030*. https://www.cdp.net/en/research/global-reports/cities-on-the-route-to-2030.

Carmichael, C. et al. 2013. Overheating and Hospitals: What Do We Know. *Journal of Hospital Administration*. 2(1).

Carney, D. 1998 Implementing the Sustainable Livelihoods Approach. In D. Carney, ed. *Sustainable Rural Livelihoods: What Contribution Can We Make*? London: Department for International Development. pp. 3–23.

Cecinati, F. et al. 2019. Mining Social Media to Identify Heat Waves. *International Journal of Environmental Research and Public Health*. 16: 762.

Centers for Disease Control and Prevention, United States (CDC). 2008. Heat-Related Deaths among Crop Workers – United States, 1992–2006. *Morbidity and Mortality Weekly Report (MMWR)*. 57: 649–53. *JAMA* 300: 1017–8.

Chambers, R., and G. Conway. 1992. *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century.* Brighton, UK: Institute for Development Studies, University of Sussex.

Chen, M.A., S. Roever, and C. Skinner. 2016. Editorial: Urban Livelihoods: Reframing Theory and Policy. *Environment and Urbanization*. 28(2): 331–42.

Chen, M.A., and S. Sinha. 2016. Home-Based Workers and Cities, *Environment and Urbanization*. 28(2): 343–58.

Chen, X. et al. 2020. Changes in Global and Regional Characteristics of Heat Stress Waves in the 21st Century. *Earth's Future*. 8(11): e2020EF001636.

Cheng, Y.T., S.C.C. Lung, and J.S. Hwang. 2019. New Approach to Identifying Proper Thresholds for a Heat Warning System Using Health Risk Increments. *Environmental Research* 170: 282–92.

Chowdhury, S., Y. Hamada, and K.S. Ahmed. 2017. Prediction and Comparison of Monthly Indoor Heat Stress (WBGT and PHS) for RMG Production Spaces in Dhaka, Bangladesh. *Sustainable Cities and Society.* 29: 41–57.

Codjoe, S. et al. 2020. Impact of Extreme Weather Conditions on Healthcare Provision in Urban Ghana. *Social Science & Medicine*. 258: 113072.

Coffel, E., R.M. Horton, and A.M. De Sherbinin. 2017. Temperature and Humidity Based Projections of a Rapid Rise in Global Heat Stress Exposure during the 21st Century. *Environmental Research Letters*. 13: 014001.

Cook, M.J., and E.K. Chu. 2018. Between Policies, Programs, and Projects: How Local Actors Steer Domestic Urban Climate Adaptation Finance in India. In *Climate Change in Cities*. Cham, Switzerland: Springer. pp. 255–77.

De Haan, L., and A. Zoomers. 2005. Exploring the Frontier of Livelihoods Research. *Development and Change.* 36(1): 27–47.

Denchak, M. 2019. Green Infrastructure: How to Manage Water in a Sustainable Way. 4 March. NRDC Stories. https://www.nrdc.org/stories/green-infrastructure-how-manage-water-sustainable-way.

Deng, H., W. Sun, W. Yip, and S. Zheng. 2020. Household Income Inequality Aggravates High-Temperature Exposure Inequality in Urban China. *Journal of Environmental Management*. 275: 1112224.

Desai, V.K., S. Wagle, S.K. Rathi, U. Patel, H.S. Desai, and K. Khatri. 2015. Effect of Ambient Heat on All-Cause Mortality in the Coastal City of Surat, India. *Current Science*. 109: 1680–6.

Design Management Institute. n.d. *dmi: 2018 Design Value Award Winner*. https://www.dmi.org/page/2018DVAModRoof.

Dinkel, A., P. Engelmann, B. Köhler, and M. Hussain. 2017. *Energy Efficient Buildings as Central Part of Integrated Resource Management in Asian Cities: The Urban Nexus II*. Freiburg, Germany: Fraunhofer Institute for Solar Energy Systems.

Dodla, V.B., G.C. Satyanarayana, and S. Desamsetti. 2017. Analysis and Prediction of a Catastrophic Indian Coastal Heat Wave of 2015. *Natural Hazards*. 87: 395–414.

Dong, W., et al. 2015. New Climate and Socio-Economic Scenarios for Assessing Global Human Health Challenges due to Heat Risk. *Climatic Change*. 130: 505–18.

Dosio, A. et al. 2018. Extreme Heat Waves under 1.5°C and 2°C Global Warming. *Environmental Research Letters*. 13: 054006.

Dunne, J.P., R.J. Stouffer, and J.G. John. 2013. Reductions in Labour Capacity from Heat Stress under Climate Warming. *Nature Climate Change*. 3: 563–6.

Environmental and Energy Studies Institute. 2012. *Cool Roofs Factsheet*. Washington, DC.

Esson, J., K.V. Gough, D. Simon, E. Amankwaa, O. Ninot, and P.W.K. Yankson. 2016. Livelihoods in Motion: Linking Transport, Mobility and Income-Generating Activities in Accra. *Journal of Transport Geography*. 55: 182–8.

Estoque, R.C., Y. Murayama, and S.W. Myint. 2017. Effects of Landscape Composition and Pattern on Land Surface Temperature: An Urban Heat Island Study in the Megacities of Southeast Asia. *Science of the Total Environment*. 577: 349–59.

Estoque, R. et al. 2020. Heat Health Risk Assessment in Philippine Cities Using Remotely Sensed Data and Social-Ecological Indicators. *Nature Communications*. 11: 1581.

Evans, G.W. 2019. Projected Behavioral Impacts of Global Climate Change. *Annual Review of Psychology*. 70: 449–74.

Fan, C. et al. 2017. Understanding the Impact of Urbanization on Surface Urban Heat Islands—A Longitudinal Analysis of the Oasis Effect in Subtropical Desert Cities. *Remote Sensing*. 9: 672.

Fluoris. A. D. et al. 2018. Workers' Health and Productivity under Occupational Heat Strain: A Systematic Review and Meta-Analysis. *Lancet Planetary Health* 2: e521-e531.

Ford, J.D., et al. 2015. The Status of Climate Change Adaptation in Africa and Asia. *Regional Environmental Change*. 15: 801–14.

Foster, J., A. Lowe, and S. Winkelman. 2011. The Value of Green Infrastructure for Urban Climate Adaptation. *Center for Clean Air Policy*. 750: 1–52.

Fox, M. et al. 2019. Integrating Public Health into Climate Change Policy and Planning: State of Practice Update. *International Journal of Environmental Research and Public Health*. 16: 3232.

Gao, J. et al. 2018. Public Health Co-Benefits of Greenhouse Gas Emissions Reduction: A Systematic Review. *Science of the Total Environment*. 627: 388–402.

Gasparrini, A. et al. 2017. Projections of Temperature-Related Excess Mortality under Climate Change Scenarios. *The Lancet Planetary Health*. 1: e360–7.

Gill, V. 2021. "Whitest Ever" Paint Reflects 98% of Sunlight. *BBC News*. https://www.bbc.co.uk/news/science-environment-56749105.

Goldstein, D.B., N. Kaur-Alum, and S. Kwatra. 2017. Hyderabad Announces Cool Roofs Initiative with Experts. 22 March. *NRDC Blog*. https://www.nrdc.org/experts/david-b-goldstein/hyderabad-announces-cool-roofs-initiative-experts.

Gough, K. V. et al. 2019. Vulnerability to Extreme Weather Events in Cities: Implications for Infrastructure and Livelihoods. *Journal of the British Academy*. 7(s2): 155–81.

Government of India. Ahmedabad Municipal Corporation. 2018. Ahmedabad Heat Action Plan 2019: Guide to Extreme Heat Planning in Ahmedabad, India. Easy Read Version. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf.

Griffiths, G.M. et al. 2005. Change in Mean Temperature as a Predictor of Extreme Temperature Change in the Asia–Pacific Region. *International Journal of Climatology*. 25: 301–1330.

Grimmond, S. 2007. Urbanization and Global Environmental Change: Local Effects of Urban Warming. *Geographical Journal*. 173: 83–8.

Gunawardena, K.R., M.J. Wells, and T. Kershaw. 2017. Utilising Green and Bluespace to Mitigate Urban Heat Island Intensity. *Science of the Total Environment*. 584: 1040–55.

Hanna, L., C. Davis, K. Dear, and T. Kjellstrom, eds. 2016. Warming in Tropical Climates: Implications for Health and Productivity. Minutes to Millennia Session. Australian Meteorological and Oceanographic Society Conference. Melbourne.

Hayes, K. et al. 2018. Climate Change and Mental Health: Risks, Impacts and Priority Actions. *International Journal of Mental Health Systems*. 12: 1–12.

Head, K. et al. 2018. Web Annex D. Report of the Systematic Review on the Effect of Indoor Heat on Health. In *WHO Housing and Health Guidelines*. Geneva: World Health Organization.

Hebbert, M. et al. 2012. Towards a Liveable Urban Climate: Lessons from Stuttgart. In *Liveable Cities: Urbanising World: ISOCARP Review 07*. Routledge. pp. 132–50.

Hendel, M. 2020. Cool Pavements. In *Eco-efficient Pavement Construction Materials*. Elsevier. pp. 97–125. https://doi.org/10.1016/B978-0-12-818981-8.00006-0.

Herold, N., L. Alexander, D. Green, and M. Donat. 2017. Greater Increases in Temperature Extremes in Low Versus High Income Countries. *Environmental Research Letters*. 12: 034007.

Hess, J.J. et al. 2018. Building Resilience to Climate Change: Pilot Evaluation of the Impact of India's First Heat Action Plan on All-Cause Mortality. *Journal of Environmental and Public Health*. 2018: 7973519.

Holmes, S.H., T. Phillips, and A. Wilson. 2016. Overheating and Passive Habitability: Indoor Health and Heat Indices. *Building Research & Information*. 44: 1–19.

Hung, T., S. Uchihama, S. Ochi, and Y. Yasuoka. 2006. Assessment with Satellite Data of the Urban Heat Island Effects in Asian Mega Cities. *International Journal of Applied Earth Observation and Geoinformation*. 8: 34–48.

Im, E.S., J.S. Pal, and E.A. Eltahir. 2017. Deadly Heat Waves Projected in the Densely Populated Agricultural Regions of South Asia. *Science Advances*. 3: e1603322.

Imada, Y. et al. 2018. Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia. *Bulletin of the American Meteorological Society*. 99: S97–101.

Imran, M., and A. Mehmood., 2020. Analysis and Mapping of Present and Future Drivers of Local Urban Climate Using Remote Sensing: A Case of Lahore, Pakistan. *Arabian Journal of Geosciences*. 13: 1–14.

Intergovernmental Panel on Climate Change (IPCC). 2018. *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, In the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield, eds.. Cambridge University Press, Cambridge.

Intergovernmental Panel on Climate Change. 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Summary for Policymakers IPCC*. WGII contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

International Labour Organization (ILO). 2019. *Working on a Warming Planet: The Impact of Heat Stress on Labour Productivity and Decent Work*. Technical report. Geneva.

Jabeen, H. 2019. Gendered Space and Climate Resilience in Informal Settlements in Khulna City, Bangladesh. *Environment and Urbanization*. 31(1): 115–38.

Jacobs, C. et al. 2019. Patterns of Outdoor Exposure to Heat in Three South Asian Cities. *Science of the Total Environment*. 674: 264–78.

Jagarnath, M., T. Thambiran, and M. Gebreslasie. 2020. Heat Stress Risk and Vulnerability Under Climate Change in Durban Metropolitan, South Africa—Identifying Urban Planning Priorities for Adaptation. *Climatic Change*. 163: 807–29.

Jaiswal, A. 2019. New Cool Roof Programs in India – Ahmedabad (Part 2). 5 April. NRDC Blog. https://www.nrdc.org/experts/anjali-jaiswal/new-cool-roof-programs-india-ahmedabad-part-2.

Jay, O. et al. 2015. Should Electric Fans Be Used During A Heat Wave? *Applied Ergonomics*. 46: 137–43.

Jones, P. 2012. Pacific Urbanisation and the Rise of Informal Settlements: Trends and Implications From Port Moresby. *Urban Policy and Research*. 30: 145–60.

Juhola, S. et al. 2016. Redefining Maladaptation. *Environmental Science & Policy*. 55: 135–40.

Kates, R.W., W.R. Travis, and T.J. Wilbanks. 2012. Transformational Adaptation When Incremental Adaptations to Climate Change Are Insufficient. *Proceedings of the National Academy of Sciences*. 109: 7156–61.

Kayaga, S. M. et al. 2021. Cities and Extreme Weather Events: Impacts of Flooding and Extreme Heat on Water and Electricity Services in Ghana. *Environment and Urbanization*. 33: 131–50.

Khan, M.A.A.S, M.H. Ahmad, and T.H. Khan. 2011. Indoor Thermal Condition of Factory Building in Bangladesh. *DIMENSI Journal of Architecture and Built Environment*. 38(2): 55–62.

Khan, N. et al. 2020. Selection of GCMs for the Projection of Spatial Distribution of Heat Waves in Pakistan. *Atmospheric Research*. 233: 104688.

Khan, N. et al. 2019. Trends in Heat Wave Related Indices in Pakistan. *Stochastic Environmental Research and Risk Assessment*. 33: 287–302.

Kim, K.H., E. Kabir, and S. Ara Jahan. 2014. A Review of the Consequences of Global Climate Change on Human Health. *Journal of Environmental Science and Health*. Part C(32): 299–318.

Kinney, P.L. 2018. Temporal Trends in Heat-Related Mortality: Implications for Future Projections. *Atmosphere*. 9: 409.

Kjellstrom, T., C. Freyberg, B. Lemke, M. Otto, and D. Briggs. 2018. Estimating Population Heat Exposure and Impacts on Working People in Conjunction with Climate Change. *International Journal of Biometeorology*. 62: 291–306.

Kjellstrom, T., I. Holmer, and B. Lemke. 2009. Workplace Heat Stress, Health and Productivity – An Increasing Challenge for Low and Middle Income Countries during Climate Change. *Global Health Action*. 2(1): 2047. https://doi.org/10.3402/gha.v2i0.2047.

Kjellstrom, T. et al. 2009. The Direct Impact of Climate Change on Regional Labour Productivity. *International Archives of Environmental & Occupational Health*. 64: 217–27.

Kjellstrom, T., and M. Meng. 2016. Impact of Climate Conditions on Occupational Health and Related Economic Losses: A New Feature of Global and Urban Health in the Context of Climate Change. *Asia Journal of Public Health*. 28(2S): 28S–37S.

Knowlton, K. et al. 2014. Development and Implementation of South Asia's First *Heat-Health* Action Plan in Ahmedabad (Gujarat, India). *International Journal of Environmental Research and Public Health*. 11: 3473–92.

Kotharkar, R. and Ghosh, A. 2021. Review of Heat Wave Studies and Related Urban Policies in South Asia. *Urban Climate*. 36: 100777. https://doi.org/10.1016/j.uclim.2021.100777.

Kotharkar, R., A. Ramesh, and A. Bagade. 2018. Urban Heat Island Studies in South Asia: A Critical Review. *Urban Climate*. 24: 1011–26.

Kovats, S., and R. Akhtar. 2008. Climate, Climate Change and Human Health in Asian Cities. *Environment and Urbanization*. 20: 165–75.

Kovats, S., and S. Hajat. 2008. Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*. 29: 41–55.

Krakauer, N.Y., B.I. Cook, and M.J. Puma. 2020. Effect of Irrigation on Humid Heat Extremes. *Environmental Research Letters*. 15(9): 094010.

Kusumasari, B., and N.P.A. Prabowo. 2020. Scraping Social Media Data for Disaster Communication: How the Pattern of Twitter Users Affects Disasters in Asia and the Pacific. *Natural Hazards*. 103: 3415–35.

Lancet Countdown: Tracking Progress on Health and Climate Change. n.d. https://www.lancetcountdown.org/.

______. n.d. Lancet Countdown on Health and Climate Change Data Explorer. https://www.lancetcountdown.org/data-platform/public-and-political-engagement/5-2-individual-engagement-in-health-and-climate-change.

Laue, F. 2020. Heat-Stress-Related Climate-Change Adaptation in Informal Urban Communities. In A. Ley, M.A.U. Rahman, and J. Fokdal, eds. *Housing and Human Settlements in a World of Change*. Bielefeld, Germany: Transcript Verlag. pp. 189–218.

Le, T., and D.H. Bae. 2019. Causal Links on Interannual Timescale between ENSO and the IOD in CMIP5 Future Simulations. *Geophysical Research Letters*. 46: 2820–8.

Li, D., J. Yuan, and R.B. Kopp. 2020. Escalating Global Exposure to Compound Heat-Humidity Extremes with Warming. *Environmental Research Letters*. 15: 064003.

Li, J. et al. 2018. Elevated Increases in Human-Perceived Temperature under Climate Warming. *Nature Climate Change*. 8: 43–7.

Li, M. et al. 2015. Mapping Heat Wave Risk of the World. In *World Atlas of Natural Disaster Risk*. Berlin and Heidelberg: Springer. pp. 169–88.

Li, X. et al. 2016. Evaluating the Impacts of High-Temperature Outdoor Working Environments on Construction Labor Productivity in China: A Case Study of Rebar Workers. *Building and Environment*. 95: 42–52.

Li, X.X. 2020. Heat Wave Trends in Southeast Asia during 1979–2018: The Impact of Humidity. *Science of the Total Environment*. 721: 137664.

Limaye, V.S. 2021. Making the Climate Crisis Personal through a Focus on Human Health. *Climatic Change*. 166: 43.

Lomas, K.J., and R. Giridharan. 2012. Thermal Comfort Standards, Measured Internal Temperatures and Thermal Resilience to Climate Change of Free-Running Buildings: A Case-Study of Hospital Wards. *Building and Environment*. 55: 57–72.

Lucas, K., and G. Porter. 2016 Mobilities and Livelihoods in Urban Development Contexts: Introduction. *Journal of Transport Geography*. 55: 129–31.

Mahadevia, D., M. Pathak, N. Bhatia, and S. Patel. 2020. Climate Change, Heat Waves and Thermal Comfort—Reflections on Housing Policy in India. *Environment and Urbanization Asia*. 11(1): 29–50. Sage Publications. https://journals.sagepub.com/doi/pdf/10.1177/0975425320906249.

Martin, R., and A. Mathema. 2009. *Development Poverty and Politics: Putting Communities in the Driver's Seat*. Routledge, Taylor and Francis.

Masood, I. et al. 2015. The Deadly Heat Wave of Pakistan, June 2015. *The International Journal of Occupational and Environmental Medicine*. 6: 247.

Masters, J. 2020. Eye on the Storm: Death Valley, California, May Have Recorded the Hottest Temperature in World History. Yale Climate Connections. 17 August. https://yaleclimateconnections.org/2020/08/death-valley-california-may-have-recorded-hottest-temp-in-world-history/#:%7E:text=Death%20Valley%2C%20California%20hit%20an,the%20final%20report%20from%20NOAA.

Masuda, Y.J. et al. 2019. How Are Healthy, Working Populations Affected by Increasing Temperatures in The Tropics? Implications for Climate Change Adaptation Policies. *Global Environmental Change*. 56: 29–40.

Matthews, T. 2018. Humid Heat and Climate Change. *Progress in Physical Geography*. 42: 391–405.

______. 2020. Death Valley: World-Beating Temperatures, No Sweat. *Weather*. 75: 347–8.

Matthews, T.K., R.L. Wilby, and C. Murphy. 2017. Communicating the Deadly Consequences of Global Warming for Human Heat Stress. *Proceedings of the National Academy of Sciences*. 114: 3861–6.

______. 2019. An Emerging Tropical Cyclone-Deadly Heat Compound Hazard. *Nature Climate Change*. 9: 602–6.

McKellar, S. 2016. Which Is Better – A Cool Roof or Green Roof? 18 November. Roofing Contractor Blog. https://www.roofingcontractor.com/blogs/16-roofing-contractor-blog/post/91898-which-is-better-a-cool-roof-or-green-roof.

McKenna, S. et al. 2020. Indian Ocean Dipole in CMIP5 and CMIP6: Characteristics, Biases, and Links to ENSO. *Scientific Reports*. 10: 1–13.

Mearns, L.O., R.W. Katz, and S.H. Schneider. 1984. Extreme High-Temperature Events: Changes in Their Probabilities with Changes in Mean Temperature. *Journal of Applied Meteorology and Climatology*. 23: 1601–13.

ModRoof. (n.d.). https://csrbox.org/India_CSR_products_ModRoof_63#:~:text=Durable%3A%20ModRoof%20panels%20are%20made,living%20spaces%20all%20year%20round.

Modroof. (n.d.). https://www.modroof.in/

Moench, M. et al. 2017. Transforming Vulnerability: Shelter, Adaptation and Climate Thresholds. *Climate and Development*. 9(1): 22–35.

Mohan, M., A.P. Sati, and S. Bhati. 2020. Urban Sprawl during Five Decadal Period over National Capital Region of India: Impact on Urban Heat Island and Thermal Comfort. *Urban Climate*. 33: 100647.

Mora, C. et al. 2017. Global Risk of Deadly Heat. *Nature Climate Change*. 7: 501–6.

Natural Resources Defense Council (NRDC). 2013. Rising Temperatures, Deadly Threat: Recommendations for Slum Communities in Ahmedabad. *NRDC Issue Brief*. https://www.nrdc.org/sites/default/files/india-heat-slum-communities-IB.pdf.

______. 2018. Cool Roofs: Protecting Local Communities and Saving Energy. https://www.nrdc.org/sites/default/files/ib_-_cool_roofs_-_hyd_workshop.pdf.

Nazarian, N., and J.K.W. Lee. 2021. Personal Assessment of Urban Heat Exposure: A Systematic Review. *Environmental Research Letters*. 16: 033005.

Neira, M. 2018. Health Must Be Number One Priority of Urban Planners. https://www.who.int/news-room/commentaries/detail/health-must-be-the-number-one-priority-for-urban-planners.

Nissan, H. et al. 2017. Defining and Predicting Heat Waves in Bangladesh. *Journal of Applied Meteorology and Climatology*. 56: 2653–70.

Oleson, K.W., G.B. Bonan, and J. Feddema. 2010. Effects of White Roofs on Urban Temperature in a Global Climate Model. *Geophysical Research Letters*. 37: GL042194.

Oleson, K.W. et al. 2015. Interactions between Urbanization, Heat Stress, and Climate Change. *Climatic Change*. 129: 525–41.

Pal, J.S., and E.A. Eltahir. 2016. Future Temperature in Southwest Asia Projected to Exceed a Threshold for Human Adaptability. *Nature Climate Change*. 6: 197–200.

Park, C.Y. et al. 2021. Differing Spatial Patterns of the Urban Heat Exposure of Elderly Populations in Two Megacities Identifies Alternate Adaptation Strategies. *Science of the Total Environment*. 781: 146455.

Parsons, K. 2014. *Human Thermal Environment: The Effects of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance*. Third edition. New York, NY: CRC Press.

Pasquini, L. et al. 2020. Emerging Climate Change-Related Public Health Challenges in Africa: A Case Study of the Heat–Health Vulnerability of Informal Settlement Residents in Dar es Salaam, Tanzania. *Science of the Total Environment*. 747: 141355.

Patel, S.K. 2018 Community-Level Assessment of Heatwaves in Odisha State, India: Effects, Resilience and Implications. *Research Brief*. New Delhi: Population Council.

Pattanaik, D.R. et al. 2017. Heat Wave over India during Summer 2015: An Assessment of Real Time Extended Range Forecast. *Meteorology and Atmospheric Physics*. 129: 375–93.

Perkins, S.E. 2015. A Review on the Scientific Understanding of Heatwaves—Their Measurement, Driving Mechanisms, and Changes at the Global Scale. *Atmospheric Research*. 164: 242–67.

Perkins-Kirkpatrick, S.E., and P.B. Gibson. 2017. Changes in Regional Heatwave Characteristics as a Function of Increasing Global Temperature. *Scientific Reports*. 7: 12256.

Phillips, C.A. et al. 2020. Compound Climate Risks in the COVID-19 Pandemic. *Nature Climate Change*. 10: 586–8.

Plante, C., J.J. Allen, and C.A. Anderson. 2017. Effects of Rapid Climate Change on Violence and Conflict. In *Oxford Research Encyclopedia of Climate Science*. Oxford, UK: Oxford University Press.

Pradhan, B. et al. 2019. Heat Stress Impacts on Cardiac Mortality in Nepali Migrant Workers in Qatar. *Cardiology* (accessed on 12 July 2019). https://www.karger.com/Article/Abstract/500853.

Qiu, W., and X. Yan. 2020. The Trend of Heatwave Events in the Northern Hemisphere. *Physics and Chemistry of the Earth*. 116: 102855.

Rahul, A., M. Mukherjee, and A. Sood. 2020. Impact of Ganga Canal on Thermal Comfort in the City of Roorkee, India. *International Journal of Biometeorology*. 64: 1933–45.

Rashidi, K., M. Stadelmann, and A. Patt. 2019. Creditworthiness and Climate: Identifying a Hidden Financial Co-Benefit of Municipal Climate Adaptation and Mitigation Policies. *Energy Research and Social Science*. 48: 131–8.

Raymond, C., T. Matthews, and R.M. Horton. 2020. The Emergence of Heat and Humidity Too Severe for Human Tolerance. *Science Advances*. https://www.science.org/doi/10.1126/sciadv.aaw1838.

Revitalizing Informal Settlements and their Environments (RISE) and ADB. 2021. Water-Sensitive Informal Settlement Upgrading: Description of Technologies. Asian Development Bank and Monash University. https://www.adb.org/publications/water-sensitive-settlement-upgrading.

Rohini, P., M. Rajeevan, and P. Mukhopadhay. 2019. Future Projections of Heat Waves over India from CMIP5 Models. *Climate Dynamics*. 53: 975–88.

Roof Knowledge. n.d. The Advantages and Disadvantages of Cool Roofing. http://www.roofknowledge.org/advantages-disadvantages-cool-roofing/.

Roos, N. et al. 2021. Maternal and Newborn Health Risks of Climate Change: A Call for Awareness and Global Action. *Acta Obstetricia et Gynecologica Scandinavica*. 100: 566–70.

Russo, S. et al. 2014. Magnitude of Extreme Heat Waves in Present Climate and Their Projection in a Warming World. *Journal of Geophysical Research: Atmospheres*. 119: 12500–12.

Saeed, F., C.F. Schleussner, and M. Ashfaq. 2021. Deadly Heat Stress to Become Commonplace across South Asia Already at 1.5°C of Global Warming. *Geophysical Research Letters*. 48: e2020GL091191.

Sanz-Barbero, B. et al. 2018. Heat Wave and the Risk of Intimate Partner Violence. *Science of the Total Environment*. 644: 413–9.

Schwingshackl, C. et al. 2021. Heat Stress Indicators in CMIP6: Estimating Future Trends and Exceedances of Impact-Relevant Thresholds. *Earth's Future*. 9(3): e2020EF001885.

Seneviratne, S.I. et al. 2016. Allowable CO_2 Emissions Based on Regional and Impact-Related Climate Targets. *Nature*. 529: 477–83.

Sett, M., and S. Sahu. 2014. Effects of Occupational Heat Exposure on Female Brick Workers in West Bengal, India. *Global Health Action*. 7(1): 21923. https://dx.doi.org/10.3402%2Fgha.v7.21923.

Sharma, R. et al. 2019. Urban Heat Island and Future Climate Change—Implications for Delhi's Heat. *Journal of Urban Health*. 96: 235–51.

Sharma, S., and P. Mujumdar. 2017. Increasing Frequency and Spatial Extent of Concurrent Meteorological Droughts and Heatwaves in India. *Scientific Reports*. 7: 15582.

Sheehan, M.C., M. Freire, and G.S. Martinez. 2021. Piloting a City Health Adaptation Typology with Data from Climate-Engaged Cities: Toward Identification of an Urban Health Adaptation Gap. *Environmental Research*. 196: 110435.

Sheridan, S.C., and M.J. Allen. 2018. Temporal Trends in Human Vulnerability to Excessive Heat. *Environmental Research Letters*. 13: 043001.

Singh, C. et al. 2021. Climate Change Adaptation in Indian Cities: A Review of Existing Actions and Spaces for Triple Wins. *Urban Climate*. 36: 100783.

Singh, S.K., S. Ali, and U. Singh. 2021. *Sustainable Building Design for Affordable Housing in Warm-Humid Climate Region of India*. NBM&CW. https://www.nbmcw.com/articles-reports/infrastructure-construction/construction-infra-industry/sustainable-building-design-for-affordable-housing-in-warm-humid-climate-region-of-india.html.

Smith, K.R. et al. 2014. Human Health: Impacts, Adaptation, and Co-Benefits. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY: Cambridge University Press. pp. 709-754.

Steadman, R.G. 1979. The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *Journal of Applied Meteorology and Climatology*. 18: 861–73.

Sultana, S., and A.N.V. Satyanarayana. 2018. Urban Heat Island Intensity during Winter over Metropolitan Cities of India Using Remote-Sensing Techniques: Impact of Urbanization. *International Journal of Remote Sensing*. 39: 6692–730.

Sun, S. et al. 2017. Evaluating the Impact of Urban Green Space and Landscape Design Parameters on Thermal Comfort in Hot Summer by Numerical Simulation. *Building and Environment*. 123: 277–88.

Sverdlik, A. 2011. Ill-Health and Poverty: A Literature Review on Health in Informal Settlements. *Environment and Urbanization*. 23: 123–55.

Switanek, M.B. et al. 2017. Scaled Distribution Mapping: A Bias Correction Method That Preserves Raw Climate Model Projected Changes. *Hydrology and Earth System Science*. 21: 2649–66.

Szabo, S., S. Ahmad, and W.N. Adger. 2018. Population Dynamics in the South-West of Bangladesh. In R. Nicholls, C. Hutton, W.N. Adger, S. Hanson, M. Rahman, and M. Salehin, eds. *Ecosystem Services for Well-Being in Deltas*. Cham, Switzerland: Palgrave Macmillan.

Taleb, H.M. 2014. Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings. *Frontiers of Architectural Research*. 3: 154–65.

Tanner, T. et al. 2009. Urban Governance for Adaptation: Assessing Climate Change Resilience in Ten Asian Cities. *IDS Working Papers*. 315: 1–47.

Tapia, C. et al. 2017. Profiling Urban Vulnerabilities to Climate Change: An Indicator-Based Vulnerability Assessment for European Cities. *Ecological Indicators*. 78: 142–55.

Theeuwes, N.E., A. Solcerova, and G.J. Steeneveld. 2013. Modeling the Influence of Open Water Surfaces on the Summertime Temperature and Thermal Comfort in the City. *Journal of Geophysical Research: Atmospheres*. 118(16): 8881–96.

Thirumalai, K. et al. 2017. Extreme Temperatures in Southeast Asia Caused by El Niño and Worsened by Global Warming. *Nature Communications*. 8: 15531.

Toloo, G. et al. 2013. Evaluating the Effectiveness of Heat Warning Systems: Systematic Review of Epidemiological Evidence. *International Journal of Public Health*. 58: 667–81.

Tran, H. et al.2006. Assessment with Satellite Data of the Urban Heat Island Effects in Asian Mega Cities. *International Journal of Applied Earth Observation and Geoinformation*. 8: 34–38.

Trang, P.M. et al. 2016. Heatwaves and Hospital Admissions for Mental Disorders in Northern Vietnam. *PloS one*. 11(5): e0155609.

Turner, S. 2007. Small-Scale Enterprise Livelihoods and Social Capital in Eastern Indonesia: Ethnic Embeddedness and Exclusion. *The Professional Geographer*. 59(4): 407–20.

UK Health Security Agency. n.d. Global Hazards Weekly Bulletin. http://www.met.reading.ac.uk/~sgs02rpa/extreme.html#210618.

United Nations Department of Economic and Social Affairs (UN DESA), Population Division. 2018. *World Urbanization Prospects: The 2018 Revision, Online Edition*. https://population.un.org/wup/Download.

United States Environmental Protection Agency (US-EPA). n.d. Heat Island Cooling Strategies. https://www.epa.gov/heatislands/heat-island-cooling-strategies.

______. n.d. What Is Green Infrastructure. https://www.epa.gov/green-infrastructure/what-green-infrastructure.

Vaughan, C., and S. Dessai. 2014. Climate Services for Society: Origins, Institutional Arrangements, and Design Elements for an Evaluation Framework. *Wiley Interdisciplinary Reviews: Climate Change*. 5: 587–603.

Vellingiri, S. et al. 2020. Combating Climate Change-Induced Heat Stress: Assessing Cool Roofs and Its Impact on the Indoor Ambient Temperature of the Households in the Urban Slums of Ahmedabad. *Indian Journal of Occupational and Environmental Medicine*. 24: 25–9.

Wang, Y. 2016. The Effect of Urban Green Infrastructure on Local Microclimate and Human Thermal Comfort. PhD thesis, Wageningen University, Netherlands.

Watts, N. et al. 2015. Health and Climate Change: Policy Responses to Protect Public Health. *The Lancet*. 386: 1861–914.

Watts, N. et al. 2017. The Lancet Countdown: Tracking Progress on Health and Climate Change. *The Lancet*. 389: 1151–64.

Watts, N. et al. 2021. The 2020 Report of The Lancet Countdown on Health and Climate Change: Responding to Converging Crises. *The Lancet*. 397: 129–70.

Wehner, M. et al. 2016. The Deadly Combination of Heat and Humidity in India and Pakistan in Summer 2015. *Bulletin of the American Meteorological Society*. 97: S81–6.

Wilby, R.L. 2007. A Review of Climate Change Impacts on the Built Environment. *Built Environment Journal* 33: 31–45.

Wilby, R.L. et al. 2021. Monitoring and Moderating Extreme Indoor Temperatures in Low-Income Urban Communities. *Environmental Research Letters*. 16: 024033.

Wong, T., M. Tapper, and S. Luby. 2020. Planetary Health Approaches for Dry Cities: Water Quality and Heat Mitigation. *BMJ*. 371: m4313. https://www.bmj.com/content/371/bmj.m4313.

World Bank. 2012. *Addressing Climate Change with Low-Cost Green Housing: Where Green Equals Affordable*. Washington, DC.

World Meteorological Organization (WMO). 2014. *Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2012)*. WMO Report 1123. Geneva.

World Meteorological Organization (WMO) and World Health Organization (WHO). 2015. *Heatwaves and Health: Guidance on Warning System Development*. https://public.wmo.int/en/resources/library/heatwaves-and-health-guidance-warning-system-development.

Xu, Y. et al. 2020. Substantial Increase in the Joint Occurrence and Human Exposure of Heatwave and High-PM Hazards over South Asia in the Mid-21st Century. *AGU Advances*. 1(2): e2019AV000103.

Yeh, S.W. et al. 2018. ENSO Atmospheric Teleconnections and Their Response to Greenhouse Gas Forcing. *Reviews of Geophysics*. 56: 185–206.

Zahid, M., and G. Rasul. 2012. Changing Trends of Thermal Extremes in Pakistan. *Climatic Change*. 113: 883–96.

Zhang, Y., I. Held, and S. Fueglistaler. 2021. Projections of Tropical Heat Stress Constrained by Atmospheric Dynamics. *Nature Geoscience*. 14: 133–7.

Zhao, L., K. Oleson, E., Bou-Zeid, E.S. Krayenhoff, A. Bray, Q. Zhu, Z. Zheng, C. Chen, and M. Oppenheimer. 2021. Global Multi-Model Projections of Local Urban Climates. *Nature Climate Change*. 11: 152–7. https://doi.org/10.1038/s41558-020-00958-8.

Zhao, Q. et al. 2015. Rooftop Surface Temperature Analysis in an Urban Residential Environment. *Remote Sensing*. 7(9): 12135–59.

Zhao, Y. et al. 2015. Estimating Heat Stress from Climate-Based Indicators: Present-Day Biases and Future Spreads in the CMIP5 Global Climate Model Ensemble. *Environmental Research Letters*. 10: 084013.

Zheng, X.T. et al. 2013. Indian Ocean Dipole Response to Global Warming in the CMIP5 Multimodel Ensemble. *Journal of Climate*. 26: 6067–80.

Zhu, S. et al. 2020. Conspicuous Temperature Extremes over Southeast Asia: Seasonal Variations under 1.5°C and 2°C Global Warming. *Climatic Change*. 160: 343–60.

Zscheischler, J. et al. 2018. Future Climate Risk from Compound Events. *Nature Climate Change*. 8: 469–77.

Zuhra, S.S., A.B. Tabinda, and A. Yasar. 2019. Appraisal of the Heat Vulnerability Index in Punjab: A Case Study of Spatial Pattern for Exposure, Sensitivity, and Adaptive Capacity in Megacity Lahore, Pakistan. *International Journal of Biometeorology*. 63: 1669–82.

Beating The Heat:
Investing In Pro-Poor Solutions For Urban Resilience

Cities in Asia and the Pacific are increasingly at risk of heat waves, which are expected to be more severe and persistent due to global warming. The urban poor are especially vulnerable to heat stress and associated health and productivity impacts as they often work outdoors and tend to live in overcrowded housing without adequate ventilation or cooling. This publication examines opportunities for countries to pursue pro-poor urban resilience initiatives to reduce the impacts of heat stress. It emphasizes the need for policies and investments to be based on long-term planning and actions at all scales: individual and household, neighborhood, and city.

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