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WHAT THE URBAN HEAT ISLAND EFFECT MEANS FOR EAST ASIA'S CITIES

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1818 H Street NW
Washington DC 20433
Telephone: +1-202-473-1000
Internet: www.worldbank.org

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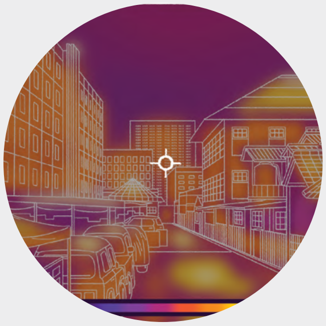

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FOREWORD

East Asia's cities are in danger of becoming unlivable because of extreme heat. Climate change has contributed to record-high temperatures across East Asia in 2023—including in China, the Lao People's Democratic Republic, Thailand, and Viet Nam—at a time when many of the region's countries already have extremely hot and humid baseline climates. However, climate change and location are not the only reasons why so many of East Asia's cities are so hot. The so-called urban heat island (UHI) effect raises temperatures in cities even further. As with climate change, the causes of this UHI effect are man-made, such as cities' relative lack of vegetation and higher prevalence of impervious surfaces compared with their surrounding rural areas.

While a city's policy makers cannot hope to solve the climate crisis alone, they can take decisive action to cool their cities by mitigating the UHI effect. This is because, unlike climate change, the UHI effect is a *local* phenomenon. With the right policies and actions, a city's leaders can reduce local temperatures and promote better adaptation to extreme heat. By reducing demand for air conditioning and investing in urban greenery, mitigation of the UHI effect at the local level can also carry important climate change co-benefits.

Through the analysis of temperature data derived from satellites and on-the-ground recordings, as well as a review of previous research, this report addresses three important questions: How strong is the UHI effect in East Asian cities? Why should policy makers be concerned about the UHI effect and extreme urban temperatures more generally? And what can city leaders do to combat extreme urban heat?

The results are sobering but, at the same time, offer cause for hope. On average, for a sample of 100 East Asian cities, cities are 2 degrees Celsius (°C) warmer than their surrounding rural areas. However, this average masks considerable variation across cities both between and within East Asian countries, as well as between neighborhoods within individual cities. Such temperature differences could mean the difference between life and death, especially for vulnerable urban residents such as the poor, the elderly, and outdoor workers. This report also shows that extremely high temperatures due to the combination of the UHI effect and climate change have severe, detrimental impacts not just on the health of East Asia's urban residents but also on the competitiveness, livability, and inclusiveness of local economies.

This report argues that, by applying a "Places, People, Institutions" framework that involves policy interventions to cool the physical spaces of a city ("Places"), to act during heatwaves to prevent death and illness among vulnerable populations ("People"), and mainstream heat resilience into city strategies, operations and budgets ("Institutions"), a city's leaders, working with other stakeholders, can reduce local temperatures and better prepare their residents for heat waves. In doing so, city leaders in East Asia can save lives and make their cities more productive, attractive, and inclusive places.

Anna Wellenstein

East Asia & Pacific
Regional Director for
Sustainable Development

The World Bank

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MAIN MESSAGES

The urban heat island (UHI) effect, especially when considered together with climate change, represents a serious and growing threat to the competitiveness, livability, and inclusiveness of East Asia's cities. However, because it is a local effect, the leaders of these cities can significantly mitigate its impact on local temperatures while also further promoting greater adaptation to extreme urban temperatures.
In this context, this report addresses three critical questions:

- How strong is the UHI effect in East Asia, and how is it interacting with climate change?
- Why should policy makers worry about the UHI effect and extreme urban temperatures more generally?
- What can city leaders do to combat extreme urban heat?

HOW STRONG IS THE URBAN HEAT ISLAND EFFECT?

- **On average, East Asian cities are 1.6–2.0 degrees Celsius (°C) warmer than their immediate rural surroundings.** Based on analysis of satellite data for 100 East Asian cities, land surface temperatures from 2016 to 2020 were, on average, 1.6°C warmer in these cities than in rural areas within 2 kilometers and 2.0°C warmer than in rural areas within 10 kilometers. Cities in Indonesia, Malaysia, and the Philippines—where average temperatures can be up to 5.9°C warmer—suffer from the strongest UHI effects.
- **UHI effects are much stronger than these averages in some neighborhoods and are strongest at night.** The averages mask considerable variation in the strength of the UHI effect *within* cities.
For example, new research for this report shows that in Bandung, Indonesia, there are heat disparities of up to 7.0°C between the hottest and coolest neighborhoods. The UHI effect is typically stronger at night than during the day because the heat stored in the built environment is gradually released after sunset.
- **The UHI effect is often stronger in poorer neighborhoods.** In Bandung, a neighborhood's UHI effect is strongly positively correlated with its poverty rate. This is consistent with evidence for many other cities around the world. Stronger UHI effects in poorer neighborhoods result from a relative lack of urban greenery and a greater prevalence of impervious surface areas.

- **The UHI effect is a particular concern for tropical East Asian cities where humidity adds to the risk of overheating.** These cities already have hot and humid baseline climates that are, furthermore, becoming even hotter and more humid over time because of climate change. In Phnom Penh, Cambodia, the UHI effect already contributes to 23–25 heat wave days a year in the city's central districts. Fast forward to 2050, and the number of heat wave days a year is projected to more than double for those neighborhoods that have the strongest UHI effects.

WHY WORRY?

- **Extreme urban heat damages competitiveness.** For the world's largest cities, literature indicates that productivity losses from the combination of the UHI effect and global warming will decrease real gross domestic product (GDP) by 1.4–1.7 percent for the median city by 2050. For the worst-affected city, the loss could reach almost 11 percent by the end of the century. New evidence presented in this report also shows that large Southeast Asian metropolitan cities and other East Asian cities with warmer baseline climates suffer significant losses in economic activity during extreme heat events.
- **Extreme urban heat hurts health.** Already more than 100,000 people in the East Asia and Pacific region die each year owing to causes linked to extreme heat. And projections indicate that future warming during this century will increase heat-related mortality more than it decreases cold-related mortality.
- **Extreme urban heat makes cities less livable.** This occurs both directly through the unpleasantness of extreme heat—especially when combined with high humidity—indirectly through other negative impacts, such as potential increases in crime, violence, and car accidents.

WHAT CAN BE DONE?

- To address the extreme urban heat challenge, East Asia's city leaders can adopt a "Places, People, Institutions" policy framework. Heat stress is experienced in the physical spaces of a city. Making streets, plazas, parks, factories, workshops, marketplaces, and homes cooler will reduce heat stress, contributing to a vibrant economy and healthy population. But heat waves are also time-bound emergencies that endanger elderly people, children, exposed workers, and people with health vulnerabilities. Understanding who is at risk and providing them with information, health care resources, and respite from extreme heat is crucial to save lives during heatwaves. Extreme heat is also a challenge that requires coordinated action across city government institutions working in tandem with local stakeholders such as employers and neighborhood associations. Accordingly, this report proposes a policy framework based around three principles: cool the physical spaces of a city ("Places"), act during heatwaves to prevent death and illness among vulnerable populations ("People"), and mainstream heat resilience into city strategies, operations and budgets ("Institutions").
- Actions in six priority areas can help city leaders deliver on a "Places, People, Institutions" agenda for heat resilience. These strategic options for action are (a) promote urban greening through strategic planning; (b) cool city spaces through wind, shade, and urban design; (c) engage building owners in tackling indoor heat; (d) save lives through heat wave early warnings; (e) protect heat-exposed workers; and (f) mainstream heat risk reduction throughout city institutions and strategies.

ABBREVIATIONS

AC	air conditioner
ASEAN	Association of Southeast Asian Nations
CO_2	carbon dioxide
°C	degrees Celsius
°F	degrees Fahrenheit
4EI	4 Earth Intelligence
GDP	gross domestic product
ILO	International Labour Organization
JMA	Japan Meteorological Agency
LST	land surface temperature(s)
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SAR	special administrative region (of China)
TFP	total factor productivity
UHI	urban heat island
URA	Urban Redevelopment Authority (Singapore)

TEMPERATURE CONVERSION

A temperature in degrees Fahrenheit (°F) can be obtained by adding 32 to a temperature in degrees Celsius (°C) multiplied by 9/5 (or 1.8). In mathematical form:

$$F = (C \times 9/5) + 32$$

where, F and C denote temperatures in °F and °C, respectively.

Celsius (°C)	Fahrenheit (°F)
-5	23
0	32
5	41
10	50
15	59
20	68
25	77
30	86
35	95
40	104
45	113
50	122

OVERVIEW

INTRODUCTION

Over the past 50 years, climate change has caused the earth's surface to warm by almost 1.2 degrees Celsius (°C) above its preindustrial levels.[1] As dangerous as this increase has been, however, it is less than the typical average temperature differential between an East Asian city and its immediate rural outskirts. Travel just 2 kilometers outside of Da Nang in Viet Nam, Mendi in Papua New Guinea, or Wuhan in China, and you will find a temperature that is, on average, 1.5–2.5°C cooler than in the city.[2] Undertake a similar journey to the rural outskirts of Bandung in Indonesia, George Town in Malaysia, or Manila in the Philippines, and you will feel an even greater temperature drop of between 3.5°C and 5.3°C.[3]

Just as with global warming, the causes of these large temperature differentials are man-made. An urban heat island (UHI) effect tends to make cities warmer than their rural surroundings because of surfaces and structures, such as roads and buildings, that absorb and retain heat. Together with a relative lack of vegetation, and hence evaporative cooling, this causes a city to be hotter than its rural surroundings. This UHI effect is further compounded by the heat from motorized vehicles and the often widespread use of air conditioning, which transfers heat to the outside of a city's buildings (Deuskar 2022).

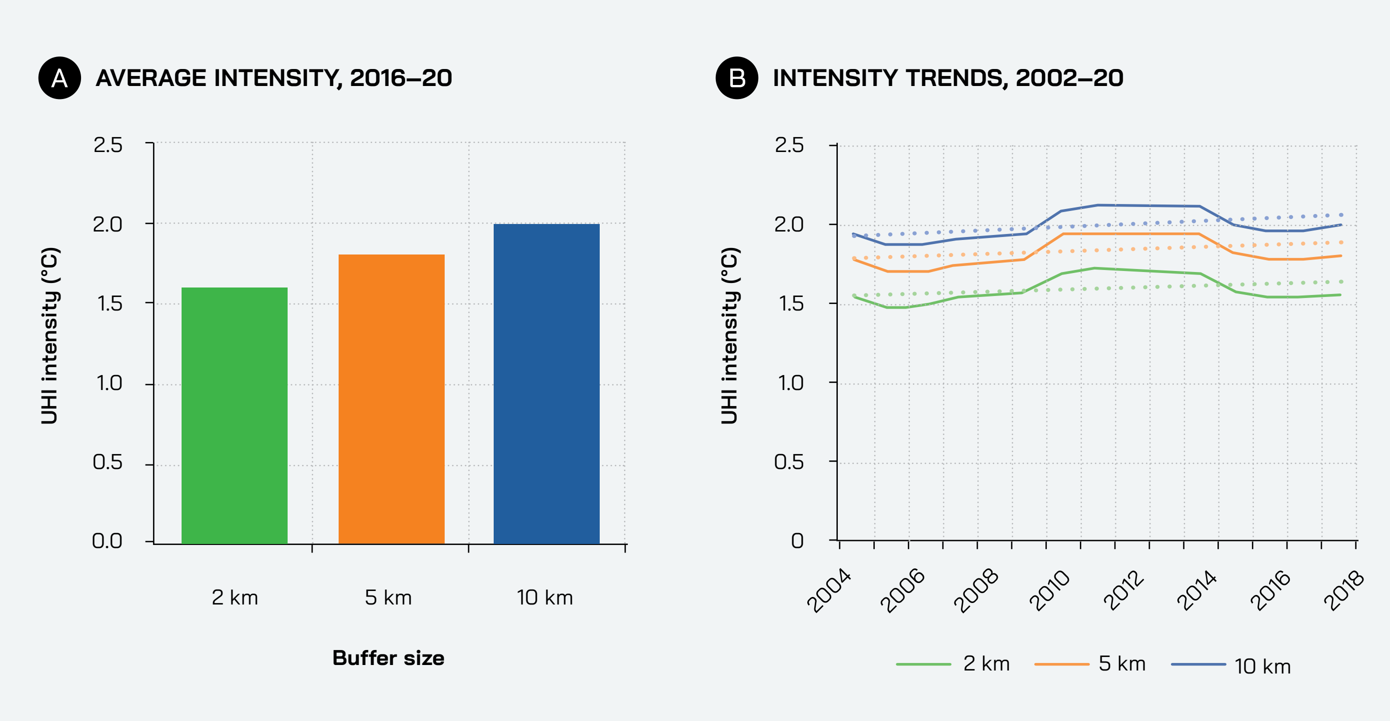
Why should an East Asian city's policy makers worry about the UHI effect? And what can they do to mitigate its impacts and help people and businesses to adapt to higher temperatures, both from the UHI effect and global warming? These are the two key questions addressed by this report. Before getting to these questions, however, the report first addresses another important question—how strong is the UHI effect in East Asia? It further explores the interactions between warming driven by the UHI effect and warming driven by climate change, noting the compounding effects of these twin threats on each other.

HOW STRONG IS THE URBAN HEAT ISLAND (UHI) EFFECT IN EAST ASIA?

UHI EFFECTS ALREADY STRONG, WITH LARGE VARIATIONS ACROSS CITIES

As noted earlier, cities such as Bandung, George Town, and Manila are, on average, 3.5–5.3°C warmer than their rural surroundings within 2 kilometers. More generally, land surface temperatures over 2016–20 were, on average, around 1.6°C warmer in the city than in the nearby countryside within 2 kilometers for a sample of 100 East Asian cities.[4] The larger the buffer used to define a city's rural surroundings, the larger the estimated average UHI effect—from 1.6°C for a 2-kilometer buffer to 2.0°C for a 10-kilometer buffer (figure O.1, panel A). Regardless of the exact distance used, however, the estimated intensity of the average UHI effect for East Asian cities has remained broadly stable since 2002 (figure O.1, panel B).[5]

Figure O.1 Average Intensity and Trends of Urban Heat Island Effects across East Asian Cities, by Buffer Size



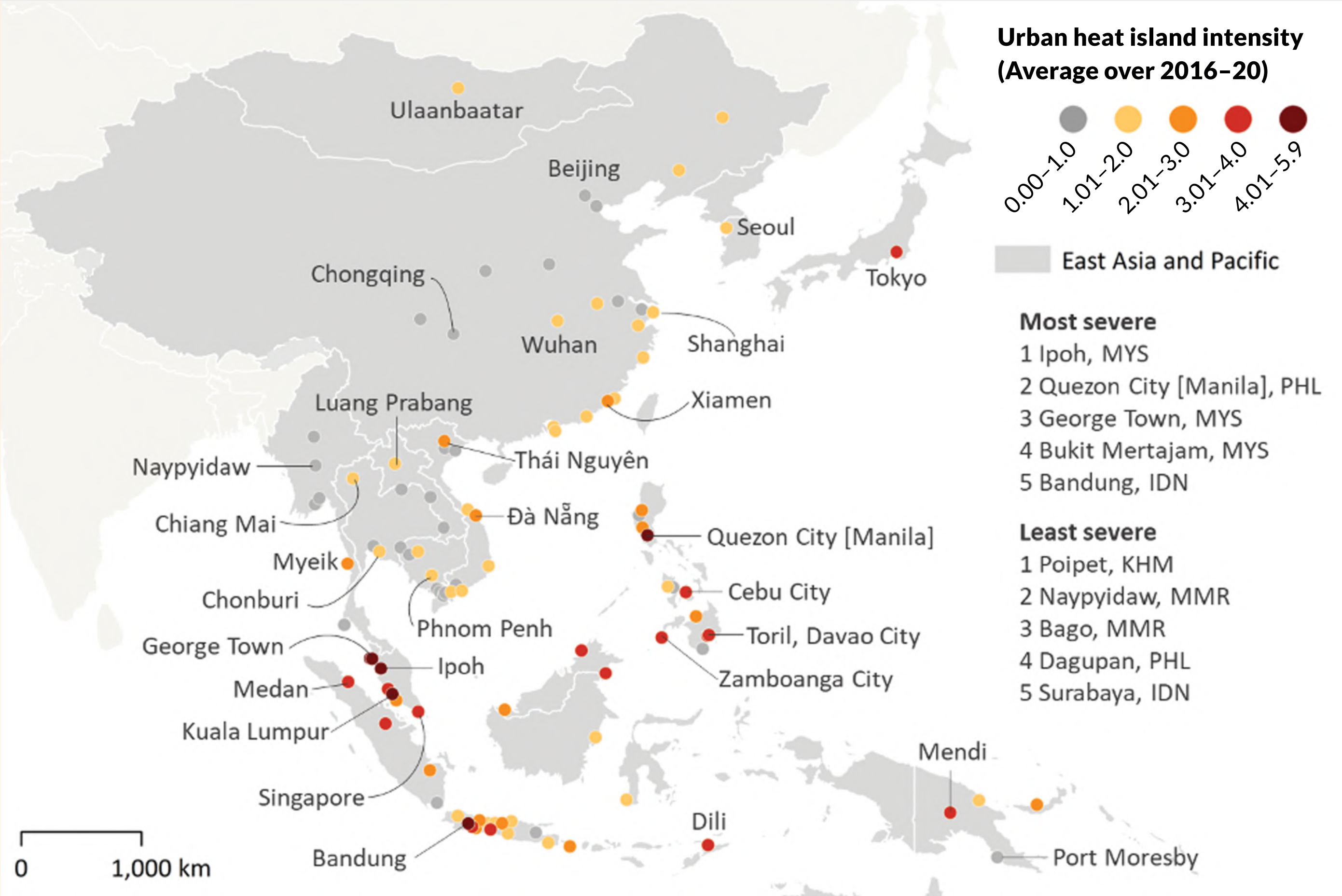
SOURCE: World Bank calculations based on estimates of urban heat island (UHI) intensity produced by 4 Earth Intelligence (https://www.4earthintelligence.com/).

NOTE: UHI intensity is estimated by averaging the daytime and nighttime differences in land surface temperatures, in degrees Celsius (°C), between urban and rural areas based on buffer distances of 2, 5, and 10 kilometers (km). Buffers define the location and size of the rural zone around a city. Panel b shows the trends of five-year moving averages. The solid and dotted lines respectively show the 5-year moving averages and their trends. Effects are estimated across a sample of 100 East Asian cities (as further described in chapter 1, box 1.2).

Behind the average UHI effect lies considerable variation across East Asian cities (map O.1). The cities with the most severe UHI effects are generally in Indonesia, Malaysia, and the Philippines. Together with Singapore, these countries dominate the list of top 10 cities with the highest estimated UHI intensities: the average of their daytime and nighttime UHI intensities, based on a 5-kilometer buffer, range from 3.5°C to 5.9°C.[6]

By contrast, cities in the continental portion of Southeast Asia, such as those in the Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam, generally exhibit less severe UHI effects—in the range of 0.1–2.4°C, based on a 5-kilometer buffer. The same is true for cities at higher latitudes, including most Chinese cities and Seoul, Republic of Korea. With an average UHI intensity of around 3.3°C, Tokyo is an exception.

Map 0.1 Average UHI Intensity in 100 Selected East Asian Cities, 2016–20



SOURCE: World Bank calculations based on the urban heat island (UHI) intensity data from 4 Earth Intelligence, https://www.4earthintelligence.com/.

NOTE: The map presents the five-year (2016–20) averages of UHI intensity, estimated by averaging the daytime and nighttime differences in land surface temperatures between urban and rural areas based on the 5 kilometer buffer. Regarding selection of the 100 cities, see box 1.2. IDN = Indonesia; KHM = Cambodia; MMR = Myanmar; MYS = Malaysia; PHL = Philippines.

PARTICULAR CONCERNS ABOUT UHI EFFECTS IN TROPICAL EAST ASIAN CITIES

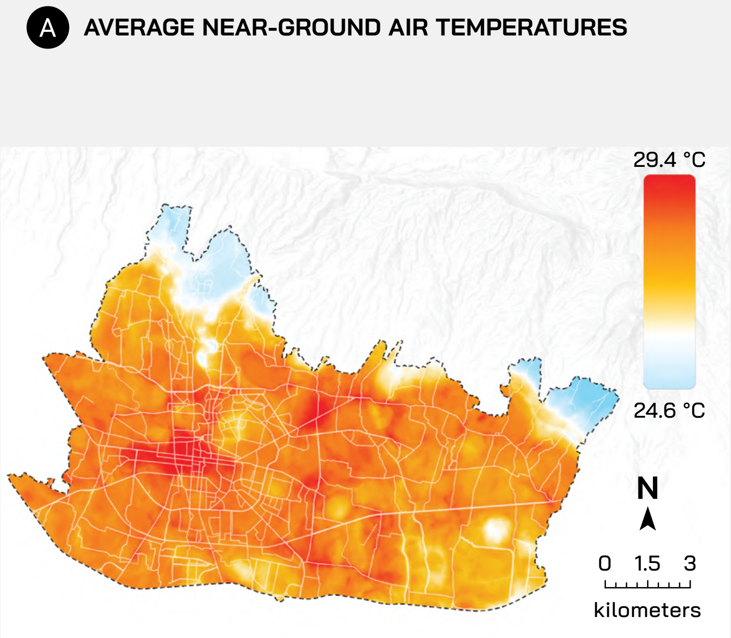
Strong UHI effects are a particular concern for the nearly 40 percent of East Asia's urban population living in humid tropical cities such as Hanoi, Viet Nam—where climate change, moreover, is making cities even hotter and more humid over time.[7]

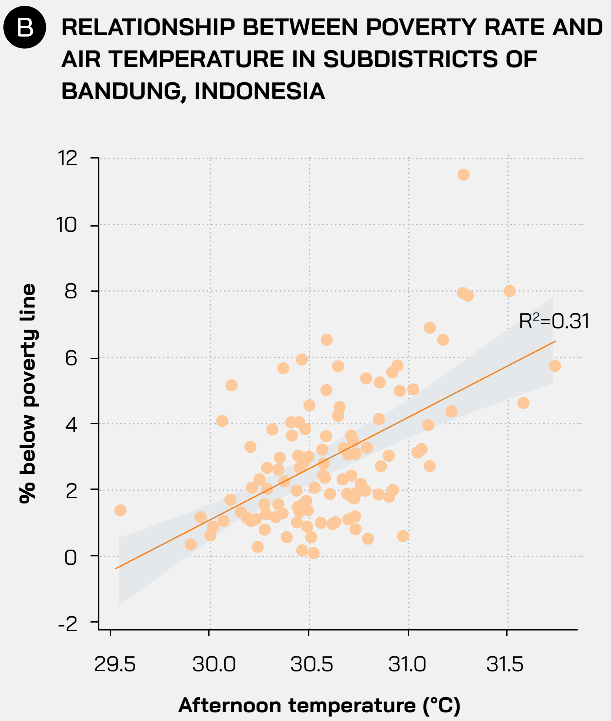
Tropical East Asian cities have also experienced an upward trend in annual precipitation since 1958.[8] This has contributed to increased humidity, compounding the adverse impacts of high temperatures on thermal comfort. Neither human bodies nor cities can cool themselves down as efficiently when extreme heat combines with high humidity. Cities can cool down through convection and the evaporation of water contained in vegetated surfaces. However, neither process works as well under highly humid conditions. Consistent with this, UHI effects and heat waves tend to be stronger in more humid cities (Manoli et al. 2019; Russo, Sillmann, and Sterl 2017).

UHI EFFECTS OFTEN STRONGER IN POORER NEIGHBORHOODS

The strength of the UHI effect also varies significantly across neighborhoods within individual East Asian cities. A good example of this is provided by Indonesia's second largest city, Bandung, which has a population of around 8.1 million in its wider metropolitan area (Roberts, Gil Sander, and Tiwari 2019). Research for this report shows that Bandung exhibits marked differences in ambient air temperatures across its neighborhoods, with poorer neighborhoods tending to be hotter (figure O.2).[9]

Figure 0.2 Ambient Air Temperatures in Bandung, Indonesia, 2022





SOURCE: Jones et al. 2023 and poverty data from Smeru Research Institute's Poverty and Livelihood Map of Indonesia 2015 (https://smeru.or.id/en/resource/poverty-and-livelihood-map-indonesia-2015).

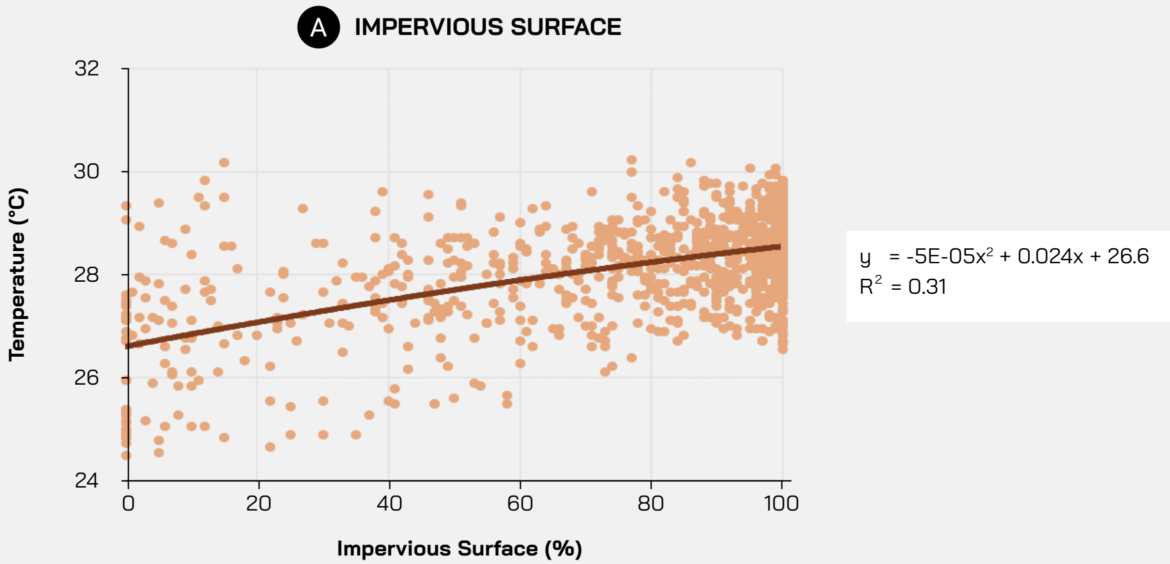
NOTE: In panel A, The ambient air temperature surface map was derived using machine learning techniques whose inputs included field measurements of near-ground air temperature taken on July 31, 2022. The map averages temperatures in degrees Celsius (°C) for three times of day (7–8 a.m., 12–1 p.m., and 5–6 p.m.) to arrive at a citywide average daytime temperature map. In panel B, poverty is defined as the proportion of people with per capita household consumption below the national poverty line (Rp 350,000 a day). Modeled heat data are based on vehicle-based ambient air temperature measurements in degrees Celsius (°C) taken on July 31, 2022.

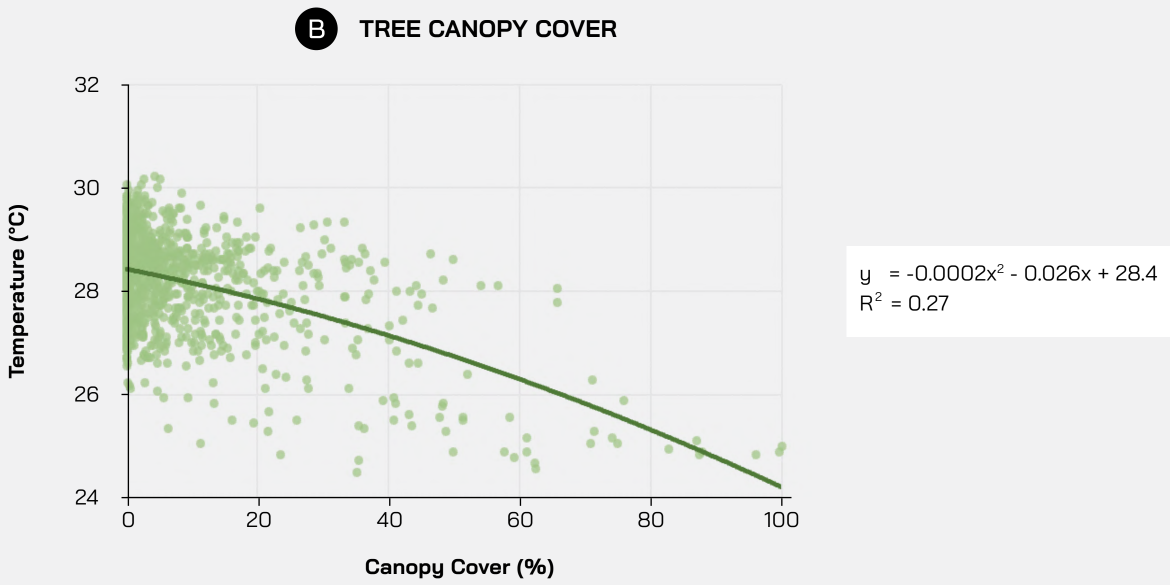
That poorer neighborhoods tend to experience stronger UHI effects in Bandung and many other cities around the world is likely the result of two processes:[10] first, richer households can outbid poorer ones when it comes to renting or buying property in more "pleasant" neighborhoods, which can include neighborhoods with more greenery and fewer impervious surfaces, both of which mitigate the UHI effect. Second, households, businesses, and governments all invest in the built form of city neighborhoods, making decisions about structural types, building materials, plot sizes, spacing between buildings, and vegetation prevalence that are shaped by their budgets and planning regulations.

In this context, households and businesses in poorer neighborhoods may be less able to afford investments in, say, urban greenery. Local governments may also target poorer neighborhoods less intensively for such investments, in part because wealthier neighborhoods may be better placed to lobby for the investments. To the extent that poorer households live in more informal or illegal slum neighborhoods, local governments may also be less likely to invest in those neighborhoods. Consistent with these processes, temperatures across Bandung's neighborhoods are positively correlated with the prevalence of impervious surfaces and negatively correlated with canopy cover (figure O.3).

Nevertheless, one must be careful not to overgeneralize—in some cities, including Beijing, Bangkok, and Manila, it is the wealthier neighborhoods that are hotter. More generally, Chakraborty et al. (2019) find that, for 7 out of a global sample of 25 cities, poorer neighborhoods are *cooler*. Several aspects of urban development, such as a city's housing market and connectivity, affect whether more affluent residents live in the city centers where UHI intensity is generally higher.
This illustrates the importance of studying individual cities in depth before drawing conclusions regarding policy interventions at a local scale.

Figure 0.3 Relationship between Air Temperature and Ground Cover Characteristics, in Bandung, Indonesia, 2022





SOURCE: Jones et al. 2023, using in situ heat measurements plus European Space Agency's World Cover 2020 dataset (https://worldcover2020.esa.int/).

NOTE: Near-ground air temperature measurements were taken during vehicle traverses of Bandung on July 31, 2022. Panels A and B present temperature measurements in degrees Celsius (°C) against the percentages of land cover that are impervious surface and tree canopy cover, respectively. The equations and R-squared values summarize relationships between air temperature and ground cover characteristics with each dot representing a 100-meter grid cell.

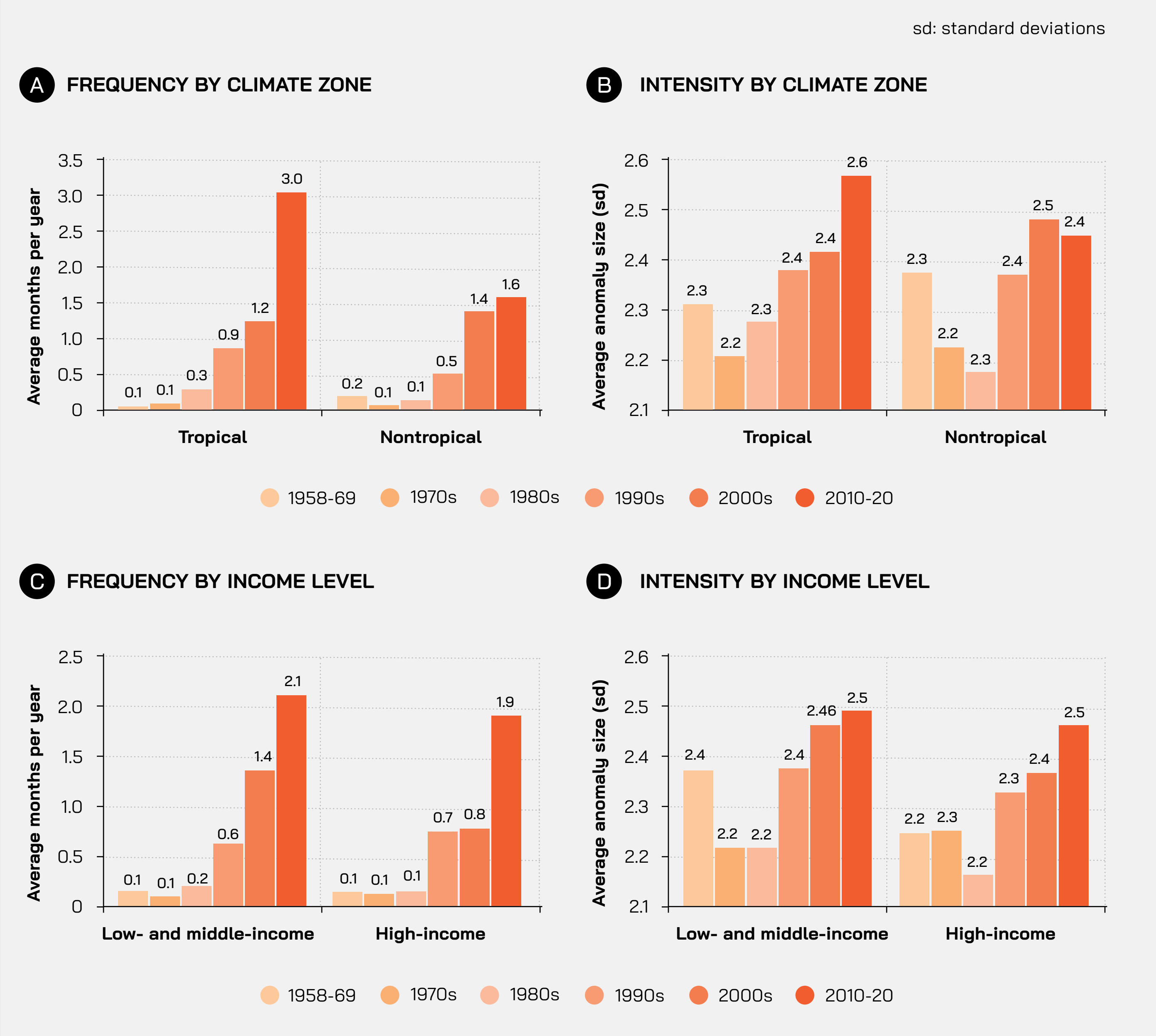
MORE SEVERE HEAT WAVES LIKELY AS UHI EFFECT INTERACTS WITH CLIMATE CHANGE

By raising its local baseline temperature, the UHI effect makes a city more prone to heat waves, the frequency and intensity of which have already been increasing in recent decades because of climate change—especially for East Asian cities in tropical zones and in low- and middle-income countries (figure O.4).

In the decades ahead, climate change will only further increase the frequency with which East Asian cities experience extreme heat. This is particularly the case for neighborhoods within cities for which the UHI effect is strongest, which, again, often tend to be the poorest neighborhoods. One such example is Phnom Penh, Cambodia's capital city, which is home to almost 3 million people. According to an urban climate model built for this report, Phnom Penh suffers from a current nighttime UHI effect (measured as the difference between the city center and outlying rural temperatures) of 2.5°C. [11]This effect already contributes to 23–25 heat wave days a year in the city's central neighborhoods, compared with only 2–5 such days a year in surrounding rural areas.

Fast-forward to 2050, however, and the number of heat wave days a year is projected to further increase to 40 in those neighborhoods of Phnom Penh most affected by the UHI effect, even under an optimistic climate change scenario.[12] Under a pessimistic climate change scenario, these heat wave days rise to 60 days a year.[13] By contrast, although they will not remain immune to climate change, leafy neighborhoods with extensive vegetation coverage and more space between dwellings are projected to remain cooler, with around one-third fewer heat wave days in 2050.

Figure 0.4 Frequency and Intensity of Extreme Heat Events by Climate Zone and Country Income Level, in East Asian Cities, by Decade (1958-69 to 2010-20)



SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: An "extreme hot month" is one in which a city's temperature for that month is at least 2 standard deviations higher than the month's city-specific historical norm, as calculated over the period January 1958–December 1999. Frequency is calculated as the number of extreme hot months per year. Intensity is calculated as the average size of the anomaly variable during consecutive extreme hot months. Panels A and C present the average frequency, and panels B and D the average intensity, across the sample of 3,033 East Asian cities. In panels A and B, "tropical" and "nontropical" refer to a city's latitude in absolute terms—"tropical" being in latitudes 0°–23.5° north and "nontropical" elsewhere.

WHY WORRY ABOUT THE URBAN HEAT ISLAND EFFECT?

THREAT OF EXTREME HEAT TO CITIES' COMPETITIVENESS

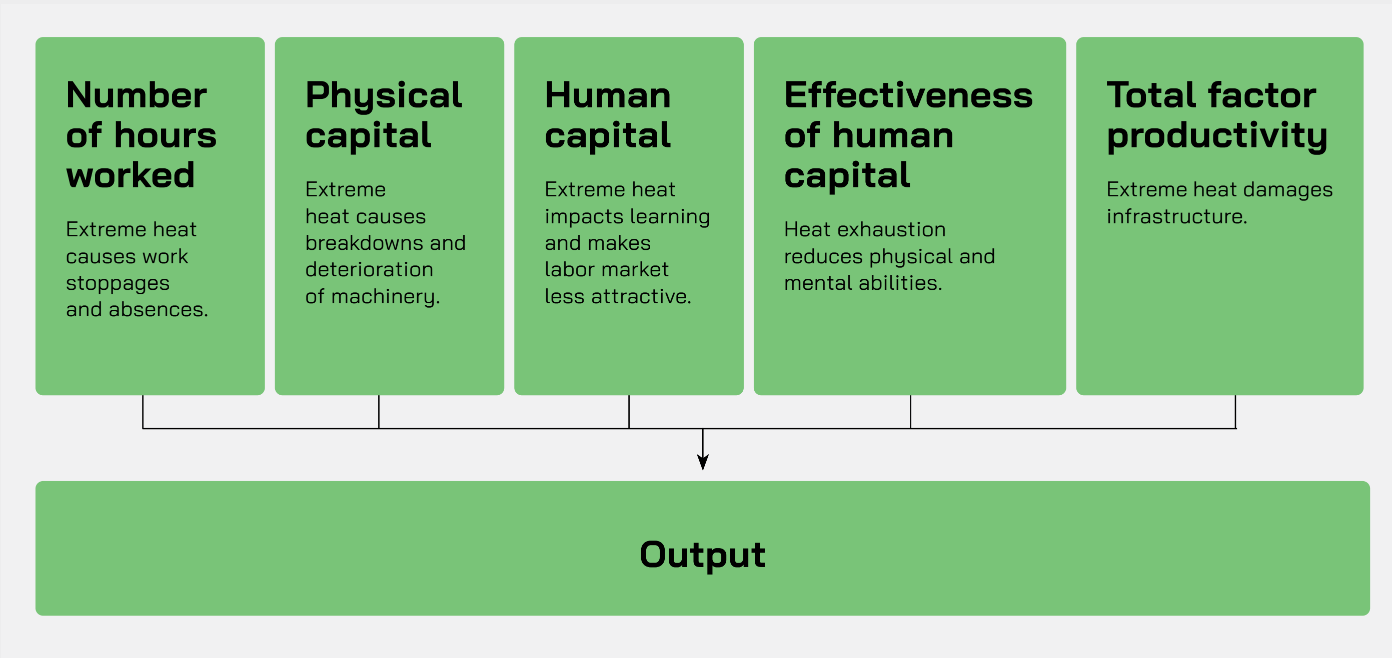
Effects on GDP. In addition to the more obvious health impacts, the UHI effect, especially when considered together with global warming, represents a serious threat to the competitiveness of East Asian cities. One recent study has estimated that, for a global sample of the world's 1,692 largest cities, productivity losses from the combination of the UHI effect and global warming will decrease the median city's real gross domestic product (GDP) by 1.4–1.7 percent by 2050 (Estrada, Wouter Botzen, and Tol 2017). For the worst-affected city, the loss could reach almost 11 percent by the end of the century. Crucially, the projected economic damage from heat in cities during the twenty-first century from both the UHI effect and climate change combined is up to 2.6 times the magnitude of projected losses from climate change alone.

Furthermore, the combined economic impact of the UHI effect and global warming is likely to be greater than the sum of their individual impacts. This is because the impact of temperature on a city's economy is nonlinear: the negative impact of a 1°C increase in temperature—say, from 35°C to 36°C—is greater than that of an increase from 30°C to 31°C (Burke, Hsiang, and Miguel 2015). Given that many East Asian cities, especially tropical ones, are starting off with higher temperatures than in cities in many other parts of the world, these global projections of economic losses probably understate the potential losses that they face in the absence of policy action.

Effects on hours worked and labor productivity. Extreme heat associated with both the UHI effect and climate change hurts a city's economy through many channels (figure O.5). Thus, increased exposure of a city's workers to extreme heat can result in involuntary reductions in hours worked, and therefore labor input, because of increased work stoppages and absences induced by heat-related illnesses.

In addition to reducing the *quantity* of labor input provided to a city's economy, exposure to extreme heat also reduces the *quality* of that input. This is because extreme heat exposure reduces both physical abilities and cognitive performance, meaning that it hinders worker performance in manual and more-skilled occupations alike (see, for example, Kahn and Li 2019; Seppänen, Fisk, and Lei 2006). The International Labor Organization (ILO) projects that, by 2030, the equivalent of 3.7 percent of total working hours will be lost in Southeast Asia owing to the combination of the reduced quantity and quality of labor inputs associated with extreme heat exposure. Losses will be particularly large in both the construction and industry sectors, for which it is projected that the equivalent of 8.9 percent and 3.9 percent of working hours, respectively, will be lost (ILO 2019). Cities that are more specialized in these sectors will, therefore, be particularly hard hit.

Figure 0.5 Channels of Extreme Heat's Impacts on a City's Aggregate Real Output



SOURCE: World Bank elaboration.

Effects on human capital. In addition to undermining the effectiveness of a city's current stock of human capital, increased exposure of the population to extreme heat can, in the longer run, also damage its economic growth by reducing its rate of human capital accumulation. This is because extreme heat exposure hurts both student learning and exam-day performance (Park, Behrer, and Goodman 2021; Park et al. 2020).[14]

Extreme heat due to the UHI effect and climate change may also undermine a city's human capital stock in the long run by making it a less attractive place to live for highly skilled workers—both because lower productivity associated with more extreme heat leads to lower wages and because workers view an overly hot city as an unpleasant place to live.[15]

Effects on physical capital. Finally, extreme heat may damage a city's economy both through its impacts on the physical capital of its firms and through damage to a city's infrastructure, thereby reducing a city's total factor productivity. Excessively high temperatures can result in heat-induced breakdowns and accelerated deterioration of machinery, particularly affecting capital-intensive industries. Meanwhile, extreme heat can damage transportation infrastructure by causing roads and rails to buckle because of thermal expansion and by melting or softening paving material. Heat can also reduce the performance of electrical power lines and photovoltaic cells, increase the risk of oil and gas pipeline ruptures, cause geotechnical failures in embankments and earthworks, and damage underground communications infrastructure (Dodman et al. 2022).

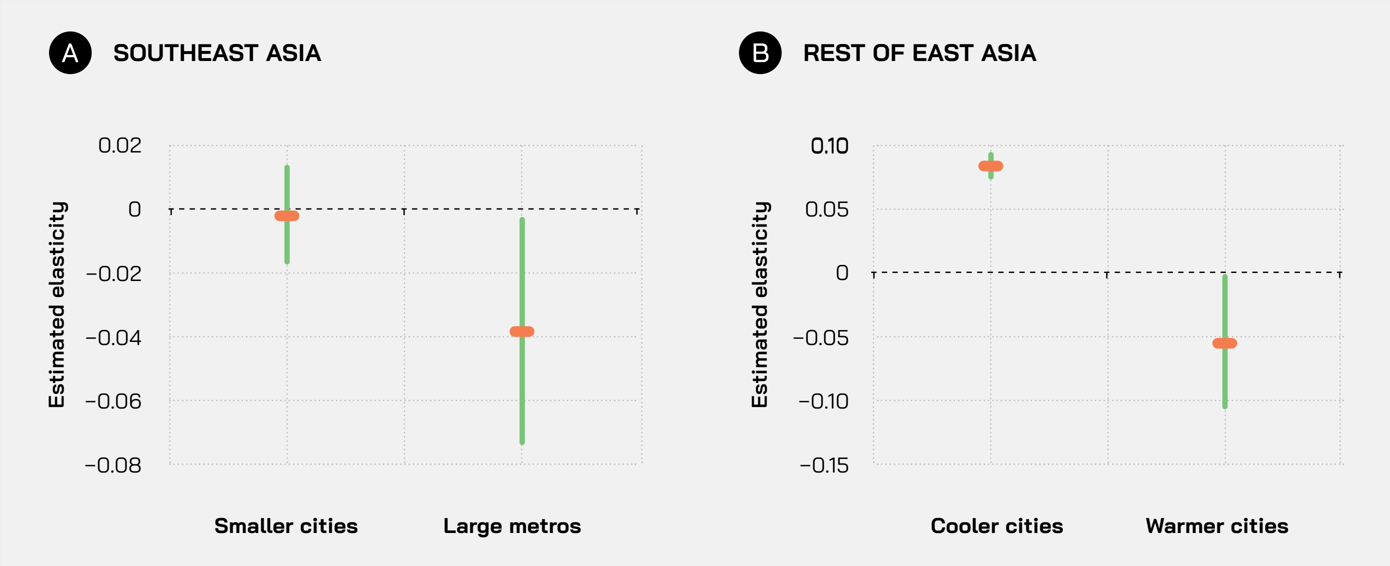
IMPACTS OF EXTREME HEAT ON URBAN ECONOMIC ACTIVITY

Original empirical research for this report for a large sample of East Asian cities (see chapter 3, box 3.3 of the main report) finds that extreme heat events have significant negative impacts on local economic activity in two city groups—large Southeast Asian metros and cities in the rest of East Asia that have warmer baseline climates. A temperature increase of more than 2 standard deviations above a city's own historical norm for any given month reduces its nighttime light intensity—a commonly used proxy for economic activity—by an estimated 3.9 percent during that month in large Southeast Asian metros (figure O.6, panel A). Elsewhere in East Asia, in cities with warmer baseline climates, such an extreme heat event has an even larger estimated impact on nighttime light intensity: −5.5 percent (figure O.6, panel B).

By contrast, extreme heat events have no significant impact on the economic activity of smaller Southeast Asian cities, and the estimated impact on economic activity for East Asian cities with cooler baseline climates is even positive. One potential explanation for this latter result could be that, for cities with cooler climates, a heat event results in more pleasant evenings, which benefit outdoor economic activity, albeit possibly at the expense of daytime economic activity.

These results highlight the fact that increases in temperature and heat events driven by the combination of the UHI effect and global warming should be a particular concern for large East Asian cities with tropical climates. Consistent with this, this report also finds that more densely populated cities in East Asia tend to suffer from more severe UHI effects.

Figure 0.6 Estimated Impacts of Extreme Heat Events on City Nighttime Light Intensity in East Asia, by Subregion, April 2012–December 2020



SOURCE: World Bank calculations based on the analysis of Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime lights monthly composites (https://payneinstitute.mines.edu/eog-2/viirs/) and monthly weather data from Climatology Lab, TerraClimate (https://www.climatologylab.org/terraclimate.html).

NOTE: Cities are defined as urban centers following the "degree of urbanization" methodology of the Global Human Settlement Layer (GHSL) Urban Centre Database. Each red marker shows the estimated impact of an extreme heat event, obtained by regressing the natural log of sum of lights in city *c* in month *m* on a dummy variable which takes the value 1 if temperature of city *c* in month *m* deviated from the city's long-run mean temperature for the month by at least +2 standard deviations; the dummy variable takes the value 0 otherwise. Vertical bars indicate the bounds of the 90 percent confidence interval associated with the corresponding estimated impact. Panel A is based on the analysis of 170 Southeast Asian cities. Panel B is based on the analysis of 536 cities in the rest of East Asia. The analysis of Southeast Asian cities (panel A) covers all 12 months of the year because monthly temperatures remain relatively warm throughout the year for those cities. In contrast, the analysis of cities in the rest of East Asia (panel B) covers only warm months, (June, July, and August) given their more variable climates.

HARMFUL IMPACTS OF EXTREME HEAT ON HEALTH AND LIVABILITY

Extreme heat makes East Asian cities not only less competitive but also less healthy and livable. More than 100,000 people in East Asia and the Pacific already die each year from causes linked to extreme heat (Zhao et al. 2021). And projections for middle-income countries in East Asia indicate that future warming during this century will increase heat-related mortality more than it decreases cold-related mortality, even after adjusting for increased resilience due to income growth (Bressler et al. 2021).[16] Evidence for North American countries furthermore suggests that heat waves can harm mental health, resulting in increased numbers of suicides (Burke et al. 2018), and lead to both more car and workplace accidents (Park, Pankratz, and Behrer 2021; Wu, Zaitchik, and Gohlke 2018).

Extreme heat is also associated with more crime, including, according to some evidence, crime that involves sexual violence (Heilmann and Kahn 2019; Hu et al. 2017; Sanz-Barbero et al. 2018). Hence, extreme heat makes cities not only less healthy but also less livable. As discussed earlier, this may, in turn, damage a city's ability to attract high-skilled labor.

HOW EXTREME HEAT LIMITS CITIES' INCLUSIVENESS

As discussed earlier, in many but not all cities, including in many East Asian cities it is the poor who live in the hottest neighborhoods with the most extreme UHI effects. It follows that, in such cities, the poor are the most likely to bear the brunt of harms from extreme heat—such as increased health risks, heightened risk of crime, and reduced productivity and wages.

The poor not only face greater exposure to extreme heat in many cities but also are less financially equipped to adapt. For example, air conditioner (AC) ownership increases with household income in both China and Indonesia (Davis et al. 2021; Pavanello et al. 2021). This lower capacity of the poor to adapt may help explain why—for example, in Hong Kong SAR, China—the relationship between heat and mortality is stronger in poorer districts than in richer ones (Chan et al. 2012).

Extreme heat can also affect other dimensions of a city's inclusiveness, beyond poor versus nonpoor. For instance, it is well known that the elderly, as well as those with disabilities or chronic medical conditions, are most at risk of the health impacts of heat (Deuskar 2022). Given the relatively elderly populations in high-income East Asian countries, extreme heat is already a pressing concern for their cities. It will also increasingly concern cities in low- and middle-income East Asian countries as their populations age. Between 2020 and 2050, the share of the population over the age of 65 is projected to almost quadruple in Mongolia; more than triple in Cambodia, Laos, and Indonesia; and nearly triple in Myanmar and Viet Nam (UN DESA 2017). Varquez et al. (2020) project that, in Jakarta, the combined effects of population aging and rising daytime temperatures will cause the total number of heat-related elderly deaths in August to be 12–15 times higher in the 2050s than it was in the 2010s.

AIR CONDITIONING: NO PANACEA

When a person faces extreme heat, the most obvious response is to purchase an air conditioner (AC) as soon they can afford it, or if air conditioning is already installed, to turn it up. And given the increasingly hot and humid climates of many low- and middle-income East Asian countries, it is unsurprising that rates of AC ownership and use are rapidly growing. Indeed, energy use for air conditioning in Association of Southeast Asian Nations (ASEAN) countries has increased by a factor of 7.5 over the past 30 years and is expected to continue to increase as incomes and temperatures in the region rise (IEA 2019).[17]

However, although AC use can cool indoor spaces and partially enclosed outdoor spaces (albeit less effectively), it cannot cool open outdoor spaces. Indeed, a local negative externality of AC use is that it exacerbates the UHI effect by transferring heat from indoors to outdoors, creating a potential vicious cycle of intensified UHI effects and increased AC use. Furthermore, AC use is energy intensive and, therefore, so long as energy mixes remain carbon intensive, contributes to climate change. As such, AC represents a serious form of "maladaptation" to extreme heat (Viguié et al. 2020). There is an urgent need for policies that promote other forms of mitigation of, and adaptation to, both the UHI effect and extreme urban heat more generally.

WHAT CAN BE DONE?

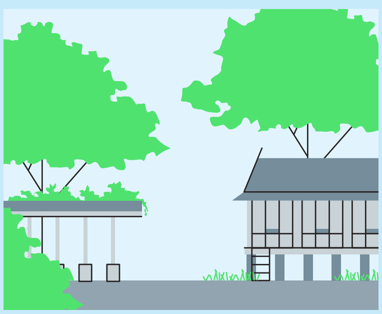
While heat stress presents growing risks to East Asia's urban populations, the challenge is one that the region's cities can address decisively and effectively. Working in tandem with national governments and neighborhood-level stakeholders, East Asian cities have at their disposal a wide range of policy and investment options to reduce heat exposure and help residents better anticipate and cope with extreme conditions. However, resilience to extreme heat is no ordinary policy challenge. At least three factors complicate the response, making new and innovative mindsets essential. Making a city resilient to heat requires:

- *Access to an unusually wide variety of skills* from across government and the private sector. Contributions are needed not only from urban planners and forestry managers but also from public health specialists, doctors, emergency managers, architects, real estate developers and business owners.
- *Action across physical scales,* from changing the material of individual walls and roofs to rethinking areawide land use plans to promote increased greenery and wind flow.
- *New governance structures* to ensure both clear lines of authority and coordination of action. Established policy priorities such as transport, health, and education typically have accountability and resources vested in clearly defined agencies, but the authority and capability to reduce heat risks is highly fragmented among government entities.

Leadership is therefore crucial. To rise to the extreme heat challenge, city leaders must establish an evidence base, articulate a vision for change, and build new coalitions for action.

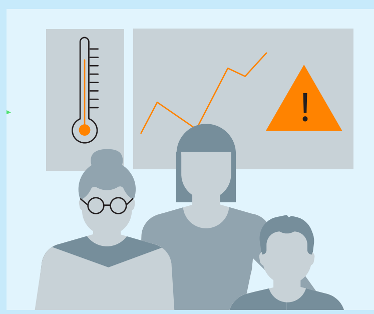
To help structure an effective response to the rising heat stress in East Asian cities, this report proposes a policy framework based around three principles: cool the physical spaces of a city ("Places"); act during heat waves to prevent death and illness among vulnerable populations ("People"); and mainstream heat resilience into city strategies, operations, and budgets ("Institutions"). Addressing the three principles in tandem is important given their interlocking nature, and it requires concerted leadership by city authorities working together with central government agencies such as health departments and national meteorological services (figure 0.7).

Figure 0.7 The "Places, People, Institutions" Framework for Urban Heat Resilience



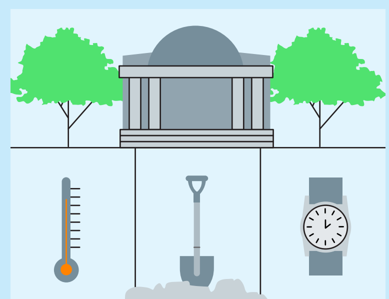
Places

- Advance urban greening through strategic planning
- Cool city spaces through wind, shade and design
- Engage building owners to tackle indoor heat



People

- Save lives through heatwave early warnings
- Protect heat-exposed workers



Institutions

- Mainstream heat mitigation into city strategies and operations

SOURCE: World Bank.

Heat stress is experienced in the physical *places* of a city, both outdoors and in. Making streets, plazas, parks, factories, workshops, marketplaces, and homes cooler will reduce heat exposure, contributing to a competitive economy and healthy population. Heat waves are also time-bound emergencies that endanger *people*—especially elderly people, children, exposed workers, and those with health vulnerabilities. Identifying the groups that are disproportionately at risk and protecting them during heat waves is critical. Finally, mainstreaming heat resilience across a city's *institutions*—its various governmental departments and agencies as well as civil society and professional groups that have essential roles to play—is a prerequisite to effective action.

The remainder of this chapter presents six strategic options for action to deliver on the "Places, People, Institutions" agenda for heat resilience. For most cities, all six strategic options are likely to be beneficial and complementary – but the relative importance of each requires careful consideration given existing policy frameworks, and local circumstances such as the prevailing climate and water availability. By considering each option and selecting those that most closely fit local needs, East Asian cities can develop strategic policy and investment frameworks for resilience to extreme heat conditions.

STRATEGIC OPTION 1: ADVANCE URBAN GREENING THROUGH STRATEGIC PLANNING

Green assets such as trees, grass, and shrubs promote cooler city spaces. However, levels of vegetation tend to be highly uneven between city neighborhoods. Prosperous residential areas tend to have better organized and resourced tree care and may have larger plot sizes, whereas central business districts and poor residential neighborhoods often lack greenery. Expanding the reach of urban nature, especially where trees and shrubs are in short supply, can increase shade and evapotranspiration, resulting in cooler temperatures.[18] Urban greening is a key ingredient in heat resilience strategies and benefits diverse groups, including workers and shoppers who frequent dense city centers as well as the poorest residents whose neighborhoods may lack grass, shrubs, and trees.

The return on investment from urban greening can be high. A metareview of 220 greening interventions found a reduction in localized temperatures exceeding 2°C in one-third of cases (Santamouris et al. 2017). Planting at "microsites," (including tree pits and on traffic medians) cools air locally, while planting at extensive sites (such as parks) can generate a "park cool island effect" that benefits surrounding blocks. Pocket parks—small parks of around 1,000 square meters—may confer greater cooling benefits than a single large park, especially in high-rise tropical regions (Giridharan and Emmanuel 2018).

One study found that expanding tree cover on 10 percent of vacant land could bring temperature reductions of 1–3°C to 647,000 people in Seoul, 772,000 people in Jakarta, and 2.2 million residents in Beijing —at a cost of just US$1–3 per beneficiary (DeJarnett, McDonald, and McDonald 2016). City leaders can consider adopting the so-called 3-30-300 rule: each resident should be able to see at least 3 trees from their home, have 30 percent canopy cover in their neighborhood, and live no farther than 300 meters from a green space (Konijnendijk 2021).

Meeting ambitious goals such as the 3-30-300 target across East Asian cities will require resources and long-term planning. Indeed, urban greening is easier said than done. Key challenges in urban forestry expansion include species selection; survival during the crucial first year after planting; tree maintenance and pruning; managing competition between tree roots and the needs of residents and infrastructure; and securing community support for planting and maintenance.[19] It further requires strategic planning to expand green assets on large and small sites as well as on publicly owned, commercial, and residential land. Forward planning with a timeline of at least a decade is particularly important for urban forestry given the speed at which trees grow.

In this context, adopting dedicated urban forestry master plans is highly advisable. By setting a strategic vision for green assets, such plans provide a powerful tool to ensure that legislative frameworks and budget availability align with a city's future greening vision and to track progress toward goals.

STRATEGIC OPTION 2: COOL CITY SPACES THROUGH WIND, SHADE, AND URBAN DESIGN

In addition to "green assets," wind is a crucial resource, especially for coastal cities. Sea breezes form when air above a city warms at a different rate than air above the sea, providing a cooling effect and dispersing air pollution. In Singapore, air temperatures fall by 2°C when wind speed increases by 1.5 meters per second (Erell, Pearlmutter, and Williamson 2011). However, urban construction can inhibit wind. Tall buildings located directly on the water's edge can block sea breezes, resulting in significantly warmer and more polluted air inland.[20]

East Asian cities where rapid growth of tall buildings along the coast is anticipated should learn from examples such as the air ventilation assessment for Hong Kong SAR, China. Just as the city's urban design guidelines (Hong Kong SAR, China, Planning Department. 2015) provide clear guidance on design features and requirements—such as stepped-back buildings, designated breezeways, and arranging buildings to channel wind—designing cities "with the wind" may offer significant benefits (Ng 2009).

As well as wind, shade and access to waterfront environments are valuable commodities in hot climates. Urban planning documents and cooling action plans should seek to increase shade in public places. In Freetown, Sierra Leone, the city government introduced awnings in public marketplaces, providing relief for shoppers and street vendors. In Singapore, a distinctive network of covered walkways adds to livability. Restoring and preserving "blue assets" such as rivers, canals and lakes can also improve thermal comfort for city residents as exemplified by the Seoul Urban Greenway: a cool and attractive 10-kilometer urban park created by revitalizing a historic stream in South Korea's capital (Cho 2010). In promoting cooler urban designs, an important source of inspiration is traditional building practices ("vernacular architecture"), which, in many East Asian cities, offer a rich tapestry of architectural practices that promote ventilation, minimize heat storage in surfaces, and provide shade (Satwiko 1999).

STRATEGIC OPTION 3: ENGAGE BUILDING OWNERS TO TACKLE INDOOR HEAT

Poorer neighborhoods often have higher outdoor air temperatures, but when indoor conditions are also considered, "thermal inequalities" loom even larger. Addressing indoor heat exposure is essential to reducing heat illness and sustaining labor productivity, since people spend much time indoors. The design and construction of buildings is a key entry point to address heat exposure. City governments' policy leverage differs depending on building ownership and established planning procedures, and hot buildings cannot be transformed into cool ones overnight. However, city authorities can systematically engage with building owners to promote cooler design and materials while keeping an eye out for "quick wins" that reduce harmful heat exposure of many people at low cost.

City authorities can employ a combination of "hard" (mandatory regulations and direct public investment) and "soft" measures (including incentives and information provision) to promote cooler buildings. Among hard measures, city governments, together with relevant national authorities, can review and strengthen building codes and zoning requirements. A case in point is India's 2016 building code, which specifies reflectivity and emissivity values for roof-covering materials on new or substantially renovated roofs (ESMAP 2020).

City governments can also lead by example through publicly owned facilities or those procured through public-private partnerships. Schools, clinics, government buildings, and sport facilities all provide opportunities to pilot solutions, build construction industry capacity, and create a local evidence base on the effectiveness of cool building measures.

Given the limits of public budgets and building code enforcement, a broader set of tools including fiscal and planning incentives and concessional finance for cool building upgrades is worth examining on a case-by-case basis. Hong Kong SAR, China; Singapore; and Tokyo are among the cities offering floor-area ratio bonuses—which permit larger buildings on a given plot size—if developers adhere to green building standards.

Property tax rebates for cool roof installations are another option.[21] Cool roof programs reduce indoor heat gain through white paint coatings that reflect away the sun's energy. They represent one of the most cost-effective and scalable heat-reduction measures, as demonstrated by Cool Roofs Indonesia, a program whose interventions have resulted in indoor temperature reductions as high as 10°C (Clean Cooling Collaborative 2022). Integrating cool roofs into public housing programs and incentivizing their adoption by commercial building owners offers major benefits.

STRATEGIC OPTION 4: SAVE LIVES THROUGH HEAT WAVE EARLY WARNINGS

While cities can take incremental steps to reduce heat exposure across indoor and outdoor settings all year round, the moment of truth for preventing heat-related deaths and illnesses is when a heat wave strikes. To a large degree, deaths during heat waves are both predictable and preventable: they are concentrated in groups that have high exposure to heat—owing to factors such as housing quality or heat-exposed occupations—as well as high *vulnerability* to heat, whether because of age, occupation, or health status. The most effective measures to prevent a heat wave death are those taken by at-risk individuals or those closest to them: their family, health care providers, or employers.

Heat waves cause most deaths when they take populations by surprise by coming early in the season. As a substantial body of evidence shows, heat early warnings can save lives by informing people that their health faces an imminent threat—prompting them to take actions to protect themselves—as well as by activating protocols in health care, education, and workplace settings (Toloo et al. 2013).

Effective early warning systems go beyond simply announcing high temperatures to predicting upcoming heat-related deaths and activating preplanned interventions to safeguard at-risk groups, as several examples illustrate. In the United States, the city of Philadelphia—which in 1995 introduced one of the world's first population health-focused heat wave warning systems—reduced heat wave mortality by 4.5 percent through the interventions it activates upon declaration of a Heat Health Emergency. These interventions range from activating a "Heatline" telephone service to using libraries and swimming pools as cooling centers and supporting homeless people (Weinberger et al. 2018). And in Hanoi, the Viet Nam Red Cross and Viet Nam Institute of Meteorology, Hydrology and Climate Change jointly implement warnings based on a combined measure of heat and humidity (Jjemba et al. 2020).

Japan, a country with a hot summer climate, has developed and refined an extreme heat early warning system centered on the concept of "heat illness reduction." Alerts are issued by the Japan Meteorological Agency and disseminated via television and radio, private weather companies, email, social media channels, and local government, including via public loudspeakers. Of alert recipients who responded to an evaluation survey, 31 percent changed their behavior to stay indoors, 52 percent hydrated more frequently, and 75 percent checked more regularly on family members (Japan MOE and JMA 2021). Japan's system has been incrementally improved over many years.

Introducing effective heat wave early warnings is not trivial; it requires researching local heat wave–mortality relationships based on public health data, establishing partnerships between the city and national levels, and setting up monitoring and warning issuance mechanisms. However, the benefit-cost ratios of such warning systems are exceptionally favorable. Heat wave early warnings can save lives during heat waves and form the hub of broader heat action plans at the city level.

STRATEGIC OPTION 5: PROTECT HEAT-EXPOSED WORKERS

Exposure to heat stress varies by occupation. Workers in physically demanding outdoor occupations such as construction, road building and repairs, and waste picking are among the most exposed. However, many indoor jobs also involve great heat stress because of physical intensity, building characteristics, exposure to indoor heat sources (especially in manufacturing), and lack of air conditioning. Many such roles skew toward a female workforce, particularly in industries such as textiles, which are widespread in East Asia.

The physiological limits of human heat endurance—established through studies in military, sports, and occupational health and safety—have motivated legislation in many countries that limits workplace heat exposure based on Wet Bulb Globe Temperature (Kjellstrom, Holmer, and Lemke 2009). Although the devices required to monitor indoor heat stress are inexpensive, enforcement is often lacking. However, as illustrated through the work of organizations such as the C40 Cool Cities network, a wide range of actions can shield city residents from heat exposure during their working day. These can include increasing access to air conditioning through cooling centers accessible to street vendors and transportation workers. They can also take advantage of heat wave early warnings (see Strategic Option 4). In Ahmedabad, India, the city's pioneering Heat Action Plan consulted heat-exposed workers and established protocols to be implemented in sectors such as construction during "orange" and "red" alerts. These protocols include distribution of drinking water and work stoppage from 12 p.m. to 4 p.m. (Knowlton et al. 2014).

STRATEGIC OPTION 6: MAINSTREAM HEAT RISK REDUCTION INTO CITY INSTITUTIONS AND STRATEGIES

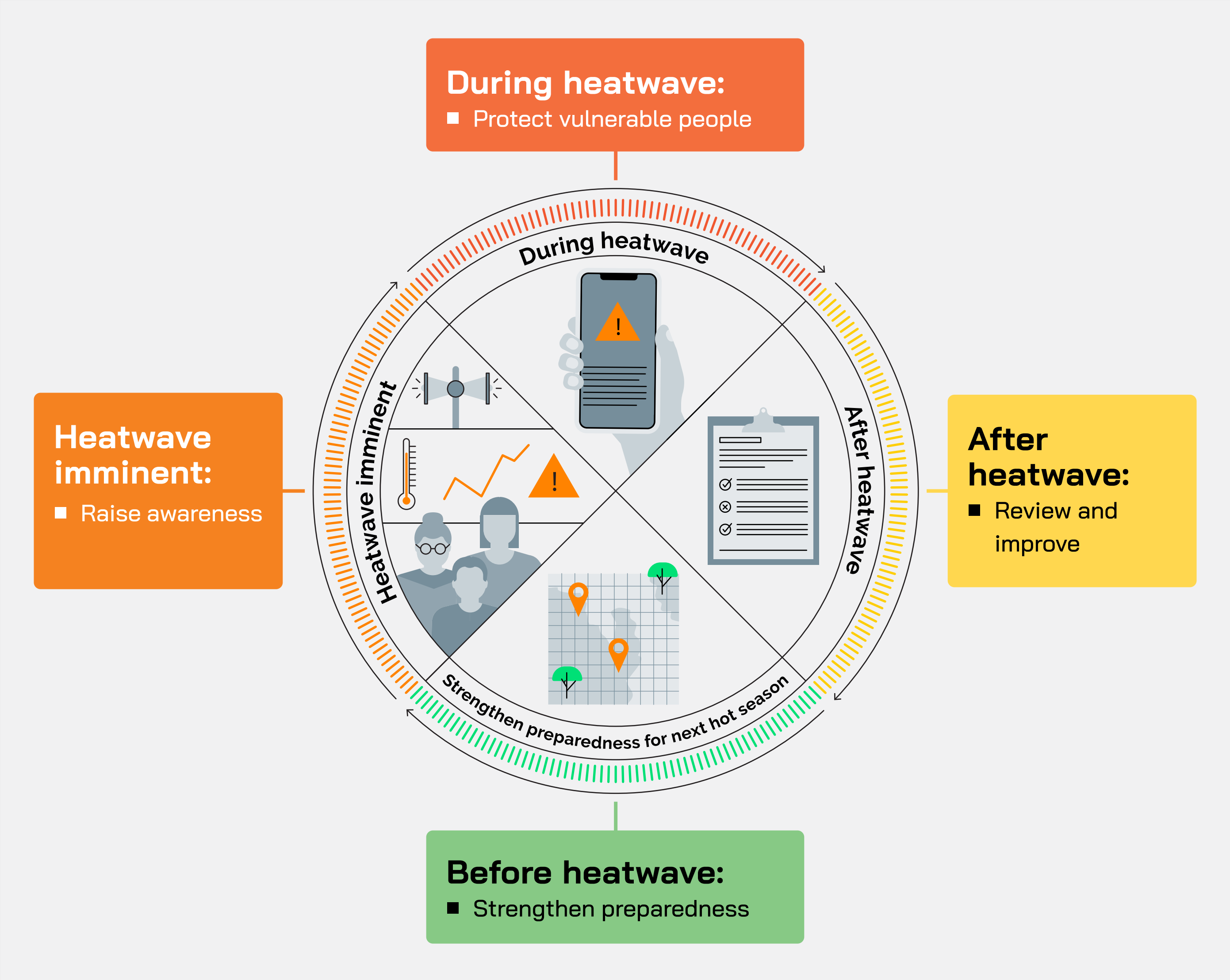
Heat mitigation presents some unusual characteristics as a public policy challenge:

- *Managing across physical scales.* Making city landscapes cooler requires action across physical scales to change construction and design practices—from the selection of roof and wall materials to the design of buildings and their surroundings as well as incorporating "green" and "blue" elements in areawide plans.
- *Utilizing diverse policy instruments.* Heat stress interventions span a wide array of policy instruments—from direct public investments in school buildings or public plazas to "hard" legislative mandates (such as vehicle use limitations) and "soft," bottom-up measures to incentivize and encourage action by building owners and residents (for example, tree stewardship schemes and public space design guides).
- *Managing across agencies.* The challenge of extreme heat in cities requires points of contact with an unusually large number of governmental agencies. From planning and parks departments to transit operators, and from health systems to meteorological agencies, effective action requires that many city and national entities work around the same table.

An important step is to elevate extreme heat response to the senior official level. One option is to follow the growing number of cities that have appointed a chief heat officer. Because the actions needed to cool cities are highly fragmented and decentralized, elevating the issues and forging collective action through consultation and public awareness campaigns are key. For cities that are beginning to recognize the need to act, a crucial first step might be to establish an extreme heat task force mandated to review evidence of extreme heat, gather and analyze data, consult affected groups, and recommend actions.

Hot weather follows an annual seasonality. It follows that heat wave preparedness and response should also follow an annual seasonality—by strengthening preparedness in the run-up to the hot season, activating protocols when a heat wave is imminent, acting to protect the vulnerable during extreme heat events, and conducting after-action reviews before recommencing the cycle (figure 0.8).

Figure 0.8 The Heat Wave Risk Management Cycle



SOURCE: World Bank elaboration based on Singh et al. 2020.

CONCLUSION

Extreme urban heat arising from the combination of the urban heat island effect and climate change represents a significant and growing drag on the economic competitiveness of many East Asian cities while also contributing to cities that are less healthy, livable, and inclusive. To rise to the urban heat challenge, leaders in East Asian cities should adopt a "Places, People, Institutions" framework that has three key elements—making places cooler, protecting vulnerable people, and mainstreaming heat into institutions. By acting now, East Asian city leaders can help make their cities not only cooler, but more prosperous, inclusive, and livable.

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NOTES

1 The surface temperature is averaged across land and water. The preindustrial period is defined as 1880–1900. Data are from Lindsey and Dahlman (2021).

2 Throughout this report, temperatures are generally referred to in degrees Celsius rather than Fahrenheit. A conversion table between Celsius and Fahrenheit can be found in the report's front matter.

3 The methods underpinning the derivation of these temperature differentials are described in more detail in the next section and chapter 1 of the main report.

4 This 100-city sample includes 20 cities each from China and Indonesia; 13 from Viet Nam; 12 from the Philippines; 9 from Malaysia, 5 from Myanmar; 4 each from Cambodia, Laos, Papua New Guinea, and Thailand; and 1 each from Japan, the Republic of Korea, Mongolia, Singapore, and Timor-Leste. For more details about how this sample was selected, see chapter 1, box 1.2, of the main report.

5 As shown in figure O.1, panel B, the mean five-year moving average UHI effect was stronger during the years 2010–14. The reasons for this are unclear and would require further investigation that is beyond the scope of this report.

6 In addition to Singapore, the top 10 list includes 1 city in Indonesia, 5 in Malaysia, and 3 in the Philippines.

7 Between 1958 and 2020, Hanoi's average land surface temperature increased by 0.9°C, to 24.3°C.

8 By contrast, average annual precipitation has remained broadly stable since 1958 for nontropical East Asian cities overall, although there is evidence of more severe year-to-year variation over 2011–20 than in earlier decades.

9 As discussed in more detail in chapter 2 of the main report, this research was undertaken by the World Bank in collaboration with Bandung Institute of Technology (Institut Teknologi Bandung) and CAPA Strategies using a "citizen science" approach to gather field measurements of ambient air temperatures. These temperature differentials were found to be highest in the evening, with a 7°C disparity between the hottest and coolest neighborhoods as measured between 5 p.m. and 6 p.m. Heat-trapping urban materials such as asphalt roads, parking lots, walls, and corrugated iron roofs absorb solar energy during the day and release it at night.

10 For evidence on other cities around the world see, among others, Chakraborty et al. (2019), Popovich and Flavelle (2019), and Rossitti (2022).

11 The analysis described in this paragraph was carried out for this report by VITO NV, using its UrbClim model.

12 For this analysis, a heat wave day is defined as a day for which the temperature exceeds the 90th percentile temperature of a historical reference period (2000–20) for at least three consecutive days. The optimistic climate change scenario corresponds to the Intergovernmental Panel on Climate Change (IPCC) Shared Socioeconomic Pathway (SSP) 1-1.9 scenario, under which global carbon dioxide emissions are curbed (cut to net zero by about 2050). Meanwhile, the pessimistic scenario corresponds to the IPCC SSP3-7.0 scenario, under which global emissions maintain a stronger upward path before stabilizing.

13 It is also projected that these neighborhoods will experience tropical nights for 80–90 percent of the year in 2050 depending on the climate change scenario, where a tropical night is one for which the Wet Bulb Globe Temperature remains above 25°C. In the absence of cooling, tropical nights place the human body under extreme stress. Particularly for old people, young children, and those with health vulnerabilities, such nighttime temperatures inhibit cooling, rest, and recovery and are associated with higher death rates.

14 Zivin et al. (2018) find that a 1 standard deviation increase in exam-day temperature (3.3°C) during the Chinese National College Entrance Examination reduces a student's test score by an estimated 1.1 percent (0.096 standard deviations). This, in turn, reduces the probability of a student's admission into a first-tier university by nearly 2 percent.

15 A worker may consider an extremely hot and humid city to be unpleasant both because they dislike the heat itself and/or because extreme heat leads to worse outcomes on various other dimensions of a city's livability, as discussed later in the Overview. An important area of future potential research would be how extreme heat affects the migration decisions of workers of different skill levels.

16 Heat-related illnesses include dehydration, heat cramps, and heat stroke. Overheating also increases the likelihood of death from preexisting conditions such as respiratory and cardiovascular diseases (WHO 2018). High temperatures further reduce water quality by enabling the development of harmful algal blooms and toxic bacteria and the depletion of oxygen in urban water bodies. Spikes in the concentrations of waterborne bacteria and viruses can trigger outbreaks of diseases including cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio (USAID 2020).

17 ASEAN member countries include Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

18 More generally, in the sample of 100 East Asian cities for which this report estimates the strength of the UHI effect, a strong negative correlation exists between the strength of this effect and a city's average level of vegetation (see chapter 1 of the main report).

19 For an overview of the key challenges in urban tree management, see Roloff (2016).

20 For an overview of how tall buildings affect airflow, heat, and air pollution, see Oke et al. (2017) (chapter 4).

21 For a detailed typology of interventions for cooler buildings, see ESMAP (2020).

CH

CHAPTER

1

THE URBAN HEAT ISLAND EFFECT AND THE EVOLUTION OF EXTREME HEAT ACROSS EAST ASIAN CITIES

KEY MESSAGES

Because of the concentration of artificial surfaces combined with a lack of vegetation, East Asian cities suffer from a strong urban heat island (UHI) effect. From 2016 to 2020, cities were, on average, around 1.6–2.0 degrees Celsius (°C) hotter than their rural surroundings, rising to over 5.0°C hotter in the most extreme case.

The UHI effect in East Asia's cities is compounded by climate change-driven heat stress. Extreme heat events—measured as abnormally high temperatures relative to historical norms—were, on average, 23 times more frequent and 13 percent stronger in 2010–20 than during the 1970s.

IIncreased severity of extreme heat varies widely across East Asian cities. The largest increase has occurred in already hot and humid tropical regions, highlighting the challenges that lower-income tropical cities face in heat mitigation and adaptation.

The adverse impacts of extreme heat could be equally serious on nontropical cities, notably in the northern and southwestern parts of China, owing to a lack of adaptation.

INTRODUCTION

Rising temperature is a growing problem across East Asia[1]. And nowhere is this problem greater than in the region's cities, where increasing average temperatures due to climate change are interacting with and compounding the so-called urban heat island (UHI) effect. This effect arises from, among other things, the concentration of impervious surfaces and relative lack of vegetation that are hallmarks of cities, especially those that are poorly planned and characterized by both slums and choking levels of traffic congestion. Indeed, travel from a less built-up part of the Bangkok Metropolitan Region to its central business district, and you will feel a change in atmosphere. The temperature difference used to be 4.4°C in 2000. Because of additional land cover modifications compounded by global warming, the difference had increased to about 5.8°C by 2020 (Pan et al. 2023).[2]

Extreme urban heat, driven by the UHI effect alongside global warming, is bad for the human body and mind. Those most at risk from heat stress include young children, the elderly, and the unwell, who have less capacity to adapt, as well as low-income populations who tend to live in low-quality housing with less access to air conditioning and other cooling solutions. Between 2000 and 2019, around 20 percent of heat-related global excess deaths occurred in East Asia—a total of just over 101,000 lives lost (Zhao et al. 2021).

As later chapters of this report will show, the negative impacts of extreme heat in cities extend well beyond those on health. Extreme heat exposure also undermines the productivity of a city's workers[3] and leads to the failure of critical infrastructure and services,[4] thereby acting as a drag on East Asia's competitiveness at a time when its cities are already struggling with an unfavorable global economic environment. Indeed, it is projected that UHI intensification resulting from urban land expansions between 2015 and 2050 will increase air temperatures by 0.5°C–0.7°C on average globally. This is on top of the average 0.9°C–1.1°C increase that is projected to occur as a result of climate change (Huang et al. 2019).[5] The combined impacts could result in a gross domestic product (GDP) loss of 1.7 percent for the global median city (Estrada, Wouter Botzen, and Tol 2017).[6]

In addition, extreme heat events can increase the risks of climate change-related hazards. In humid conditions, extreme heat increases the risk of flooding by causing more frequent extreme rainfalls. Conversely, in dry conditions, extreme heat enhances evaporation, contributing to water shortages and droughts. Such hot and dry conditions can, in turn, create massive bushfires as in Australia in the summer of 2019/20, adding large amounts of carbon dioxide (CO_2) to the atmosphere (Robinson et al. 2021).

Despite its profound impacts, extreme heat has seldom attracted as much attention from East Asia's policy makers as have other types of hazards such as floods and tropical cyclones, which tend to cause more obviously apparent damage to people and property. In a warming world, however, rapid urbanization in East Asia means that extreme heat will increasingly threaten city competitiveness as well as human health. The good news is that city officials can undertake concrete actions and policies to promote mitigation and adaptation to extreme urban heat. Although they may not be able to influence global climate change, they can reduce the severity of the UHI effect by, among other things, promoting better urban planning and design. As explored in chapter 4, they can also promote adaptation to extreme heat through a variety of measures.

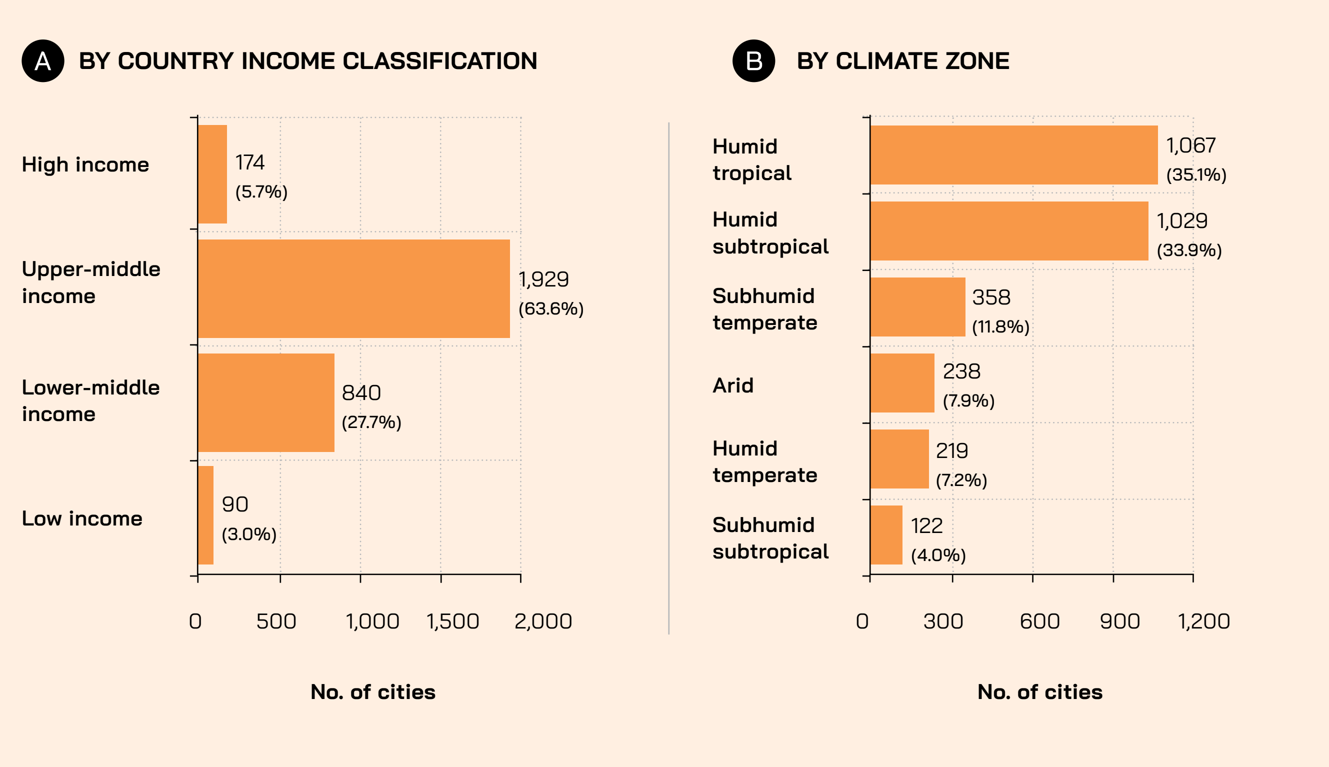
Against this backdrop, this chapter aims to inform the discussions of adverse impacts and policies in later chapters of this report by describing detailed trends of extreme urban heat for East Asian cities. Drawing on a sample of 100 major cities in the region, this chapter provides evidence that the average UHI intensity across the cities has been strong—raising temperatures by around 1.6–2.0°C compared with surrounding rural areas. It also confirms, based on a broader sample of over 3,000 cities (box 1.1), that extremely higher than normal temperatures in East Asia's cities have become increasingly frequent and intense over the past six decades. The severity of extreme urban heat, however, varies widely across the region. And the UHI intensity depends on a variety of factors, including background climates and a city's urban form. These findings signpost the importance of designing locally tailored interventions for heat mitigation and adaptation underpinning the policy discussion in chapter 4.

BOX 1.1 THE SAMPLE OF EAST ASIAN CITIES: AN OVERVIEW

East Asian countries vary widely in how they officially define cities. To overcome the problems of lack of comparability, this chapter defines cities using a globally consistent definition—the *degree of urbanization* (Dijkstra et al. 2021). This definition classifies a settlement as a city if it has a population of at least 50,000 and a population density of at least 1,500 people per square kilometer throughout its entire extent. As such, it identifies 3,033 cities in the East Asia region.[a]

Over 90 percent of identified cities are from middle-income countries (figure B1.1.1, panel A). China accounts for 61 percent of the cities, followed by Indonesia (13 percent), Viet Nam (5.4 percent), and Myanmar (4.2 percent). In terms of baseline climates, nearly 75 percent of the cities are in either tropical or subtropical zones between latitudes 35° south and 35° north, of which around 95 percent have somewhat wet climates with annual total precipitation of 750 millimeters or more (figure B1.1.1, panel B). This implies that many East Asian cities and their residents are exposed to hazardous humid heat.

Figure B1.1.1 Distribution of East Asian Cities, by Country Income Classification and Climate Zone



NOTE: Panel A is based on World Bank country income classifications in fiscal year 2022/23. In panel B, the climate zone of each city is defined based on the combination of two parameters: aridity and latitude. Aridity, based on a city's annual total precipitation averaged over 1958–2020 is classified as arid (less than 500 millimeters), subhumid (500–750 millimeters), and humid (750 millimeters or more). Latitude in absolute terms classifies cities as tropical (0°–23.5° north), subtropical (23.5°–35° north), and temperate (35° and farther north).

a. The sample excludes Australia, New Zealand, and Pacific island countries. To obtain a full picture of the overall trend in the region, it includes the Democratic People's Republic of Korea even though it is not a World Bank member economy.

DEFINING EXTREME URBAN HEAT

The *Glossary of Meteorology* defines a heat wave as "a period of abnormally and uncomfortably hot and usually humid weather" (Glickman 2000). As this definition implies, various combinations of measures and thresholds that quantify the duration of abnormal and uncomfortable temperature as well as humidity can be applied to identify extreme heat events. To measure temperature thresholds, for example, studies generally use daytime maximum and/or nighttime minimum as well as the daily average temperature (Meehl and Tebaldi 2004). For the duration of the event, the temperature should exceed an agreed-upon threshold for at least one day but generally for at least several consecutive days (Glickman 2000).

The abnormality and discomfort thresholds also depend on the normal conditions in the area of interest. In Canada, for example, the threshold for Prince Edward Island with a mild climate is 27°C, whereas a threshold of 35°C is applied to Southeastern British Columbia.[7]

Nonetheless, three broad definitions of an extreme heat event are apparent in the literature: (a) absolute temperature; (b) extreme heat as an *absolute* "anomaly" from a city's long-run average temperature; and (c) extreme heat as a *relative* "anomaly" from a city's long-run average (see annex 1A).

These definitions capture a person's perception of an extremely hot day in different ways. Consistent with the absolute temperature definition, someone may perceive a day to be extremely hot because its temperature approaches, say, 40°C. On another day, per the absolute anomaly definition, the same person may feel extremely hot because the temperature is, say, 10°C higher than is historically typical for that time of year. Finally, as implied by the relative anomaly definition, even a smaller temperature anomaly (say, 5°C higher) may feel extremely hot to someone who has lived in a city where the temperature is normally stable throughout the year. By contrast, an absolute anomaly of the same size may have little impact on heat perception in another city with a historically more volatile climate.

WHAT DRIVES EXTREME URBAN HEAT?

LOCAL WARMING DRIVEN BY THE URBAN HEAT ISLAND EFFECT

Urban heat islands are urbanized areas where temperatures are higher than they otherwise would be if the areas were rural. The "UHI effect" is a local negative environmental externality that may expose urban residents to extreme heat events more often than their observationally equivalent rural counterparts by artificially elevating a city's long-run average temperature (Houghton 2015).

The primary cause is the conversion of natural land to urban land, which reduces a city's cooling capacity available through evapotranspiration and convection while trapping more heat on artificial surfaces (Zhao et al. 2014).[8] Rapid urbanization additionally contributes to the UHI effect because it increases the amount of heat released from human activities such as motor vehicle uses and industrial processes (Li et al. 2020). This highlights the opportunities for local policy makers to target heat mitigation and adaptation through urban planning and local policies.

GLOBAL WARMING DRIVEN BY CLIMATE CHANGE

Since the 1950s, cities across the globe have experienced large changes in the weather patterns that define their local climates. Global warming, one of the key symptoms of climate change, has been contributing to increased long-run average temperatures in cities and, at least so long as the average temperatures continue to rise, is driving larger absolute and relative temperature deviations from the historical norms to which people have acclimated.[9]

A small increase in average temperature can have a drastic effect on both the frequency and intensity of extreme heat events. According to the Intergovernmental Panel on Climate Change (IPCC), hot extremes, which used to occur only once in every 50 years during the preindustrial period (1850–1900), now occur every 10 years.[10] Furthermore, global warming of 1.5°C and 4.0°C, respectively, are projected to lead hot extremes to occur 8.6 times and 39.2 times in every 50 years and to raise their intensities by 2.0°C and 5.3°C (IPCC 2021).

Global warming is a global negative externality, meaning the burning of fossil fuel somewhere in the world can cause adverse impacts elsewhere. Hence, city leaders cannot mitigate it by acting in isolation as they might mitigate the UHI effect through local planning and policies. But they can take steps to help make their cities and residents more resilient to rising temperatures—both through immediate-term adaptation measures and longer-term planning to reduce future risks.

INTERACTIONS BETWEEN UHI EFFECTS AND CLIMATE CHANGE

Although the interactions between UHI effects and climate change-induced extreme heat events are not yet fully understood (Souverijns et al. 2022), research shows that, in the face of global warming, city cores are heating up faster than adjacent rural areas because of the UHI effect (Liu et al. 2022). This suggests that the UHI effect can interact with climate change to increase the likelihood of extreme urban heat.

Also, it is widely accepted that the surface UHI intensity normally increases with city size, because larger cities tend to be covered by a larger built-up area while emitting a larger amount of anthropogenic heat (Imhoff et al. 2010). Given that East Asian countries are projected to add roughly 141 million inhabitants to their cities by 2050,[11] heat stress posed by the UHI effect in combination with global warming will likely increase.

HOW IS AN EXTREME URBAN HEAT EVENT MEASURED?

This chapter's analysis draws on two measures of extreme urban heat derived from the local and global drivers discussed in the previous section. Specifically, local and global drivers are measured by the intensity of UHI effect and by the frequency and intensity of *relative* temperature anomalies, respectively.

LOCAL DRIVER: INTENSITY OF THE UHI EFFECT

Traditionally, the intensity of the UHI effect, defined as the difference in mean temperatures between urban and surrounding rural areas, was based on in situ readings of air temperatures at 2 meters above ground level (Liu et al. 2022). With recent advances in space technology, however, it is now feasible to quantify spatially detailed land surface temperatures (LST) for the entire globe through the processing of satellite imagery using remote sensing techniques.

The estimates of UHI intensity used in this chapter were derived by 4 Earth Intelligence (4EI) in support of the World Bank[12]. Bringing LST images together with global land cover images, 4EI classified each pixel in the LST images in and around a sample of 100 East Asian cities (box 1.2) as either urban or nonurban.[13] In delineating the location and size of the nonurban zone surrounding a city, three buffer zones with distances of 2, 5, and 10 kilometers were iteratively created around the cluster of urban pixels extracted from the land cover classification. The intensity of a city's UHI effect was then calculated as the yearly average of daytime and nighttime UHI intensities for each of the years from 2002 to 2020, where UHI intensity is the difference in LSTs averaged across urban and nonurban pixels.

BOX 1.2 HOW WERE THE 100 CITIES SELECTED?

For satellite mapping of UHI effects across cities and over time, this chapter focuses on a sample of 100 East Asian cities. This sample was constructed in three steps:

1. After first excluding Brunei Darussalam, the Democratic People's Republic of Korea, and Pacific island countries, the four most populous cities in each low- and middle-income country in East Asia were selected alongside the single most populous city in each of the region's high-income countries. This step identifies 45 cities.
2. The only national capital unselected in step 1—Naypyidaw, Myanmar—was manually added to the sample.
3. The remaining 54 cities were selected from low- and middle-income countries, in descending order of population, with a cap of 20 cities per country.

The final sample includes 20 cities each from China and Indonesia; 13 from Viet Nam; 12 from the Philippines; 9 from Malaysia; 5 from Myanmar; 4 each from Cambodia, the Lao People's Democratic Republic, Papua New Guinea, and Thailand; and 1 each from Japan, the Republic of Korea, Mongolia, Singapore, and Timor-Leste.

Seventy-seven cities are in tropical subregions, while 23 are in temperate subregions. These 100 cities have an aggregate population of around 417 million people, covering 41.3 percent of East Asia's urban population.[a]

A. Based on population data from the European Commission's Global Human Settlement (GHS) Urban Centre Database R2019 (https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php).

GLOBAL DRIVER: RELATIVE TEMPERATURE ANOMALIES

In the climate literature, an extreme heat event in a city is often defined as an "absolute" heat anomaly—that is, based on how many degrees Celsius the temperature exceeds its long-run historical average (Dell, Jones, and Olken 2014). This definition may suffice for comparisons of the evolving patterns of extreme heat events across a few cities with similar background climates.

Given that this report focuses on the *impacts* of extreme urban heat with a broad geographic coverage, however, this chapter's analysis focuses on *relative* instead of absolute temperature anomalies in measuring extreme urban heat events (a calculation further described in annex 1A). Hence, for any given city, an extreme heat event for any given month is defined in terms of the number of *standard deviations* of temperature above a city's own long-run average temperature for the same month.[14] The city-specific long-run average and the standard deviation for each month are calculated for the base period January 1958–December 1999.[15] When the measure takes on a value of at least +2 standard deviations, a temperature anomaly is considered an extreme heat event because, under normal circumstances, this would be a highly unusual event that occurs less than 2.5 percent of the time and hence comes as a surprise to society at large.

The idea behind the choice is that people adapt to local climatic conditions while updating their expectations based on experience over time. Hence, human activities are more likely to be affected by temperatures that are surprisingly higher than long-run averages—for which people are unprepared—rather than by high temperatures per se (Thomson et al. 2022; Tol 2021).[16] Research also shows a distinct geographical pattern of future extreme heat events in relation to a specific atmospheric circulation pattern in the background (Meehl and Tebaldi 2004). This implies that, for a cross-city analysis on a broader geographic scale, relative anomalies may be more appropriate to account for diverse local climatic conditions.

At the same time, it is important to recognize that, based on the relative anomaly definition, extreme heat may occur across a wide range of absolute background temperatures with a variety of adverse impacts. In the United States, for example, warmer winters, reduced snowfalls, and shorter snow seasons driven by global warming translated into reduced revenues and job losses in winter tourism industries, thereby reducing people's income and government tax revenues (Burakowski and Magnusson 2012). On the other hand, certain impacts of heat will only manifest themselves at high absolute temperatures, such as melting power transmission lines, railroad tracks, and airport runways. This suggests that there is no one single "correct" definition or threshold of an extreme heat event. For this reason, the analysis of relative anomalies will be accompanied by that of absolute temperatures, which will be further complemented by the analysis of relative anomalies across cities in different climate zones.[17]

In addition to absolute background temperatures, the *duration* of excessive heat, *nighttime temperatures*, and the local level of *air pollution* provide important context for understanding potential adverse impacts of extreme urban heat. Prolonged exposure to anomalous temperatures, driven by a longer extreme heat event or a nighttime heat stress, can trigger sleep deprivation and cardiovascular stress with direct and indirect health impacts (Deschenes and Moretti 2009; He et al. 2022; Obradovich et al. 2017). Moreover, extreme heat and air pollution—which often co-occur—tend to compound the adverse health impacts of each on the other, increasing the risk of mortality, on days hit by both, significantly beyond the sum of their individual risks (Rahman et al. 2022).[18] Although the evolving patterns of these dimensions are not analyzed in this regional study, they certainly warrant future research.

When it comes to mitigation and adaptation measures, humidity, not just temperature, matters. This is because the ability of both the human body and cities to efficiently dissipate heat depends on the combined level of heat and ambient humidity (Manoli et al. 2019). To highlight the unique challenges posed by humid heat in the tropics (box 1.3),[19] we further analyze the evolution of relative temperature anomalies across cities with different levels of humidity.[20]

BOX 1.3 HUMIDITY: A HIDDEN THREAT TO THERMAL COMFORT

The urban heat island (UHI) effect and global warming have often been measured in terms of temperature alone. However, recent research shows that factoring in humidity alongside heat makes the temperature increase associated with climate change since 1980 nearly twice as bad as previously calculated (Song et al. 2022). Based on temperature alone, the 1980–2019 increase in global surface air temperature appears to be about 0.79 degrees Celsius (°C). If humidity is factored in, surface equivalent potential temperature, which is an integrated measure of surface air temperature and humidity, increased by about 1.48°C on average globally and by about 4°C in the tropics. This is because, in a warming world, the air can hold more moisture—nearly 7 percent more for every added 1°C.[a] When the moisture condenses, this then releases heat. Moreover, water vapor itself is a heat-trapping gas that exacerbates climate change.

The combined impact of heat and humidity is felt most acutely in cities in humid tropical regions, where nearly 40 percent of East Asia's urban population reside. Cities can cool down through the processes of convection (the cycle of heat release to, and cool air from, the atmosphere) and the evapotranspiration of natural surfaces. Under humid conditions, neither process works as efficiently as under drier conditions, however. Indeed, studies suggest that humid cities experience stronger UHI effects and heat waves (Manoli et al. 2019; Russo, Sillmann, and Sterl 2017).

Higher humidity affects not only cities. Human bodies, likewise, cannot cool themselves down efficiently when extreme heat is compounded by high humidity. Humans can self-regulate body temperatures through sweating. However, a high level of ambient humidity interferes with the evaporation of sweat (UNEP 2021). Exposure to humid heat not only has adverse effects on human health (Raymond, Matthews, and Horton 2020) but also leads to significant productivity losses for outdoor workers. Parsons et al. (2022), for example, estimate that globally, annual labor productivity losses driven by humid heat can amount to roughly US$2.1 trillion (in constant 2017 US dollars adjusted for purchasing power parity).[b]

a. This relationship is based on the increase in the water-holding capacity of the atmosphere specified by the Clausius–Clapeyron relation (Robinson et al. 2021).

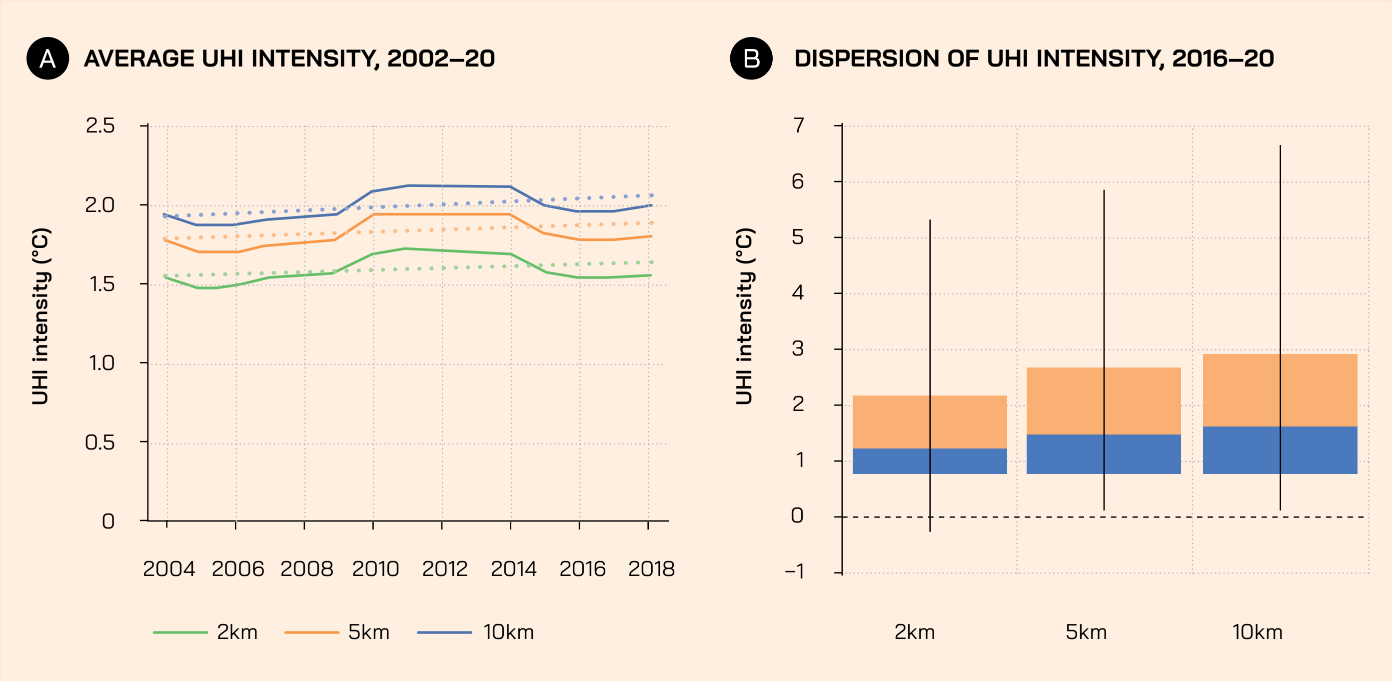
b. This estimate is based on the construction, as well as the agriculture, forestry, and fisheries sectors—that is, both urban and nonurban economic activities.

UHI EFFECTS MAKE EAST ASIAN CITIES, ON AVERAGE, 1.6–2.0°C WARMER THAN RURAL SURROUNDINGS

STRONG AVERAGE UHI INTENSITIES

During 2002–20, the average intensity of the UHI effect across the sample of 100 East Asian cities increased modestly with minimal fluctuations around the trend. Hence, regardless of the distance used to define the buffer area of each city, the five-year moving average shows that the intensity slightly increased from 2005 to circa 2014, then marginally declined afterward (figure 1.1, panel A).[21] When rural surroundings are delineated conservatively based on a 2 kilometer buffer, urban areas are, on average, around 1.6°C hotter than surrounding rural areas over 2016–20. Relaxing the buffer sizes to 5 kilometers and 10 kilometers results in stronger average UHI intensities at around 1.8°C and 2.0°C, respectively. During the same period, most cities experienced estimated UHI effects below 3.0°C, as indicated by the third quartile of UHI intensity. Across the 100 cities, however, wide variations exist, with the intensity ranging from around zero to 5.3–6.6°C depending on the choice of buffer distance (figure 1.1, panel B).

Figure 1.1 Trends in the average UHI Intensity and Dispersion across 100 East Asian Cities

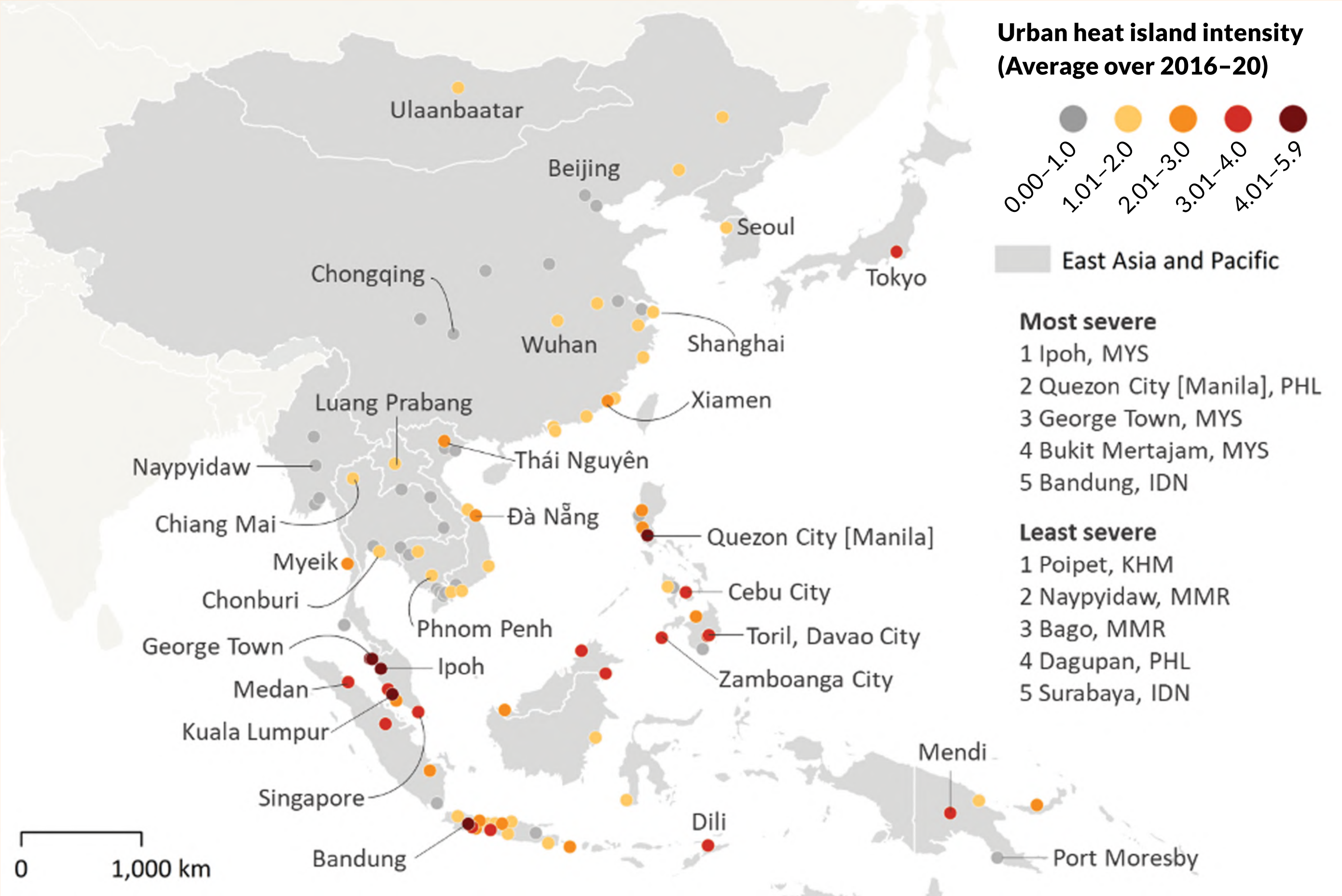


SOURCE: World Bank calculations based on estimates of urban heat island (UHI) intensity produced by 4 Earth Intelligence, https://www.4earthintelligence.com/.

NOTE: In both panels, UHI intensity is estimated by averaging the daytime and nighttime differences in land surface temperatures between urban and rural areas based on buffer distances of 2, 5, and 10 kilometers (km), where each buffer distance defines the location and size of the nonurban zone around the cluster of urban pixels extracted based on the land cover classification. In panel A, the solid and dotted lines show the regional averages of UHI intensity (measured as the five-year moving average of the intensities) across 100 East Asian cities over time and the best fitting straight line of the regional averages, respectively. In panel B, the bottom and top ends of each black line indicate the minimum and maximum values of UHI intensity, respectively. The bottom of the box, the border of two colors, and the top of the box, respectively, depict the first, second (median), and third quartiles of UHI intensity.

Cities with the most severe UHI effects generally belong to Malaysia and the Philippines (map 1.1). These countries, along with Indonesia and Singapore, dominate the list of top 10 cities in terms of estimated UHI intensity—with the average intensity across the 10 cities, based on a 5 kilometer buffer, ranging from 3.5°C to 5.9°C.[22] On the other hand, cities in the continental portion of Southeast Asia—those located in Cambodia, Laos, Myanmar, Thailand, and Viet Nam—generally exhibit less severe UHI intensities, in the range of 0.1–2.4°C. The same is true for cities in higher latitudes, including most Chinese cities and Seoul, Republic of Korea. Tokyo is an exception in that its average UHI intensity was around 3.3°C between 2016 and 2020—higher than in other cities around the same latitude.

Map 1.1 Average UHI Intensity in 100 Selected East Asian Cities, 2016–20



SOURCE: World Bank calculations based on the urban heat island (UHI) intensity data from 4 Earth Intelligence, https://www.4earthintelligence.com/.

NOTE: The map presents the five-year (2016–20) averages of UHI intensity, estimated by averaging the daytime and nighttime differences in land surface temperatures between urban and rural areas based on the 5 kilometer buffer. Regarding selection of the 100 cities, see box 1.2. IDN = Indonesia; KHM = Cambodia; MMR = Myanmar; MYS = Malaysia; PHL = Philippines.

DIVERGING UHI INTENSITIES WITHIN A CITY AND DURING THE DAY

The above averages, however, mask considerable variations in UHI intensities across neighborhoods within individual cities as well as across times of the day. Hence, even within cities with relatively low average UHI intensities, some neighborhoods could be disproportionately exposed to stronger UHI effects.

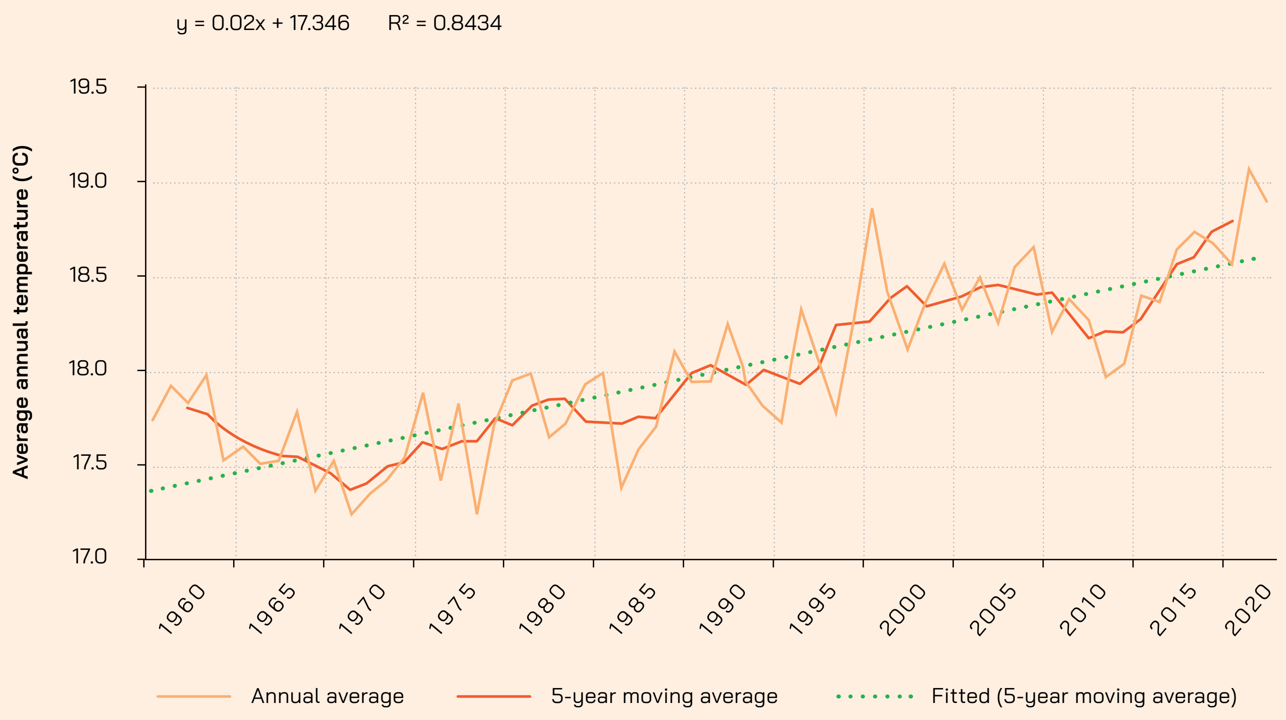
Bangkok provides such an example. During 2000–20, the city was, on average, only 1.4°C warmer than its rural surroundings, where the average temperature was 33.5°C.[23] However, residents in the city's hottest neighborhood had endured the average temperature of 46.3°C during the same period. Relatedly, as chapter 2 shows, the temperature difference between the hottest and the coolest neighborhoods in Bandung, Indonesia, reaches 7°C in the early evening. Also, the UHI intensity is usually stronger at night than during the day because the heat stored in the built environment is gradually released after sunset (Li et al. 2020). Because this chapter's measure of UHI intensity is constructed by averaging the daytime and nighttime intensities across all pixels in a city throughout the year, it inevitably understates the intensity for some neighborhoods or at night while overstating others or during the day.

WHILE TEMPERATURES INCREASED EVERYWHERE, RAINFALLS AMPLIFIED IN THE TROPICS

RISING ABSOLUTE TEMPERATURES

Previous studies based on satellite measurements or the analysis of observations from weather stations worldwide confirm that, overall, Earth's temperature has risen by around 1.1°C since the 1880s (Woetzel et al. 2020). An analysis based on the broader sample of 3,033 East Asian cities (box 1.1) shows that, overall, mean annual temperature across the cities increased by around 1.0°C—from 17.8°C to 18.8°C—between 1958 and 2020 (figure 1.2).[24]

Figure 1.2 Evolution of Average Annual Temperature in East Asian Cities, 1958–2020



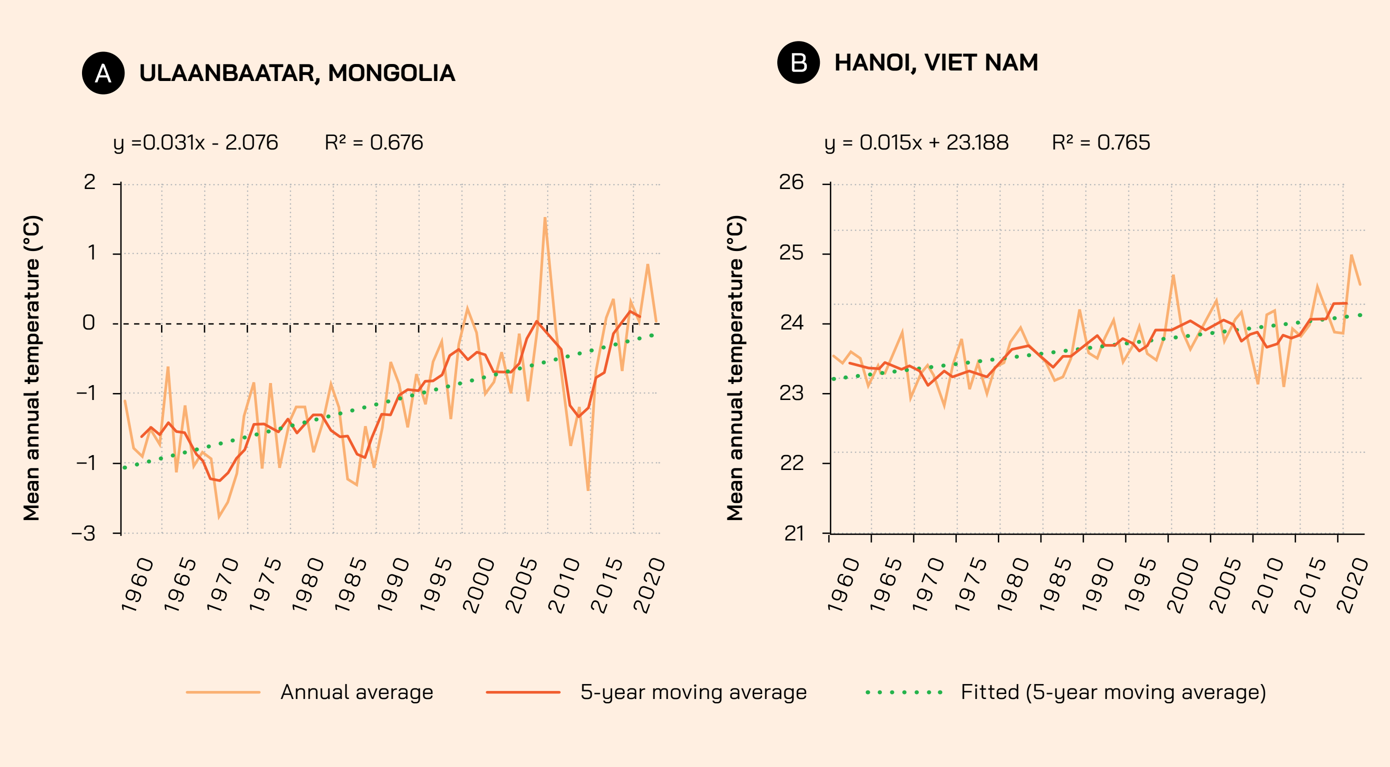
SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: The region's mean annual temperature is calculated by averaging the mean annual temperatures of the 3,033 cities in the full sample (described in box 1.1), by year. The equation and the R-squared value are based on the fitted line of the five-year moving averages.

COOLER CITIES WARMING FASTER AND HOTTER CITIES HEATING UP FURTHER

Although temperatures have increased everywhere in the region, the magnitude of increase has varied across cities. Whereas Ulaanbaatar, Mongolia, which has a cold arid climate, experienced a sharp increase of 1.7°C in its mean annual temperature (from −1.6°C to +0.1°C) during 1958–2020 (figure 1.3, panel A), the increase in a humid tropical city such as Hanoi, Viet Nam, was below 1.0°C—increasing from 23.4°C to 24.3°C (figure 1.3, panel B).

Figure 1.3 Evolution of Mean Annual Temperature in Selected East Asian Cities, 1958–2020

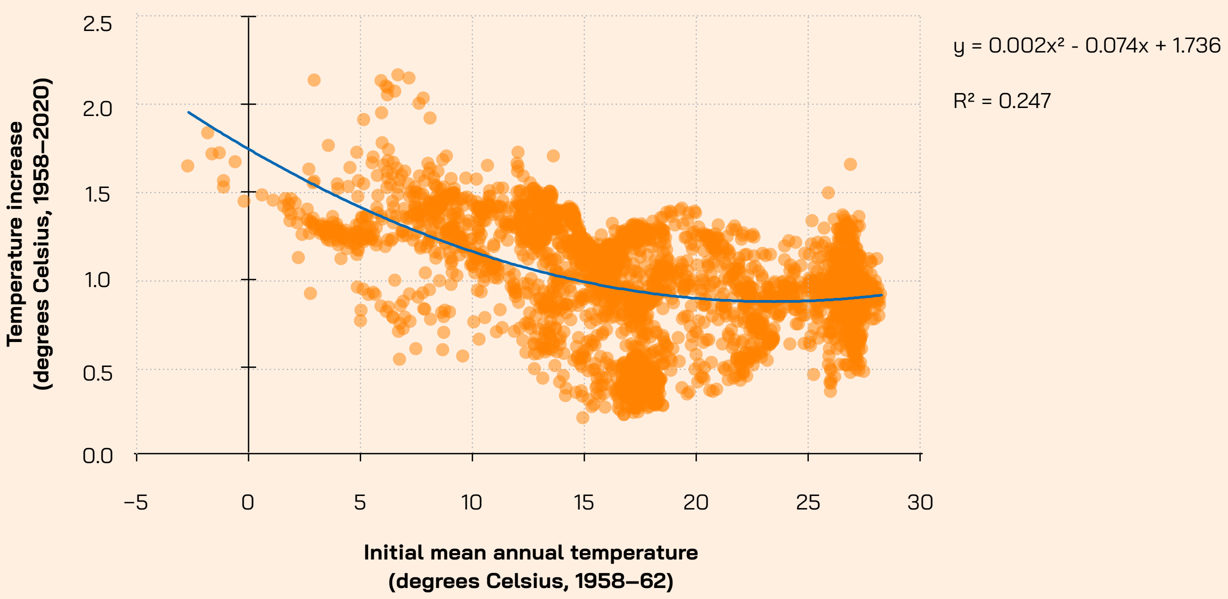


SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: The equations and the R-squared values are based on the fitted lines of the five-year moving averages.

More generally, increases in mean annual temperature tend to be sharper for cities with arid or semiarid temperate climates (such as Beijing and Ulaanbaatar) than for those with humid tropical climates (such as Hanoi and Manila) (figure 1.4).[25] Given the high absolute mean temperatures, however, even relatively modest temperature rises could be stressful for tropical cities. Indeed, the effect of higher temperatures on economic outcomes tends to be nonlinear such that the negative impacts of a given temperature increase are larger for cities with a higher baseline temperature than for those with a lower baseline temperature (see chapter 3).

Figure 1.4 Pace of Temperature Increases in East Asian Cities, 1958–2020



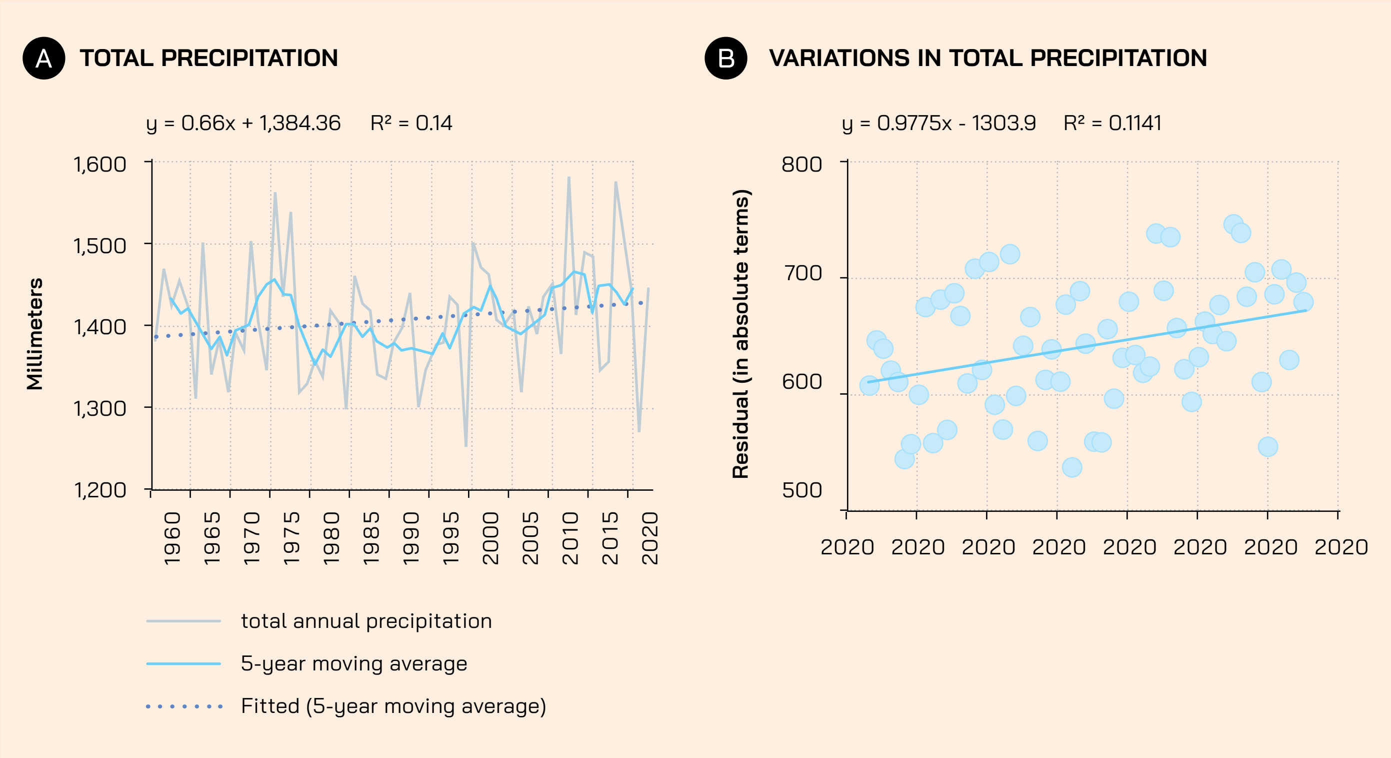
SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: The initial mean annual temperature (x-axis value) and the temperature increase (y-axis value) are calculated as the five-year average of mean annual temperatures during 1958–62 and the increase from the initial value to the five-year average of mean annual temperatures during 2016–20, respectively, for each of 3,033 East Asian cities in the sample (described in box 1.1).

INCREASING RAINFALL TOTALS AND VARIABILITY IN THE TROPICS

Although temperature has risen across East Asian cities by an average of 1.0°C since 1958, the average of total annual precipitation has remained relatively stable, albeit with a slight upward trend (figure 1.5, panel A). Over time, however, cities have experienced more severe variations in their levels of total annual precipitation, which affect humidity and thus, in combination with temperature, thermal comfort. Hence, the variation—measured by the absolute values of the residuals from the linear trend of total annual precipitation across cities—has become larger over time (figure 1.5, panel B). This increased variability around the trend may pose challenges for precipitation forecasting and hence for preparedness for weather extremes.

Figure 1.5 Evolution of Total Annual Precipitation in East Asian Cities, 1958–2020

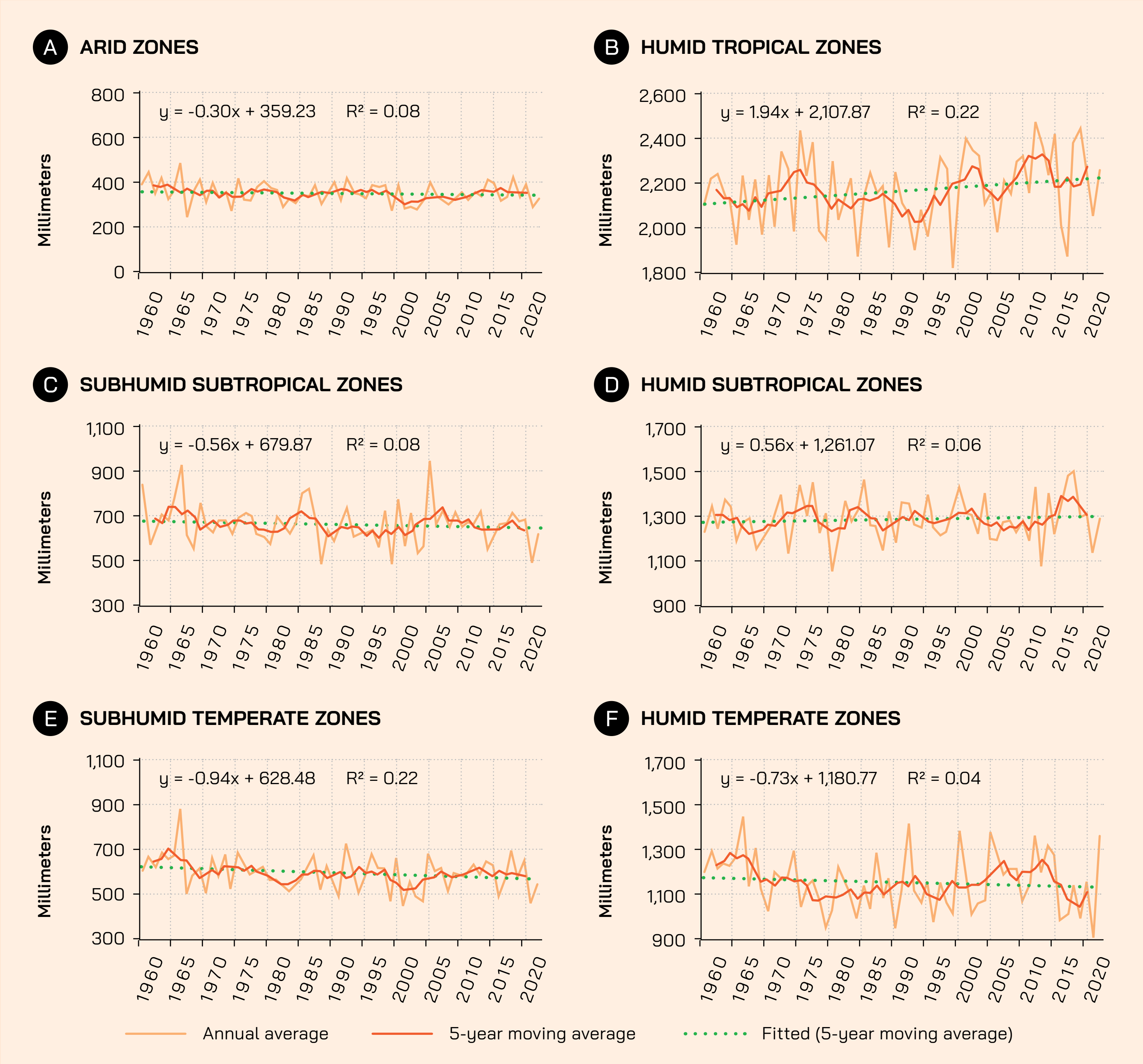


SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: In panel A, the equation and the R-squared value are based on the fitted line of the five-year moving averages. In panel B, variations are calculated as the absolute values of the residuals from the linear trend presented in panel A.

Once again, however, this regional trend conceals wide disparities across cities with different baseline climates. Overall, cities with the most humid conditions—notably, those in the tropics—have had increasing total annual precipitation, whereas others (except in humid subtropical regions) have exhibited the opposite trend. This can be seen by comparing panel B of figure 1.6 with the other panels in the same figure. This suggests that the already humid climates of East Asia's tropical cities are becoming even more humid. The trends in figure 1.6 also show considerable interannual variation in total annual precipitation in tropical regions, particularly in the latest decade.

Figure 1.6 Evolution of Total Annual Precipitation in East Asian Cities, by Climate Zone, 1958–2020



SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: The equations and the R-squared values are based on the fitted line of the five-year moving averages. Collectively, the panels represent calculations across the full sample of 3,033 East Asian cities (see box 1.1). For each city, the climate zone is defined based on the combination of two parameters: aridity and latitude. Aridity, as determined by annual total precipitation (averaged over 1958–2020), is classified as either "arid" (less than 500 millimeters); "subhumid" (500–750 millimeters); or "humid" (750 millimeters or more). Latitude in absolute terms classifies cities as "tropical" (0°–23.5° north), "subtropical" (23.5°–35° north), and "temperate" (35° and farther north).

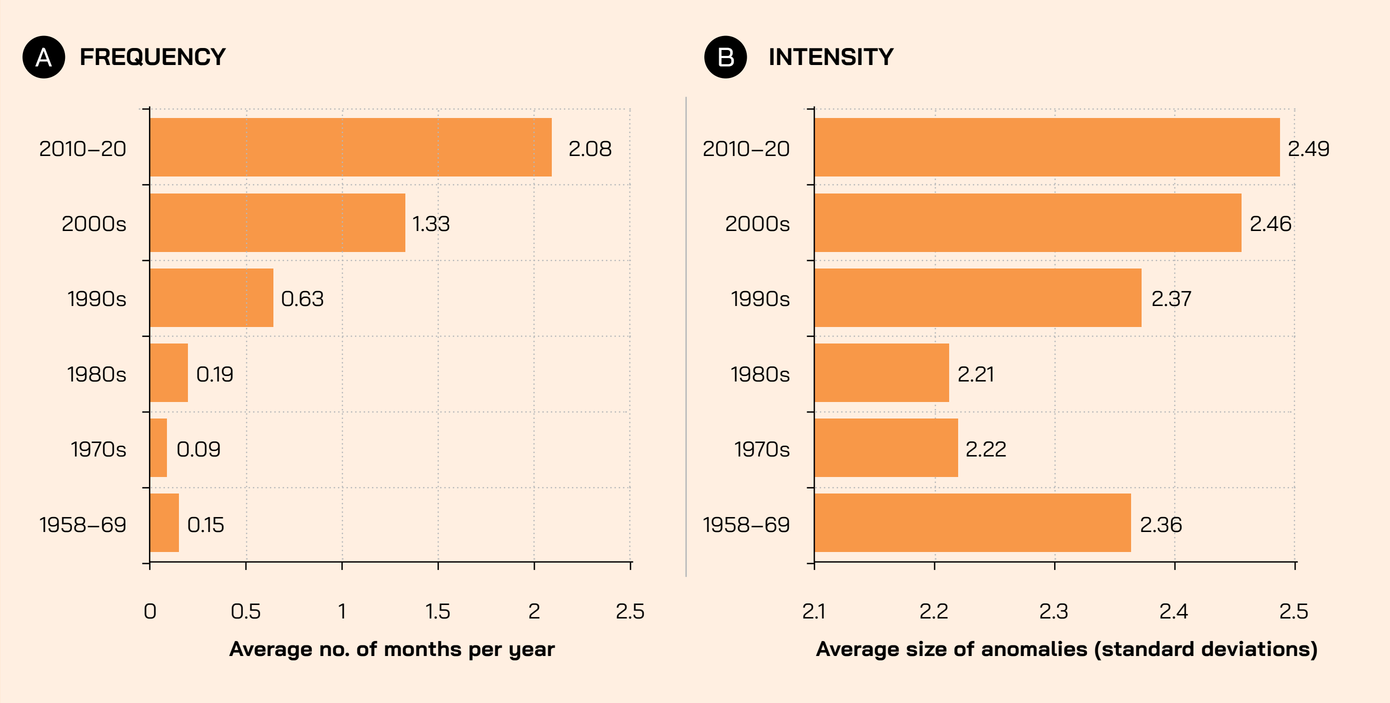
EXTREME HEAT EVENTS BECAME INCREASINGLY SEVERE, AND MORE SO IN THE TROPICS

This section highlights the increasing effect of climate change on the frequency and intensity of abnormal heat events, or "temperature anomalies," over the past six decades for East Asian cities. Again, a temperature anomaly is defined *relative* to a city's own long-run mean temperature while considering its historical variability for the second half of the twentieth century (1958–99).

INCREASING OVERALL FREQUENCY AND INTENSITY OF EXTREME HEAT EVENTS

Overall, East Asian cities experienced an average of only 0.1 extremely hot months per year in the 1970s, which increased to an average of 2.1 months per year during 2010–20 (figure 1.7, panel A). Put differently, extreme heat events increased from under three days per year to over two months per year—a 23-fold increase in four decades. Over the same period, extreme heat events also intensified. The average extreme heat event recorded a temperature that was, on average, around 2.2 standard deviations above a city's own long-run average in the 1970s. By 2010–20, however, the average intensity had increased to almost 2.5 standard deviations (figure 1.7, panel B).

Figure 1.7 Frequency and Intensity of Extreme Heat in East Asian Cities, by Decade (1958–69 to 2010–20)



SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

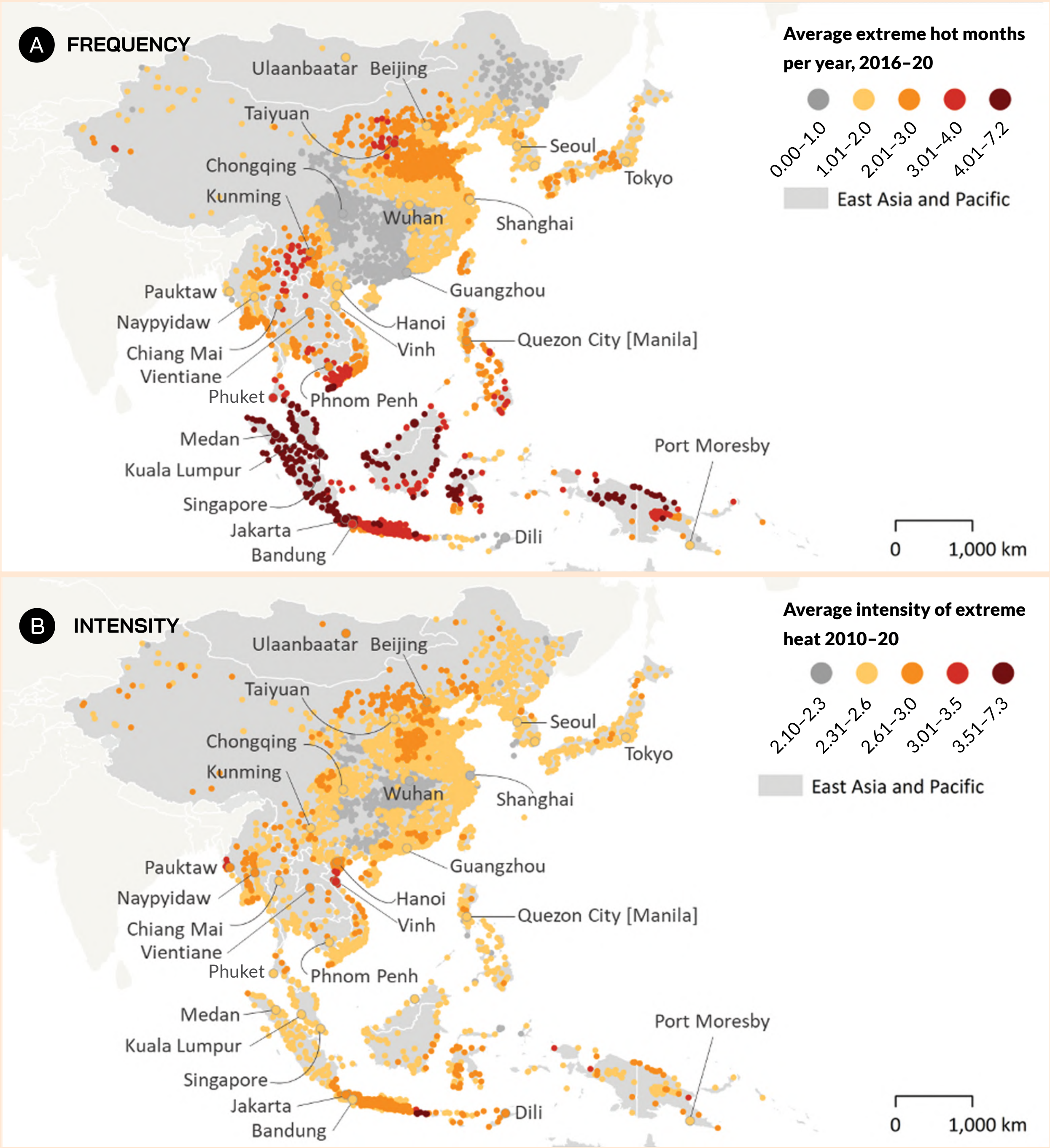
NOTE: An "extreme hot month" is one in which a city's temperature for that month is at least 2 standard deviations higher than the month's city-specific historical norm, where the historical norm is calculated over January 1958–December 1999. Frequency is calculated as the number of extreme hot months per year and intensity as the average size of the anomaly variable during an extreme heat event—which is defined as a set of consecutive extreme hot months. Panel A presents the average frequency, and panel B the average intensity for each time period, across the full sample of 3,033 East Asian cities (see box 1.1).

WIDE VARIATIONS ACROSS CITIES IN EVOLVING PATTERNS OF EXTREME HEAT EVENTS

The spatial distributions of the frequencies and intensities of extreme heat events in the latest decade (2010–20) confirm large differences across East Asian cities. Extreme heat events were frequent throughout Southeast Asia (map 1.2, panel A). Jakarta, Indonesia, is the worst-positioned megacity in the region, but such events are pervasive across all Indonesian cities.[26] The same is true for Malaysia, the Philippines, and cities in the southern part of Viet Nam. Unfortunately, these cities also face stronger UHI intensities, exacerbating the challenges they face in adapting to extreme urban heat.

In higher latitudes, cities in northeast China (such as those around Shanxi Province) and southern China (such as those around Yunnan Province), in the north of Laos, and in Myanmar also frequently experience extreme heat events. Despite their locations, those cities were, on average, exposed to extreme heat events for over three months per year. And when they did occur, these events were particularly intense for cities in East Java (Indonesia), Thailand, and northern Viet Nam as well as cities in northeast China (map 1.2, panel B).

Map 1.2 Frequency and Intensity of Extreme Heat Events in East Asian Cities, 2010–20



SOURCES: World Bank calculations based on Climatology Lab, TerraClimate https://www.climatologylab.org/terraclimate.html; and European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

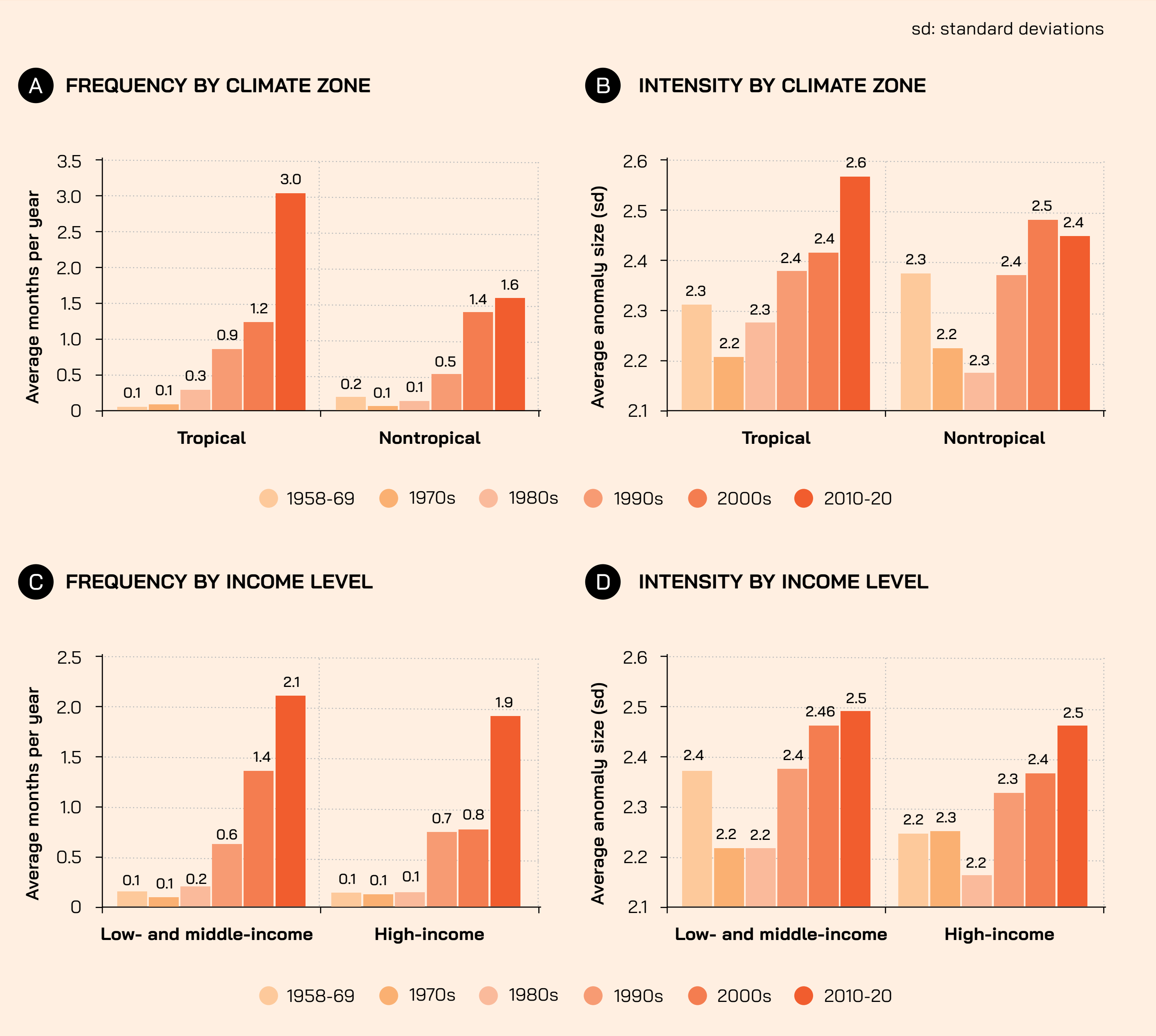
NOTE: Panels A and B present the average frequency and intensity, respectively, of extreme hot months from January 2010 to December 2020 for each of 3,033 cities in the full regional sample (see box 1.1). An "extreme hot month" is one in which a city's temperature anomaly variable records a value of at least 2 standard deviations. Frequency is defined as the number of extreme hot months per year and intensity as the average size of the anomaly variable during an extreme heat event—which is defined as a set of consecutive extreme hot months.

SHARPER INCREASES IN EXTREME HEAT SEVERITY IN WARMER CITIES OF POORER COUNTRIES

The extent to which the frequency and intensity of extreme heat events have evolved diverges according to background climates. While cities in cooler subregions experienced fewer than two extremely hot months per year in the 2010s, those in the tropics had to endure extreme heat events for over three months per year during the same period (figure 1.8, panel A). Although cities do not diverge much in terms of the intensity (figure 1.8, panel B), extreme heat events in tropical cities can translate into more serious threats to thermal comfort because their higher background temperatures are already amplified by high humidity.

Although these evolving patterns confirm increasingly severe extreme heat events as common challenges for many East Asian cities, the heterogeneous patterns highlight the particularly severe struggles faced by tropical cities where the UHI effect also adds stronger heat stress than in nontropical cities. Because low- and middle-income countries tend to be in warmer regions (Diffenbaugh and Burke 2019; Huang et al. 2019), these results by climate zone align with more frequent—and to a lesser extent, more intense—extreme heat events across cities in low- and middle-income countries with lower capacities to cope (figure 1.8, panels C and D). Without adequate strategies for mitigation and adaptation, such challenges alongside these cities' fast-growing urban populations will likely harm their quality of life and the prospect of economic growth.

Figure 1.8 Frequency and Intensity of Extreme Heat Events by Climate Zone and Country Income Level, in East Asian Cities, 2010–20



SOURCE: World Bank calculations based on Climatology Lab, TerraClimate, https://www.climatologylab.org/terraclimate.html; European Commission, Global Human Settlement (GHS) Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

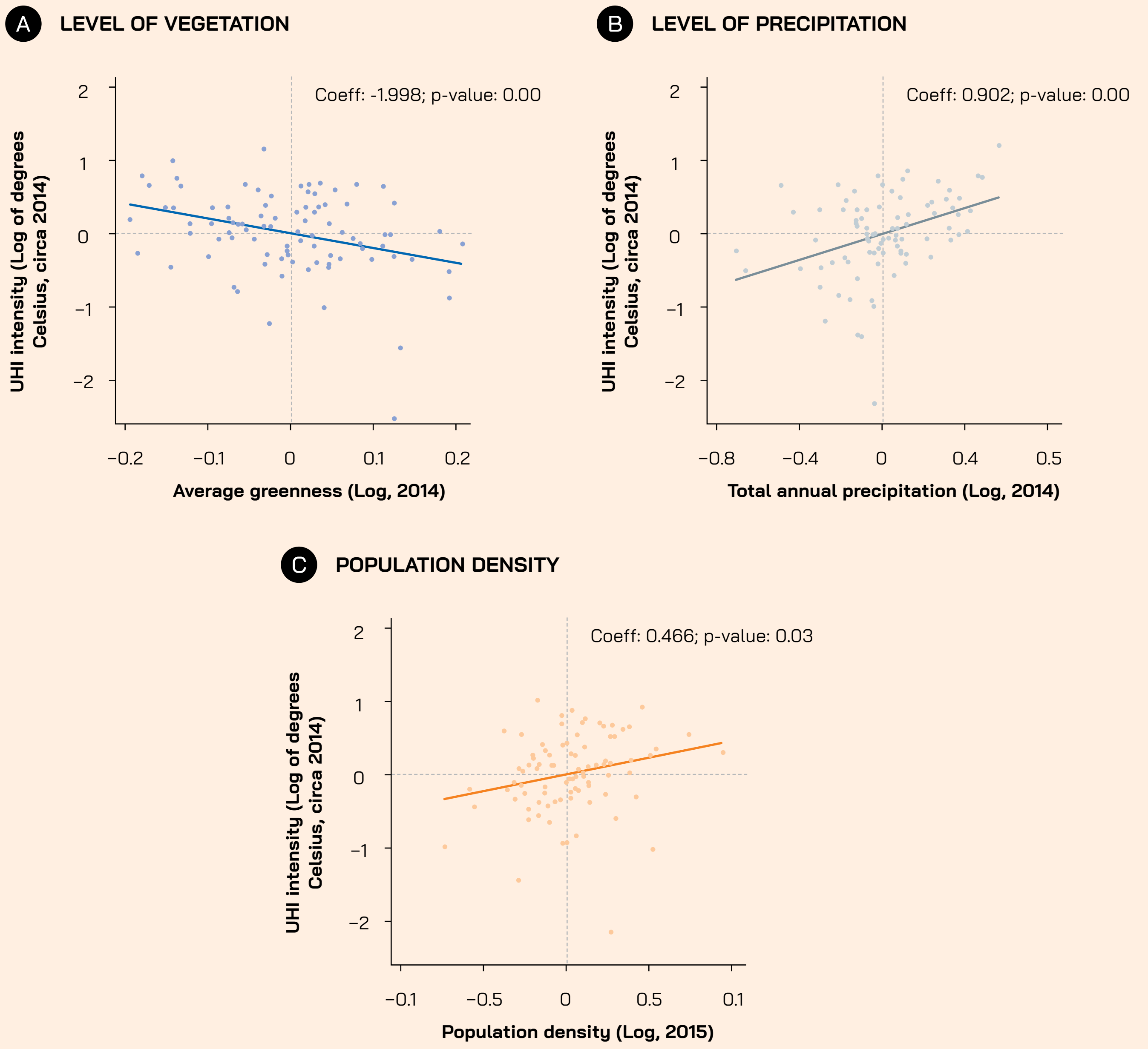
NOTE: An "extreme hot month" is one in which a city's temperature for that month is at least 2 standard deviations higher than the month's city-specific historical norm, as calculated over the period January 1958–December 1999. Frequency is calculated as the number of extreme hot months per year. Intensity is calculated as the average size of the anomaly variable during consecutive extreme hot months. Panels A and C present the average frequency, and panels B and D the average intensity, across the sample of 3,033 East Asian cities. In panels A and B, "tropical" and "nontropical" refer to a city's latitude in absolute terms—"tropical" being in latitudes 0°–23.5° north and "nontropical" elsewhere.

URBAN GREENING MITIGATES UHI EFFECTS, BUT LOCAL CONDITIONS ALSO MATTER

Although a city's local policy makers cannot alone affect the global path of climate change, local policies can significantly help reduce the severity of the UHI effect as a local environmental problem. Given the magnitude of the UHI effect, local action could make a telling reduction in the thermal discomfort that a city's residents face. To provide insights into potential urban heat mitigation strategies, this section draws on the same sample of 100 cities used for the analysis of UHI intensity (see box 1.2) and evaluates the relative importance of local characteristics—such as a city's average level of greenness, its population size and density, and its background climatic conditions and topography—in determining its UHI intensity.

Consistent with the existing literature (see Bowler et al. 2010 for a review), the results of the analysis highlight the effectiveness of urban greening in mitigating UHI intensity after controlling for other factors that may be correlated with both average greenness and UHI intensity.[27] The estimated effect is strong: all else being equal, UHI intensity could be halved if a city's average level of greenness is doubled (figure 1.9, panel A), or the intensity could decrease by around 40 percent with a 1 standard deviation increase in a city's average level of greenness (figure 1.10) This confirms a well-established notion that cities with more vegetation and fewer impervious surfaces store less heat while also being able to cool themselves down more effectively through evaporative processes. Vegetation can also enhance pedestrian comfort by offering shade.

Figure 1.9 Relationship between UHI Intensity and Vegetation, Precipitation, and Population Density in East Asian Cities, Circa 2014



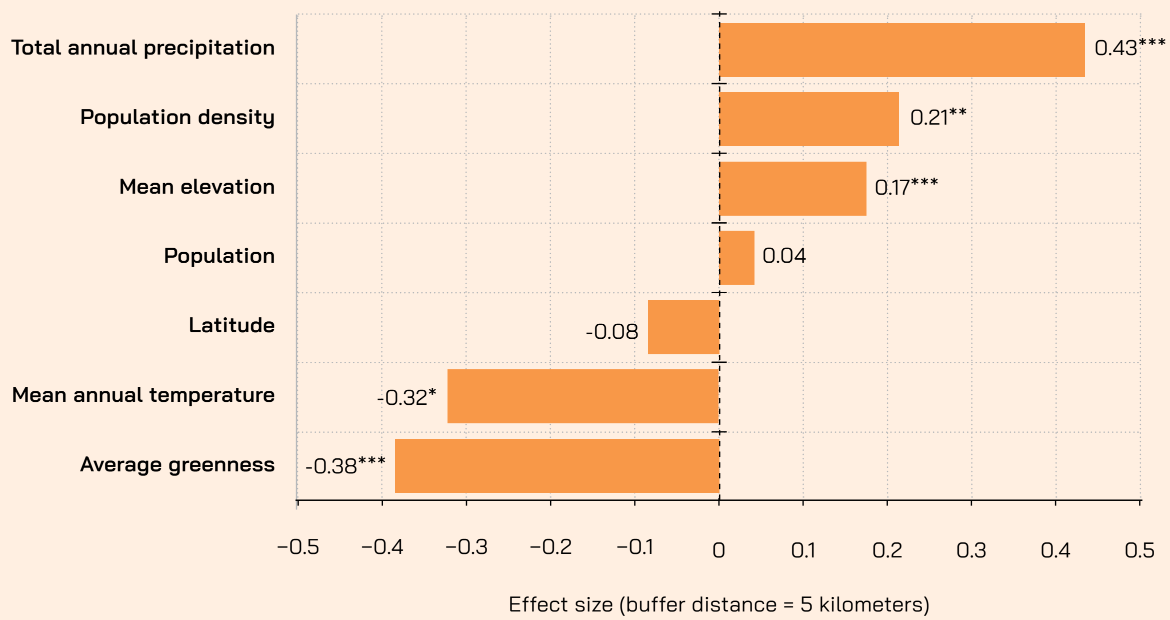
SOURCE: World Bank calculations based on the urban heat island intensity (UHI) data from 4 Earth Intelligence, https://www.4earthintelligence.com/; and the boundaries of 100 cities from the European Commission, Global Human Settlement Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: The figures show the empirical relationships between the intensity of UHI effects—calculated as the averages of the intensities over 2012–16 based on the 5 kilometer buffer—and the level of greenness, population density, and the level of precipitation across 100 East Asian cities in the sample. The regression equation also includes a city's population, mean annual temperature, mean level of elevation, and the absolute value of latitude, all in the natural log scale, as well as country dummies. Full regression results are presented in Annex 1B. Coeff = Coefficient.

Despite the importance of vegetation for relieving heat stress, it is not alone sufficient to keep cities as cool as their rural surroundings, especially in humid tropical cities. This is not only because the cooling effect of vegetation is limited to a relatively small geographic scale[28] but also because background climates matter for the effectiveness of cooling processes.[29] In rural areas, natural environments facilitate air movement from the surface to the atmospheric boundary—that is, the efficiency of convection is enhanced. In urban areas, by contrast, the process is suppressed by artificial structures that impede air flow, resulting in larger heat gains during the day. The difference in convection efficiency and evaporative cooling between cities and their rural surroundings is even larger in humid regions where ample precipitation promotes forest cover in rural areas. Thus, under humid environments, the UHI intensity remains high unless the urban morphology is fundamentally changed through, for example, significant citywide increases in green spaces (Manoli et al. 2019; Zhao et al. 2014).

Indeed, our analysis of 100 cities finds that UHI intensity tends to increase with the level of precipitation, all else being equal (figure 1.9, panel B). The intensifying effect of precipitation comes out even stronger than the mitigating effect of vegetation (figure 1.10). These pieces of evidence together suggest that, in cities with humid climates, greening must be accompanied by additional heat mitigation strategies, such as increasing the amount of sunlight reflected by artificial surfaces, that is, albedo (Zhao et al. 2014), and improving ventilation. The latter is particularly important for thermal comfort because having more trees can interfere with the body's cooling mechanism by increasing air humidity while reducing wind speed (Manoli et al. 2019). These various strategies will further be discussed in chapter 4.

Figure 1.10 Relative Effect Sizes of Local Characteristics on UHI Intensity in East Asian Cities



SOURCE: World Bank calculations based on the urban heat island intensity (UHI) data from 4 Earth Intelligence, https://www.4earthintelligence.com/; and the boundaries of 100 East Asian cities from the European Commission, Global Human Settlement Urban Centre Database R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: For each variable, the effect size measures the estimated impact on a city's UHI intensity of a 1 standard deviation increase in the value of the variable based on the sample of 100 East Asian cities in the sample (see box 1.2). Full regression results are presented in annex 1B. Significance level: * = 10 percent, ** = 5 percent, *** = 1 percent.

It is also noteworthy that, all else being equal, population density tends to increase the UHI intensity although the magnitude of its impact is smaller than those of greenness and precipitation (figure 1.9, panel C; figure 1.10). High-density, compact urban forms have often been identified as key development strategies for positive agglomeration forces[30] with potential co-benefits of climate change mitigation.[31]

However, the direct and indirect impacts of city densification on the UHI effect is an ongoing debate. On the one hand, a high density associated with well-connected public transportation networks and relatively small property sizes may help ameliorate the UHI effect by reducing human-generated heat from, for instance, private vehicle travels and the energy consumption of buildings (Glaeser 2012; Viguié and Hallegatte 2012). Acting against this, a high density may intensify UHI effects because tall buildings, despite their shading effects, trap heat and pollutants (Li et al. 2020).

The positive correlation between the UHI intensity and population density may also be because of factors that are unaccounted for in this analysis, such as a city's layout, whereby a grid layout accompanied by tall buildings and narrow streets tends to increase heat storage through radiative exchanges of energy within street canyons (Sobstyl et al. 2018). Although further investigation of these mechanisms is beyond the scope of this report, the above results are suggestive of the importance of urban design and building codes in relieving heat stress especially for cities actively being built out.

SUMMARY AND CONCLUSION

To help East Asia's city stakeholders better grasp the threats posed by extreme heat, and to inform the policy discussion of chapter 4, this chapter has presented the evolving patterns of extreme urban heat across East Asian cities. The analysis of 100 major cities in the region reveals that cities are, on average, hotter than their rural surroundings by around 1.6–2.0°C and, in the most extreme case, by over 5°C, presumably owing to inadequate urban planning and policies that contributed to the formation of UHIs. Moreover, these average values mask considerable within-city variation in UHI intensities such that the maximum intensity experienced in some neighborhoods within a city is considerably higher than the average, an issue that chapter 2 explores in depth.

A complementary analysis based on a sample of over 3,000 East Asian cities further confirms that global climate change compounds heat stresses posed by the UHI effect. Abnormally high temperatures, relative to the historical norm of each city, have become 23 times more frequent in the past four decades while increasingly deviating from the normal climatic condition over time. Although increasing exposure to extreme heat events is pervasive across the region, more dramatic increases occurred in already hot and humid tropical cities, where the UHI effect is the strongest. Along with the gradually increasing precipitation in the tropics, these evolving patterns highlight the unique struggles that confront rapidly growing cities in Southeast Asian countries. However, cities outside tropical regions, notably those in northern and southwestern China, may also struggle with adverse socioeconomic impacts of extreme heat events because they may not be as well adapted to them.

As chapters 2 and 3 will discuss, extreme urban heat affects virtually every aspect of urban life, and the most vulnerable city residents, with limited capacity to adapt, are disproportionately more exposed. Hence, the findings of this chapter suggest that it is imperative to implement adequate strategies for heat mitigation and adaptation to safeguard the prosperity, livability, and inclusiveness of East Asian cities and to reduce economic inequality within and across cities.

Although local decision-makers, acting in isolation, cannot significantly mitigate global climate change, they can ameliorate the UHI effect through better planning and design of cities in consideration of local climatic conditions. Moreover, they can promote adaptation to extreme urban heat—whether driven by the UHI effect or abnormally high temperatures—through a variety of physical and behavioral measures to be discussed in chapter 4.

ANNEX 1A DEFINING EXTREME HEAT EVENTS

The first definition, which may be considered an *absolute definition*, goes back to A. T. Burrows (1901), who defined a heat wave (or, as he termed it, "hot wave") as a spell of three or more days, on each of which the maximum shade temperature reaches or exceeds 90 degrees Fahrenheit. Based on this definition, a city's temperature on a given day can be regarded as an extreme heat event if it exceeds a predetermined absolute temperature threshold, say, 35°C, on that day. Formally, it can be written as:

$$T_{c,d} > T_{c,d}^{Threshold}, \qquad (1A.1)$$

where, $T_{c,d}$ and $T_{c,d}^{Threshold}$ respectively refer to a city's temperature on a given day and an absolute temperature threshold.

The second definition, which associates an extreme heat event with an *absolute temperature anomaly*, is derived from that of the World Meteorological Organization (WMO). According to this, a heat wave is defined as five or more consecutive days of prolonged heat "during which the daily maximum temperature surpasses the average maximum temperature by 5°C (9°F) or more."[32] More generally, a city is considered as having an extremely hot day if its temperature on that day deviates from a reference temperature by more than a certain absolute threshold—for example, 5°C, as in the WMO definition. The reference is often calculated as the city's long-run average temperature over a base period. This definition may be expressed as follows:

$$Anomaly^{a}_{c,d} = (T_{c,d} - \overline{T}_{c,d}) > T^{Threshold\ (a)}_{c,d}, \qquad (1A.2)$$

where, $T_{c,d}$, $\overline{T}_{c,d}$, and $T^{Threshold\ (a)}_{c,d}$ respectively denote a city's temperature on a given day, its long-run average temperature, and a threshold absolute temperature.

The third definition, which is based on the concept of a *relative temperature anomaly*, is derived by standardizing a city's absolute anomaly on a given day by the variation in the city's temperature over the same base period applied to calculate the absolute anomaly. With the absolute anomaly alone, it is inadequate to draw a full picture of extreme heat events because the same degrees of absolute anomaly could be more significant in cities with stable climates than in those with more variable climates. Based on a relative anomaly, a city's temperature on a given day can be considered an extreme if the *standard deviation* of the temperature on that day exceeds a predefined threshold, such as +2 standard deviations. Formally, a relative anomaly of a city on a given day can be written as

$$Anomaly^{r}_{c,d} = \frac{T_{c,d} - \overline{T}_{c,d}}{SD_c} > T^{Threshold\ (r)}_{c,d} \qquad (1A.3)$$

where, $T_{c,d}$, $\overline{T}_{c,d}$, SD_c, and $T^{Threshold\ (r)}_{c,d}$ respectively refer to a city's temperature on a given day, its average temperature over a base period, the standard deviation of the city's temperatures over the base period, and a threshold standard deviation.

ANNEX 1B DETERMINANTS OF URBAN HEAT ISLAND INTENSITY

Table 1B.1 Regression Results for the Potential Determinants of Urban Heat Island Intensity

DEPENDENT VARIABLE:	UHI INTENSITY (LN, AVERAGE 2012–16)		
BUFFER DISTANCE	2 KM	5 KM	10 KM
Average greenness (ln, 2014)	−1.077	−1.998***	−1.755***
	[−1.64]	[−2.94]	[−3.17]
Total annual precipitation (ln, 2014)	.894***	.902***	.848***
	[3.84]	[3.88]	[4.06]
Mean annual temperature (ln, 2014)	−.590*	−.569*	−.458
	[−1.81]	[−1.86]	[−1.45]
Latitude (ln of absolute values)	−.0601	−.0933	−.0697
	[−0.57]	[−0.84]	[−0.59]
Mean elevation (ln, 2014)	.056	.122***	.114**
	[1.29]	[2.68]	[2.53]
Population (ln, 2015)	.0245	.0264	.00419
	[0.36]	[0.34]	[0.06]
Population density (ln, 2015)	.711**	.466**	.406**
	[2.63]	[2.19]	[2.29]
Constant	−12.5***	−11.5***	−10.6***
	[−5.20]	[−5.64]	[−5.20]
No. of observations	99	100	99
R^2	.651	.671	.678
Adjusted R^2	.556	.582	.590

SOURCE: Results based on the analysis of the urban heat island (UHI) intensity data processed by 4 Earth Intelligence, https://www.4earthintelligence.com/, and the rest of the data from European Commission, Global Human Settlement Urban Centre Database (GHS-UCDB) R2019, https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php.

NOTE: Discussions in the main text refer to the result in the 5 km column. Numbers in brackets are robust t-statistics. Regressions also include country dummies. The regressions based on the buffer sizes of 2 km and 10 km exclude Bago and Mandalay (both from Myanmar), respectively, because the log transformation of the dependent variable omitted those cities that had negative average UHI intensities during 2012–16. km = kilometers; ln = natural logarithm Significance level: * = 10 percent, ** = 5 percent, *** = 1 percent.

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NOTES

1 This chapter covers 16 World Bank member countries (Brunei Darussalam, Cambodia, China, Indonesia, Japan, the Republic of Korea, Laos, Malaysia, Mongolia, Myanmar, Papua New Guinea, the Philippines, Singapore, Thailand, Timor-Leste, and Viet Nam) and the Democratic People's Republic of Korea in East Asia while excluding Australia, New Zealand, and the Pacific island states.

2 Throughout this report, temperatures are generally referred to in degrees Celsius rather than Fahrenheit. A conversion table between Celsius and Fahrenheit can be found in the report's front matter.

3 Labor productivity losses due to extreme heat exposure are estimated to cost the global economy US$300 billion every year. The Southeast Asia region is projected to experience the world's largest labor productivity loss from such exposure—16 percent by 2045 (Maplecroft 2017).

4 When China was grappling with its summer 2022 heat wave, for example, many energy-intensive firms had to reduce their hours of operation because of power shortages, while others had to shut down entirely (Yu 2022).

5 Based on multi-model ensemble average projections in Representative Concentration Pathway (RCP) 4.5, an intermediate greenhouse gas emission scenario adopted by the IPCC.

6 The projected GDP loss is based on temperature increases due to global warming under RCP 8.5, the highest greenhouse gas emissions scenario adopted by the IPCC. Under RCP 4.5, Estrada, Wouter Botzen, and Tol (2017) project the GDP loss for the median city globally to be 1.4 percent. When the UHI effect is considered, the projected total economic damage from heat in cities during the twenty-first century is 2.6 times the magnitude of losses when it is not. For further discussion, see chapter 3.

7 Some cities and countries even consider the duration of an event to define extreme heat. Adelaide, Australia, for example, defines a heat wave as five consecutive days at or above 35°C or three consecutive days at or above 40°C. Chapter 4 discusses locally appropriate thresholds in more detail.

8 Evapotranspiration removes heat through evaporation from natural surfaces and transpiration from stomata. Convection releases heat from the surface back into the atmospheric boundary and brings in fresh cool air. This process is more efficient in an environment with rough surfaces, such as rocks and dense vegetation, than in urban areas with smooth surfaces of buildings and pavements or in rural areas with low stature, such as shrubs and grasses (Zhao et al. 2014).

9 As hotter days become more frequent, this will slowly pull up the historical long-run average as more recent hotter days are averaged with relatively more distant cooler days. In the process, these more recent hotter days will also appear as larger absolute and relative temperature anomalies.

10 In defining hot temperature extremes, IPCC (2021) considers both absolute (days when maximum daily temperature exceeds, say, 35°C) and relative (the 90th or higher percentile of maximum daily temperature for the calendar day over a base period) definitions.

11 Population projections are based on data from the Shared Socioeconomic Pathway (SSP) Database, version 2.0, on the International Institute for Applied Systems Analysis (IIASA) website: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10.

12 4 Earth Intelligence (4EI) (https://www.4earthintelligence.com/) is a global firm with expertise in earth observation, geographic information systems (GIS), and remote sensing analytics. It was competitively selected through the Digital Earth Partnership Technology Challenge (https://www.space.org.sg/digital-earth-partnership-technology-challenge/) jointly organized by the World Bank and Singapore Space & Technology Ltd during December 2021–March 2022.

13 The LST images used as input for estimating the intensity of the UHI effect were produced by the National Aeronautics and Space Administration's Moderate Resolution Imaging Spectroradiometer onboard

the Earth Observing System (EOS-MODIS) and the National Oceanic and Atmospheric Administration's Advanced Very High-Resolution Radiometer aboard the Meteorological Operational satellite (MetOp-AVHRR). To classify urban and nonurban pixels, 4EI leveraged the WorldCover products from European Space Agency (https://esa-worldcover.org/) and land cover maps from Copernicus Global Land Service (https://land.copernicus.eu/global/products/lc).

14 The monthly temperature and precipitation datasets used in this chapter are drawn from Climatology Lab's TerraClimate (https://www.climatologylab.org/terraclimate.html), which covers global terrestrial surfaces at a spatial resolution of 1/24th degree (about 4 kilometers) for the period January 1958–December 2020.

15 The choice of the base period varies widely across meteorological organizations. For global mean surface temperature datasets, for example, NOAA uses 1901–2000, whereas NASA, the Hadley Centre/Climatic Research Unit Temperature (HadCRUT), and the Japan Meteorological Agency use 1951–80, 1961–90, and 1991–2020, respectively. The choice affects the sizes of anomalies but not the trends over time.

16 The relative anomaly definition of extreme heat events is consistent with the theory that people possess "rational expectations." According to this theory, people are forward-looking agents who base their expectations and therefore behavior on all relevant available information. This also implies that they adapt to predictable trends and past experiences of events. Under this theory, for an event to have an impact on outcomes, it must come as a "surprise." The theory of rational expectations was first introduced into economics by Muth (1961) before subsequently being widely integrated into macroeconomic theory by, among others, Lucas (1972) and Sargent (1972).

17 An alternative—and, in principle, very appealing—approach to measuring extreme heat events would be to define a given temperature as extreme if there is evidence to show it has significant adverse impacts on the outcomes of interest. However, in practice, it is difficult to implement such a definition, especially when considering a wide range of different outcome variables, as is the case in this report. Thus, for example, as the discussion in chapter 3 makes clear, there is no unique threshold across different outcomes, countries, or even time of the year within countries, that can be identified as triggering negative impacts of high temperatures. Furthermore, the level of thermal comfort that a given temperature translates into also depends on other factors, most notably humidity.

18 Extreme heat and air pollution tend to occur together with the same underlying meteorological conditions that reduce the flow of winds, thus interfering with convection cooling and pollutant dissipation.

19 This is, however, not to downplay the health risk of dry heat that can be experienced in, for example, northern China. In a dry atmosphere, people can be easily dehydrated because moisture evaporates off their skin too quickly, even before they realize they are sweating (Cappucci 2023).

20 A city's level of humidity is proxied by its annual total precipitation averaged over January 1958–December 1999.

21 Visual inspections of various trends—for example, of other statistics or by country—suggest that the temporary increases in the UHI intensities during 2010–14 may not be data artifacts. Nevertheless, further research beyond this report is required to establish the reasons for such trends.

22 The list of top 10 cities in estimated UHI intensity includes 1 city each from Indonesia and Singapore, 5 from Malaysia, and 3 from the Philippines.

23 The 2000–20 average temperature estimate for Bangkok's rural surroundings is based on a 10 kilometer buffer.

24 The analysis in this section emphasizes five-year moving averages. This allows it to take account of the average intervals of recurring climate patterns such as El Niño and La Niña, which occur every two to seven years on average (https://oceanservice.noaa.gov/facts/ninonina.html). The use of five-year moving averages also helps smooth potential temporary measurement errors in the data.

25 The negative relationship between the increases in mean annual temperature and the initial temperatures is even stronger when the increases are measured as the average annual growth rates (AAGRs) rather than as absolute increases. However, we chose to present the pace based on the absolute increases in figure 1.4 because the calculation of AAGRs, by definition, omitted nine cities that had a negative mean annual temperature in the initial year (for example, Ulaanbaatar, Mongolia).

26 Megacities are defined as cities with populations over 10 million (World Bank 2015). The full sample of 3,033 East Asian cities includes 11 megacities, in descending order of 2015 population: Guangzhou, China; Jakarta, Indonesia; Tokyo, Japan; Shanghai, China; Quezon City-Manila, Philippines; Seoul, Korea; Beijing, China; Osaka-Kyoto, Japan; Bangkok, Thailand; Ho Chi Minh City, Viet Nam; and Jieyang, China.

27 A city's average greenness is calculated as the unweighted mean level of greenness across all pixels within its spatial extent, where the level of greenness of a pixel is derived based on the highest value of the Normalized Difference Vegetation Index (NDVI) for the reference year of 2014. For more details, see Corbane et al. (2020).

28 For example, Singapore's Urban Redevelopment Authority (URA) and the Housing and Development Board (HDB) find—in their joint study on residential areas (Jurong Lake District and Punggol housing estate) and a new business area (near Asia Square)—that plants along building façades can provide heat stress relief to people within a 4 meter range, beyond which the green façades have little or no effect (Neo 2018).

29 It is worth noting that maintaining more green spaces can be challenging for water-scarce cities.

30 For example, Bosker, Park, and Roberts (2021) estimate that, in Java-Bali, Indonesia, a doubling of urban density is associated with a 14.2 percent increase in an average worker's nominal wage.

31 Evidence based on a global sample of cities shows that, after controlling for a city's size and level of development, city compactness is negatively associated with the amount of production-based CO_2 emissions from the residential and transportation sectors. Lower emissions could be largely attributed to more infill as opposed to leapfrog development and fewer vehicle miles travelled—a result achieved especially by discouraging personal motorized vehicles (Mukim and Roberts 2023).

32 Rafferty, John P., "Heat Wave." *Encyclopedia Britannica*, accessed November 29, 2022, https://www.britannica.com/science/heat-wave-meteorology

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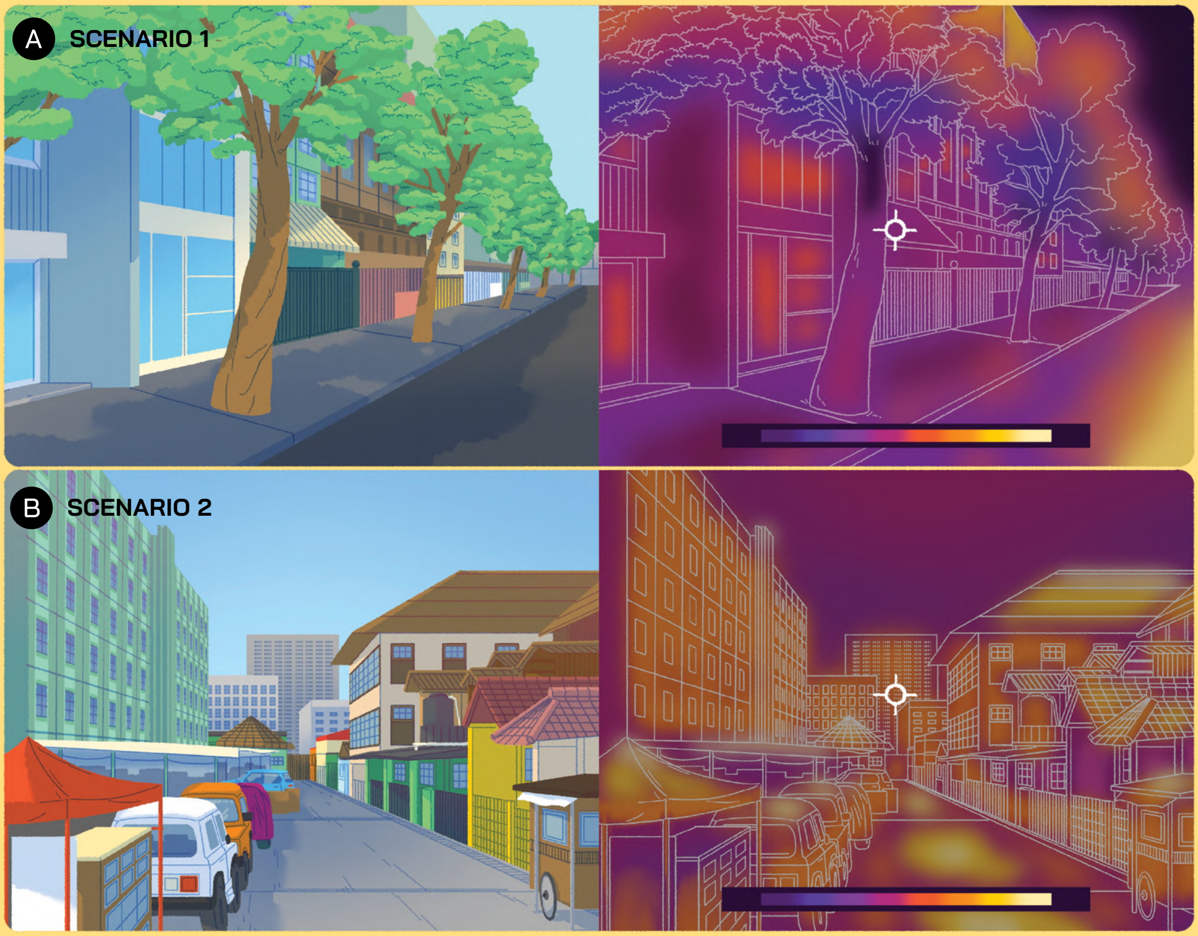
CHAPTER
2



THE HEAT ISLAND EFFECT WITHIN EAST ASIAN CITIES: WHO IS MOST EXPOSED & WHAT DETERMINES ITS STRENGTH?

KEY MESSAGES

- Within East Asian cities, temperatures can vary sharply between pairs of neighborhoods in close proximity, as evident from in situ measurements in cities such as Bandung, Indonesia.

- Neighborhoods with densely packed homes, heat-trapping materials, and limited vegetation give up their heat at night more slowly than those with widely spaced buildings and plentiful tree cover.

- These "thermal inequalities" within cities can be large: heat disparities of up to 7 degrees Celsius (°C) were measured in Bandung, Indonesia, through fieldwork conducted for this report.

- Climate modeling indicates that East Asian cities will face more hot days and nights per year by midcentury because of the warming background climate, but interventions to reduce heat-trapping surfaces, increase wind flow, and add vegetation could partially counteract this effect.

INTRODUCTION

Each day, when city dwellers step outside, they experience the weather: temperature, precipitation, wind, cloud cover, and other atmospheric conditions that (averaged over time) make up the local climate. East Asian cities are experiencing climatic warming due to global processes (see chapter 1). However, urban climates are also shaped by meteorological phenomena that take place on a much finer geographic scale. Urban landscapes, having absorbed the sun's energy during the day, cool more slowly than do nearby rural areas, owing to the thermal properties of building and paving materials. The density of such materials and their arrangement into built forms such as street canyons differ markedly between neighborhoods. Just as city blocks vary sharply in appearance and character, so too do their thermal properties when interacting with the atmosphere and the sun's energy—resulting in hyperlocal differences that accentuate the impact of global climate change on residents of heat-prone neighborhoods.

Heat in city neighborhoods often tends to reflect and reinforce existing inequalities. Indeed, research across world regions has identified "thermal inequalities" whereby residents of different neighborhoods, despite living very short distances apart, experience sharply different levels of heat stress (Chakraborty et al. 2019). Thermal differences between neighborhoods can be identified and addressed through actions at different spatial scales—from painting an individual building's roof white to planning urban landscapes for improved wind flow and vegetation coverage. This chapter explores the extent of variation in local temperatures within East Asian cities and the factors that correlate with this variation through two case studies: Bandung (Indonesia) and Phnom Penh (Cambodia). Through local heat stress measurements and climate simulations, the chapter documents variation in heat stress between city neighborhoods, providing insights on a granular level that complement those in chapter 1 on the overall strength of heat island effects in a broad sample of East Asian cities.

WHEN CITIES ARE BUILT, LOCAL CLIMATE PROCESSES CHANGE

Urbanization transforms landscapes. When humans build cities, they level terrain, remove vegetation, and introduce new surfaces and structures. They use materials such as asphalt, packed earth, wood, concrete, steel, and glass to introduce buildings and paved surfaces. Such materials are selected for physical properties such as strength and durability, but they also have thermal characteristics such as higher absorption and retention of heat. A city neighborhood, compared with the same site in its undisturbed state, therefore exhibits a radically different interaction with the earth's atmosphere.

In considering neighborhoods from a meteorological perspective, several aspects of urban form are important:

- *Land cover*, notably the fraction of land area that is vegetated or sealed with impervious materials such as asphalt
- *Fabric*, including the characteristics of the materials used to construct paving and buildings
- *Geometry*, including the shape, height, and spacing of buildings.

In city landscapes with little vegetation and extensive heat-trapping surfaces, net energy transfers between the earth's surface and its atmosphere are modified, resulting in higher local air temperatures (box 2.1). The size and orientation of buildings also affect microclimates. Street canyons with a high height-to-width ratio retain thermal energy longer because tall buildings obstruct the release of radiation back into the atmosphere (Johansson 2006; Oke et al. 2017).

Cities influence the climate at different scales—from individual parts of buildings to metropolitan regions. Table 2.1 identifies a hierarchy of such scales and the corresponding meteorological phenomena that buildings, neighborhoods, and cities affect. At the level of an individual building, differences in atmospheric conditions can readily be experienced by standing in the shade of a building on a hot day or moving from its wind-exposed side to its sheltered side. At the block and neighborhood levels, pedestrians in East Asian cities routinely adapt their behavior to urban climate effects by walking on sunny or shady sides of the street or seeking out cool, breezy parks for rest and recreation. On the metropolitan scale, differential warming of air above urban areas and their surroundings can induce wind flows that affect heat stress and air pollution. At each scale, design and planning interventions can mitigate the heat island effect and promote cooler spaces for the benefit of residents and workers.

Table 2.1 Climate Processes at Different Urban Scales

URBAN UNIT	FEATURES	CLIMATE PHENOMENA	TYPICAL HORIZONTAL SCALE
Facet	Roof, wall, road, lawn, pond	Shading, storage heat flux, dew, and frost patterns	10 x 10 meters
Element	Building, tree	Wind flow effects (for example, wake behind tall building)	50 x 50 meters
Street canyon	Row of buildings, line of street trees	Cross-street shading, pedestrian microclimate	30 x 200 meters
Neighborhood	City center, residential quarter, industrial zone, park, lake	Local neighborhood climate, park cool island effect, local breezes	2 x 2 kilometers
City	Built-up area	Urban heat island, urban effects on humidity and wind	50 x 50 kilometers

SOURCE: Modified based on Oke et al. 2017.

BOX 2.1 HOW DO A NEIGHBORHOOD'S VEGETATION AND BUILT SURFACES AFFECT ITS CLIMATE?

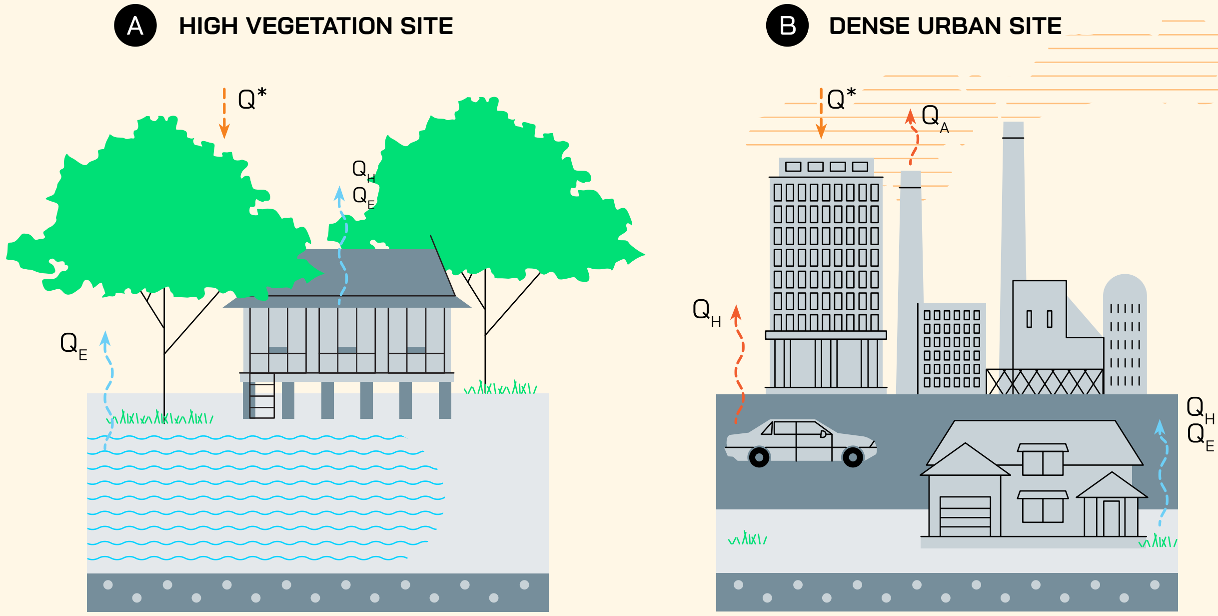
Trees and vegetation promote cool urban environments through their influence on local meteorological processes. Figure B2.1.1 illustrates their influence by means of the surface energy balance—a framework used by meteorologists to characterize the transfer of energy between atmosphere and surface at given locations.

In the left panel (figure B2.1.1, panel A), solar energy meets the earth's surface at a rural location with trees. Energy heats the air (generating "sensible heat"). Through evapotranspiration, energy also transforms the water contained in leaves from liquid to a gas state (generating "latent heat").

The right panel (figure B2.1.1, panel B) portrays an urban location. With little vegetation in this location, a higher share of energy is used to generate sensible heat than latent heat, contributing to higher air temperatures. Vehicles and factories ("anthropogenic heat" sources) raise temperatures further. Materials with high thermal inertia such as asphalt retain energy during the day and radiate it back at night, contributing to higher nighttime temperatures.

Urban forestry initiatives can increase vegetation cover and change the surface energy balance to promote cooler environments. When trees are planted across sufficiently large areas, a "park cool island" effect can be observed: differential heating of air across green versus built-up areas creates localized breezes that exert a cooling influence on adjacent city blocks. Reduction of areas under asphalt and similar heat-trapping materials can likewise mitigate urban heat islands. Such potential interventions are discussed further in chapter 4.

Figure B2.1.1 The Surface Energy Balance: How Reduced Vegetation and Increased Human-Generated Heat Result in Warmer Urban Temperatures



SURFACE ENERGY BALANCE: $Q^* + Q_A = Q_H + Q_E + \Delta Q_S$

SOURCE: World Bank elaboration based on Oke et al. 2017.

NOTE: The figure presents a simplified representation of the surface energy balance in a densely vegetated site and in a densely built-up urban site. Incoming solar radiation (Q^*) + human-generated heat (Q_A) = sensible heat (Q_H) + latent heat (Q_E) + heat storage in substrate and surfaces (ΔQ_S).

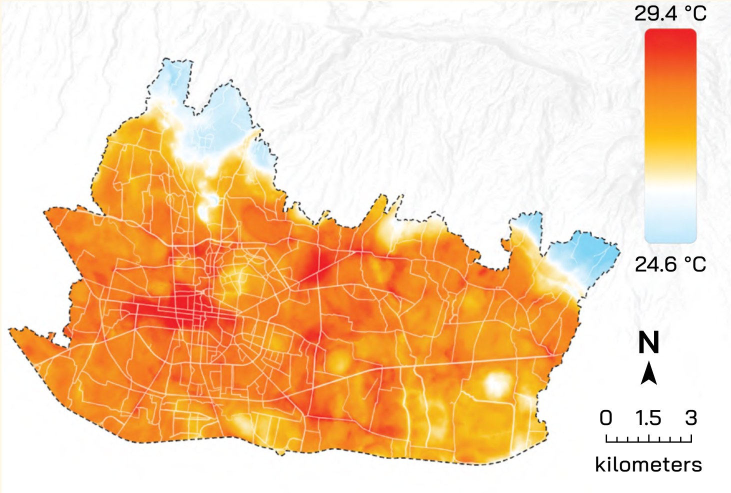
TEMPERATURES DIFFER SHARPLY BETWEEN CITY NEIGHBORHOODS

Like many East Asian cities, Bandung, Indonesia, has experienced rapid demographic and territorial growth in recent decades that has transformed its physical character. Located some 90 miles southeast of Jakarta and serving as capital of West Java Province, Bandung's population grew rapidly in the decades after Indonesia's independence in 1945, expanding by 2021 to 2.4 million within city limits and around 8.1 million in the Greater Bandung metropolitan area. Rapid growth has resulted in neighborhoods that differ in density, construction type, prevalence of green cover, and building materials. As Indonesia's second largest metropolitan area, Bandung occupies a position of key economic importance in the country's urban hierarchy (Roberts, Gil Sander, and Tiwari 2019).[1]

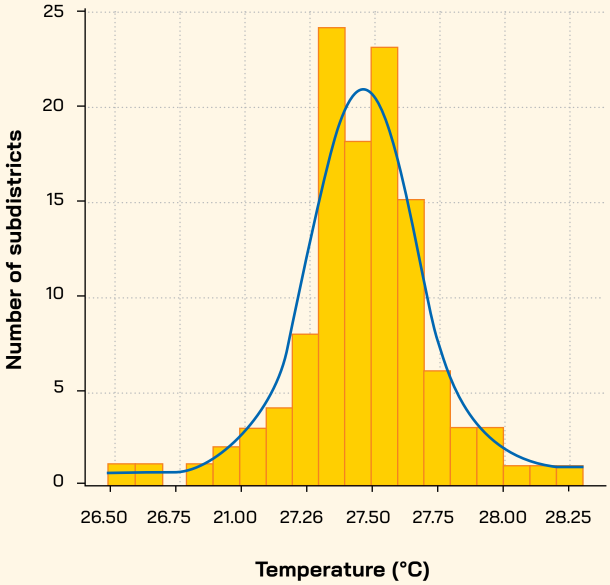
To gain a fine-grained understanding of heat stress across the city, a "vehicle traverse" study was undertaken for this report in summer 2022 by a team recruited by Bandung Institute of Technology (Institut Teknologi Bandung).[2] Thirty-three student "citizen scientists" fitted heat and humidity sensors to motorbikes and drove preplanned routes around the city. More than 51,000 measurements of near-ground air temperature and humidity were conducted in three separate vehicle traverses (conducted at 7–8 a.m., 12–1 p.m., and 5–6 p.m.). By relating the heat measurements to land surface characteristics using a machine learning model, high-resolution heat maps for the entire city area were developed (figure 2.1).

Figure 2.1 Ambient Air Temperatures in Bandung, Indonesia, 2022

A AVERAGE NEAR-GROUND AIR TEMPERATURES



B MEAN NEAR-GROUND AIR TEMPERATURES, BY SUBDISTRICT



SOURCE: Jones et al. 2023.

NOTE: The ambient air temperature surface map was derived using machine learning techniques whose inputs included field measurements of near-ground air temperature taken on July 31, 2022. The map averages temperatures in degrees Celsius (°C) for three times of day (7–8 a.m., 12–1 p.m., and 5–6 p.m.) to arrive at a citywide average daytime temperature map.

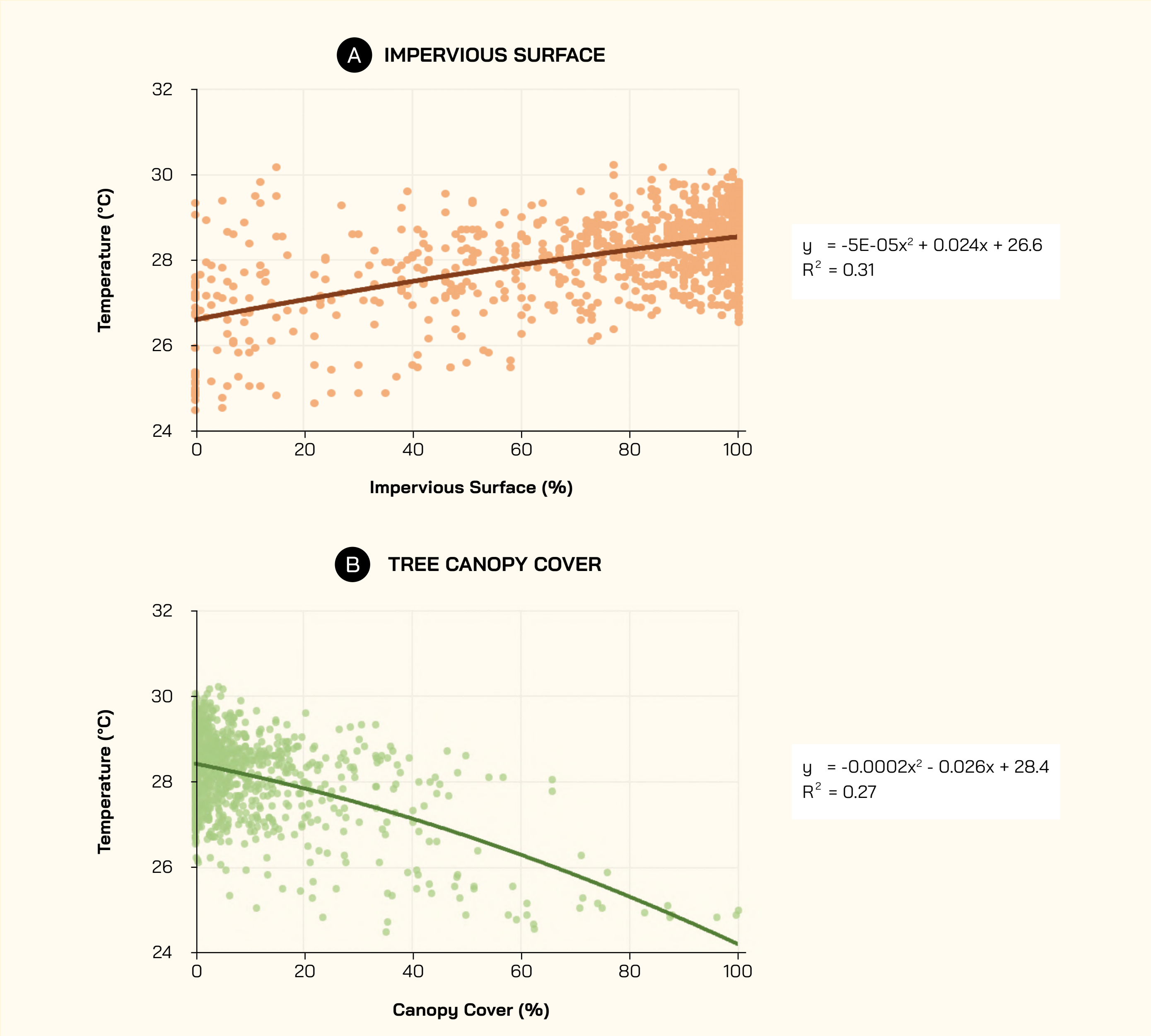
DIFFERENCES IN VEGETATION AND BUILT FORM DRIVE HEAT DIFFERENTIALS

The resulting datasets show strong spatial variation in heat exposure across Bandung at the time of the heat mapping campaign. Temperature differentials were highest in the early evening, with a 7 degrees Celsius (°C) disparity between hottest and coolest neighborhoods measured via the vehicle traverses conducted at 5–6 p.m. This is consistent with previous urban climate research, which finds the heat island effect is most intense at night, when differential rates of cooling between green and open landscapes versus dense and crowded landscapes drive sharp temperature differences (see, for example, Jáuregui 2000; Oke 1982).

Heat island intensity varies systematically with characteristics of the urban surface. Areas where a higher proportion of surface area comprises sealed, impervious surfaces—such as roadways, parking lots, and buildings—show higher temperatures (figure 2.2, panel A). Areas where tree canopy is a higher proportion of surface area are systematically cooler (figure 2.2, panel B).

Through hyperlocal measurements of the atmospheric layer that human beings experience daily (that is, ambient air temperatures at near-ground level), the heat mapping campaign provides a more accurate description of spatial variation in heat than is possible through satellite observations or local weather stations (Shandas et al. 2019). In so doing, it draws attention to the pronounced disparity in heat stress experienced between city neighborhoods. Because of the urban heat island (UHI) effect, residents in cities like Bandung already face local temperature disparities that are large enough to influence local health.

Figure 2.2 Relationship between Air Temperature and Ground Cover Characteristics, in Bandung, Indonesia, 2022



SOURCE: Jones et al. 2023, using in situ heat measurements plus European Space Agency's World Cover 2020 dataset (https://worldcover2020.esa.int/).

NOTE: Near-ground air temperature measurements were taken during vehicle traverses of Bandung on July 31, 2022. Panels A and B present temperature measurements in degrees Celsius (°C) against the percentages of land cover that are impervious surface and tree canopy cover, respectively. The equations and R-squared values summarize relationships between air temperature and ground cover characteristics with each dot representing a 100-meter grid cell.

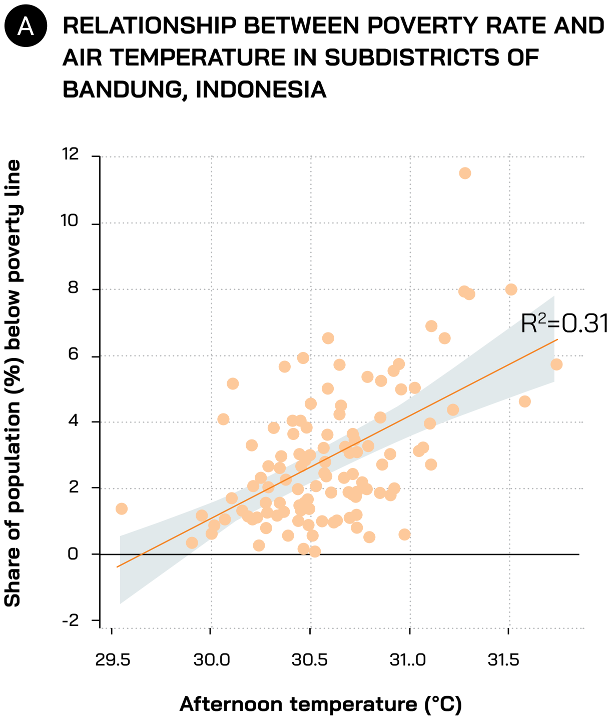
POOR RESIDENTS ENDURE HOTTER ENVIRONMENTS

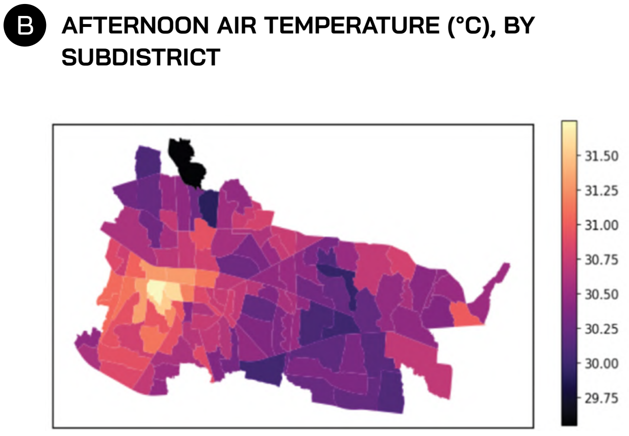
Urban climate studies have frequently found a link between the prosperity of neighborhoods and how hot they are. (See, for example, Chan et al. (2012) and Hoffman, Shandas, and Pendleton (2020) as well as the discussion in chapter 3.) Households, businesses, and governments all invest in the built form of city neighborhoods, making decisions about structural type, building materials, plot size, spacing between buildings, and vegetation prevalence that are shaped by their budget constraints and, to varying degrees (depending on the level of enforcement), planning regulations.[3] Households also choose residential neighborhoods based, in part, on the "amenities" those neighborhoods offer. Richer households can outbid poorer households when renting or buying in more "pleasant" neighborhoods, which can include those with more greenery and less-impervious surfaces.[4] To the extent that a household's socioeconomic status is correlated with the race or ethnicity of its members, this may also result in racial or ethnic inequalities in exposure to heat island effects.

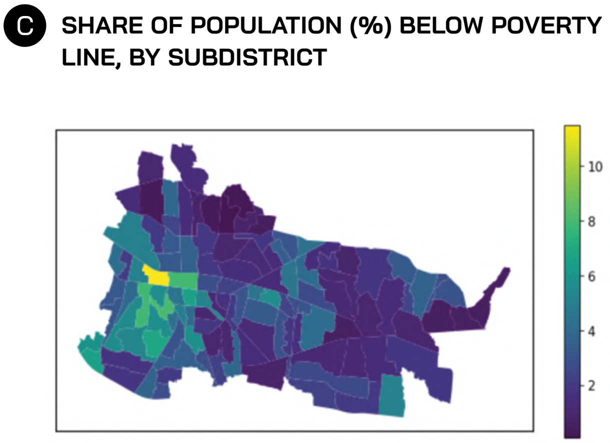
Tree canopy cover and building density are both closely associated with the physical processes that promote heat in urban settings. Poor neighborhoods represent many—but not all—of the city neighborhoods where density is highest and vegetation is lowest. Central business districts and districts where government buildings are concentrated often exhibit high densities of buildings and impervious surfaces and may have low vegetation densities while hosting high-paying residents and workers.

In Bandung, similar patterns in the relationship of heat and neighborhood prosperity are evident. Based on poverty map data that estimated the number of people living below Indonesia's national poverty line in each of the city's 153 subdistricts, poorer parts of the city systematically have fewer trees. Indeed, the share of area covered by tree canopy in the richest 20 percent of subdistricts is more than double that of the poorest 20 percent of subdistricts (at at 9.2 percent and 3.6 percent of surface area, respectively). Comparing heat stress levels in Bandung with the poverty rates of its subdistricts shows that poorer neighborhoods tend to be hotter than richer neighborhoods (figure 2.3).

Figure 2.3 Relationship between Poverty Rate and Afternoon Temperature, by Subdistrict, in Bandung, Indonesia, 2022







SOURCE: World Bank calculations based on temperature data from Jones et al. 2023 and poverty data from Smeru Research Institute's Poverty and Livelihood Map of Indonesia 2015 (https://smeru.or.id/en/resource/poverty-and-livelihood-map-indonesia-2015).

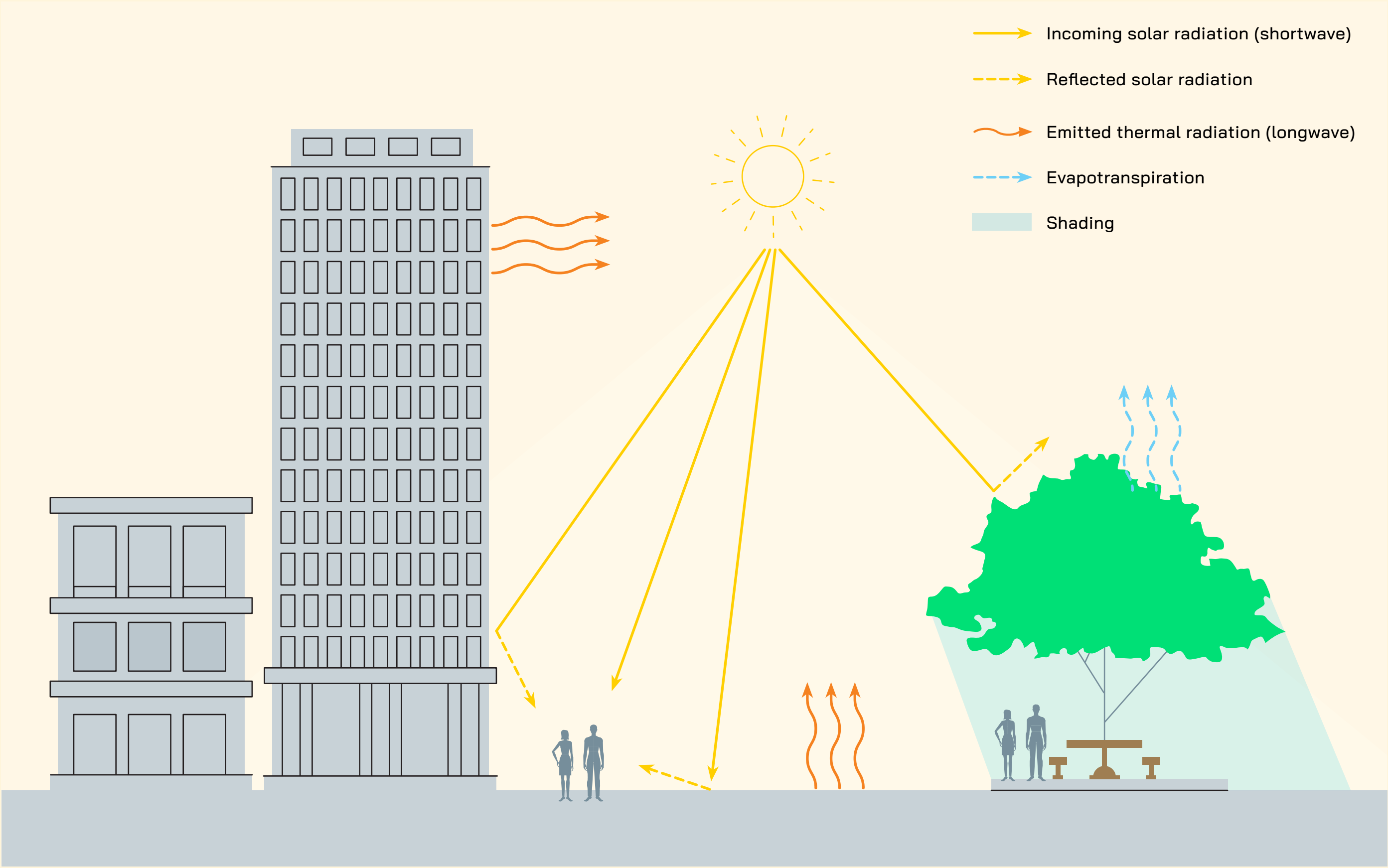
NOTE: Poverty is defined as the proportion of people with per capita household consumption below the national poverty line (Rp 350,000 a day). Modeled heat data are based on vehicle-based ambient air temperature measurements in degrees Celsius (°C) taken on July 31, 2022. In panel (A), a linear regression best fit line is presented with the shaded area denoting the 95% confidence interval.

HEAT AT THE MICRO LEVEL: BUILT FORM AND THERMAL COMFORT

Building materials and street layout contribute to city-scale phenomena such as the UHI effect, but they also affect physical processes at the building and block level—including absorption and radiation of heat from surfaces, shading from the sun's rays, and flow of breezes.

Examination of individual sites can yield insights about microfactors that make them hotter or cooler. Whereas temperature measurements are easily relatable, heat stress is necessarily a broader concept than air temperature alone. The human body uses several mechanisms to maintain an internal temperature of 37°C, including sweating and vasodilation (increase of blood flow close to the body's surface to increase heat shedding). Heat stress results not only from ambient air temperature but also from exposure to radiant heat—such as the sun's rays (direct or reflected from building materials) or mechanical heat sources such as motor vehicles or the hot air vented outdoors by air conditioners. Humidity is another important contributor to heat stress, because higher water content in the air inhibits heat loss through sweating (see also chapter 1). Finally, wind flow contributes importantly to cooling. When considering heat stress at individual sites, it is important to view these influences holistically (figure 2.4).

Figure 2.4 Factors Affecting Heat Stress at the Site Level

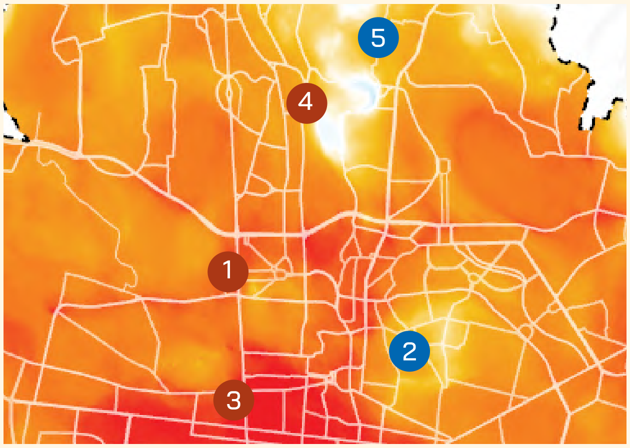


SOURCE: World Bank elaboration / Estudio Relativo.

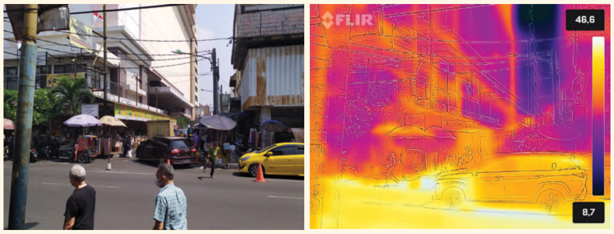
NOTE: The figure illustrates the effects of solar radiation (both direct and reflected), humidity, shade, and air flow—which, in addition to ambient air temperature, affect levels of heat stress.

Local knowledge can be highly applicable to identify and prioritize sites where cooling actions would deliver the greatest benefits. In daily life, heat stress is experienced where daily routines and activities take place in hot environments. Based on a participatory mapping exercise—again involving student "citizen scientists" recruited by Bandung Institute of Technology—figure 2.5 shows sites in Bandung that local residents considered important and representative from a heat mitigation perspective. These include a high school where a lack of shade exposes children to heat; a commercial precinct where dense asphalt adds to a hot experience for shoppers; and a dense settlement where building materials (including iron roofs) and tightly packed buildings contribute to heat stress for primarily low-income residents.

Figure 2.5 The Microcauses of Heat and Cooling in Selected Public Spaces, Bandung, Indonesia



3 A SHOPPING CENTER OF "PASAR BARU"



Heat trapping materials and little shade cause heat exposure for shoppers and merchants.

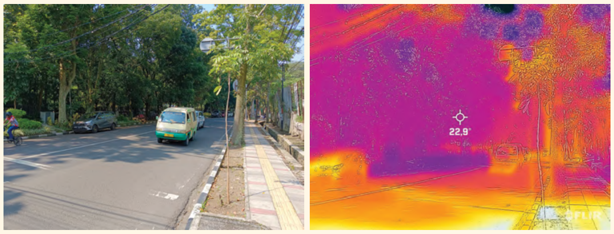
1 IN FRONT OF THE HIGH SCHOOL BUILDING (SMAN 6 BANDUNG)

Lack of shade or vegetation. Heat affects school children and parents.

4 A DENSE SETTLEMENT IN CHAMPELAS ROAD

Dense settlement, lack of trees, metal roofs.
Hot environment affects low-income residents.

2 COOL SPOT NEAR STADIUM



Dense tree canopy makes for a cool environment.

5 A RECREATION AND SPORT AREAS ("BABAKAN SILIWANGI")

Sports and recreation facilities situated in urban forest provide an attractive amenity.

SOURCE: World Bank elaboration / Estudio Relativo.

NOTE: The pairs of photographs and thermal images from selected sites illustrate volunteers' perceptions of why these sites are hotter (red-shaded numbers) or cooler (blue-shaded numbers) than average. The top left map shows these sites' locations in relation to Bandung city center. The shading of the map indicates near-ground air temperatures derived from field measurements taken on July 31, 2022. The map averages temperatures for three times of day (7–8 a.m., 12–1 p.m., and 5–6 p.m.) to arrive at a citywide average daytime temperature map.

URBAN HEAT WILL INTENSIFY IN COMING DECADES

Heat stress disparities are already starkly evident in East Asian cities and often cause low-income communities—which have a lower capacity to adapt through air conditioning and other means—to bear the brunt of heat waves.[5] But as climate change intensifies in the coming decades, the combined effects appear certain to place heat-prone neighborhoods under extreme stress, requiring urgent steps to protect vulnerable residents and safeguard labor productivity.

Cambodia's capital city, Phnom Penh, presents one such example. It underwent rapid expansion and densification of its urban footprint between 1995 and 2010, during which its population more than doubled (UN DESA 2015). An urban climate model built for this report estimates the city's current nighttime UHI effect, measured as the difference between city center and outlying rural temperatures, at 2.5°C.[6] Central districts of Phnom Penh already experience strong additional heat stress owing to human influences—some 23–25 heat wave days per year, compared with 2–5 such days in surrounding rural areas.

Using temperature datasets for the recent past and modeled atmospheric data for future periods, heat stress variables were modeled for the city. This was done for both (a) an optimistic scenario in which global emissions are curbed (the "SSP1-1.9" scenario); and (b) a pessimistic scenario in which carbon emissions maintain a stronger upward path before stabilizing ("SSP3-7.0").[7]

Under the high-emission scenario, the number of heat wave days is projected to increase to 60 days per year (more than a twofold increase) in the most-affected areas by 2050 (table 2.2). Neighborhoods with extensive trees and vegetation, and more space between dwellings, are projected to remain cooler on average, with around one-third fewer days classified as heat waves.

Table 2.2 Projected Heat Wave Days, Tropical Nights, and Energy Needs for Space Cooling, by Climate Change Scenario, in Phnom Penh, Cambodia, 2050

METRIC	OPTIMISTIC SCENARIO	PESSIMISTIC SCENARIO
Annual number of heat wave days[a]	40 (73 percent increase)	60 (160 percent increase)
Tropical nights (% of year)[b]	80 percent	90 percent
Energy needs for space cooling[c]	14 percent increase	30 percent increase

SOURCE: VITO NV, using its UrbClim model for this report.

NOTE: Under the "optimistic scenario," global carbon emissions are curbed; under the "pessimistic scenario," emissions maintain a stronger upward path before stabilizing. These scenarios correspond to the selected Shared Socioeconomic Pathways (SSPs) developed for the Intergovernmental Panel on Climate Change—namely, SSP1-1.9 and SSP3-7.0, respectively.

a. Heat wave days: the annual number of days where temperatures exceed the 90th percentile temperature of a historical reference period (2000–20) for at least three consecutive days.

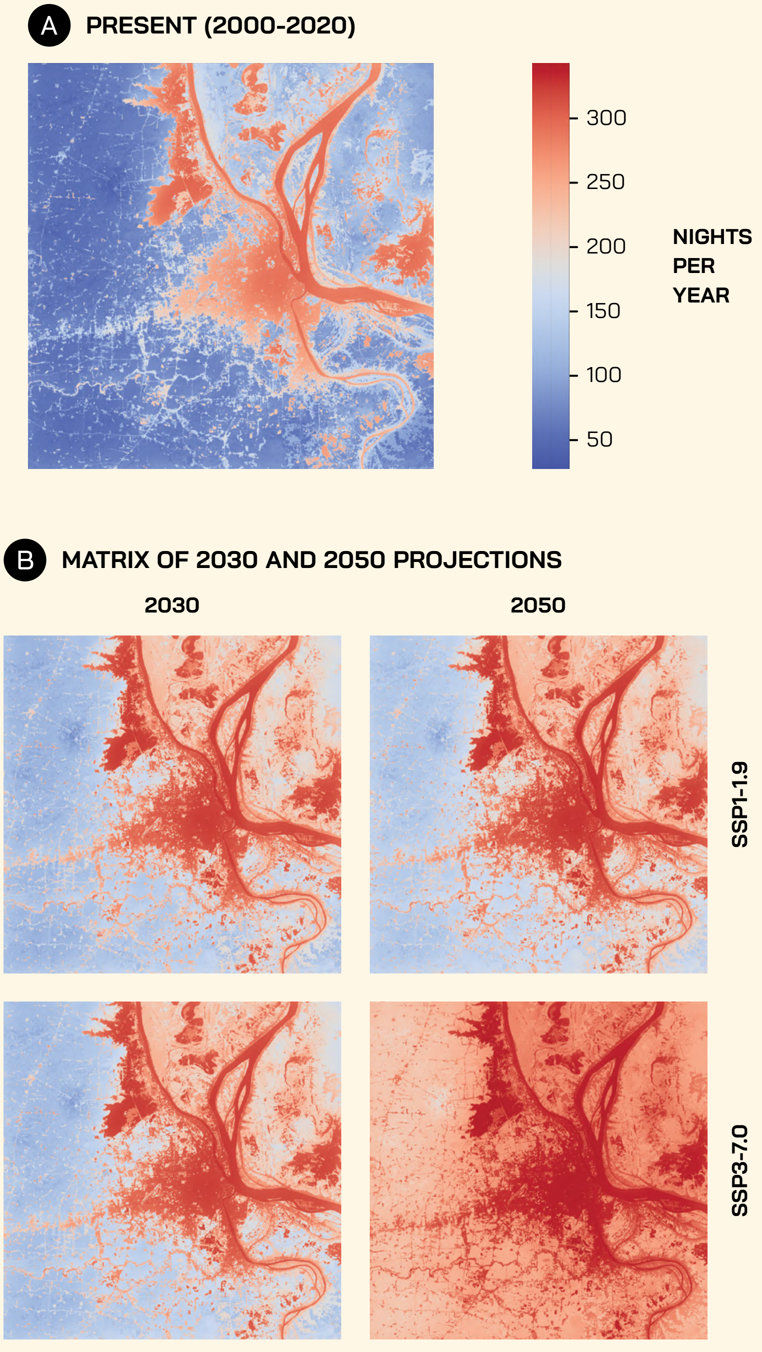
b. Tropical nights: the annual number of nights where temperature remains above 25 degrees Celsius

c. Measured as cooling degree days. Daily cooling needs are calculated by comparing outdoor temperatures with a reference point representing indoor thermal comfort. The cooling requirement for each period is multiplied by the length of the period. This metric captures projected energy demand driven by temperature effects, ignoring the growth driven by increased adoption of air conditioning.

Perhaps the most crucial impact of these heat stress disparities, as climate change progresses, will be the health implications of differences in nighttime temperatures. Very hot nights where temperatures remain above 25°C place the human body under extreme stress. Particularly for old people, young children, and those with health vulnerabilities, such temperatures at night inhibit cooling, rest, and recovery and are associated with higher death rates.

Even under an optimistic climate scenario, Phnom Penh is projected to experience hot nights for 80 percent of the year by 2050. Under a high-climate-change scenario, the most heat-prone neighborhoods would experience such conditions nearly all year round (map 2.1). Such heat stress levels present a direct threat to human health, particularly where construction quality is poor. In such circumstances, measures to promote cooler physical spaces are essential but not sufficient; city authorities also face a pressing need to intervene in a targeted manner to protect the lives of vulnerable residents during heat waves.

Map 2.1 Projected Number of Hot Nights Per Year for a Present-Day Reference Period and under Future Climate Scenarios, Phnom Penh, Cambodia



SOURCE: Analysis conducted using VITO NV's UrbClim model for this report.

NOTE: "Hot nights" are defined as nights where air temperature does not fall below 25 degrees Celsius. In the matrix of models for 2030 and 2050, "SSP1-1.9" represents an optimistic scenario, under which global carbon emissions are curbed. "SSP3-7.0" represents a pessimistic scenario, under which emissions maintain a stronger upward path before stabilizing. These scenarios correspond to the selected Shared Socioeconomic Pathways (SSPs) developed for the Intergovernmental Panel on Climate Change.

SUMMARY AND CONCLUSION

Using Bandung in Indonesia and Phnom Penh in Cambodia as case studies, this chapter has shown how neighborhoods within individual East Asian cities are marked by sharp differences in heat stress. These differences result from, among other things, differences in vegetation and built form. And in East Asian cities such as Bandung, the differences also correlate strongly with poverty rates: poorer neighborhoods also tend to be hotter neighborhoods.

The chapter also finds that, in future decades, the interaction of the UHI effect with climate change will cause the neighborhoods that are already hottest to become even more uncomfortable, especially at night.

The next chapter in this report, chapter 3, further explores how extreme heat affects a city's competitiveness, livability, and inclusiveness.

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NOTES

1 Bandung was chosen for this case study after consultations with Indonesia's Ministry of National Development Planning (Bappenas) and the city's local authorities.

2 The study was also undertaken in collaboration with CAPA Strategies. Further details of the study, including of the machine learning models applied to derive heat maps for the entire city, can be found in a background paper for this report (Jones et al. 2023).

3 For a discussion of Indonesia's planning system, see chapter 7 of Roberts, Gil Sander, and Tiwari (2019).

4 As the discussion in this paragraph makes clear, the relationship between a neighborhood's temperature (and, more generally, the level of thermal comfort it offers) and its prosperity potentially runs in both directions. Hence, wealthier households may choose to "sort" toward cooler neighborhoods. They may also, for example, have more success, or be more active in, lobbying for investments in urban greenery that help to make a neighborhood cooler and therefore more pleasant. To the extent that poorer households live in more informal or illegal neighborhoods, local governments may also be less likely to invest in those neighborhoods.

5 As discussed in chapter 3, this is not necessarily the case for all East Asian cities. Hence, out of a sample of 25 cities globally, Chakraborty et al. (2019) find that although temperatures are higher in poorer neighborhoods in 18 out of 25 cities, this is not the case in the remaining 7 cities, which include Bangkok, Beijing, and Manila. Several aspects of urban development, such as a city's housing market and connectivity, affect whether more affluent residents live in the city centers where UHI intensity is generally higher.

6 Differential cooling between urban and surrounding rural areas is most pronounced at night, with urban surfaces giving up their heat less quickly because of the thermal inertia of materials and obstruction of radiation by buildings. For these reasons, the nighttime UHI effect is more pronounced than the daytime effect. Climate modeling allows estimation of nighttime UHI effects that are less readily perceptible through satellite imagery but have major implications for human health by impeding sleep and recuperation. Modeling was conducted for this study using the UrbClim framework (De Ridder et al. 2015).

7 The Shared Socioeconomic Pathways (SSPs) are a set of five scenarios for global socioeconomic changes projected up to 2100. Developed to inform the Intergovernmental Panel on Climate Change's Sixth Assessment Report, they present plausible future states of the world under differing social and political pathways, each with different implications for greenhouse gas emissions and climate change outcomes. The optimistic scenario corresponds to "SSP1: Sustainability (Taking the Green Road)," which presents a world that turns toward sustainability and cooperative management of the global commons. Global emissions peak between 2040 and 2060, and global mean air temperatures rise by 1.0–1.8°C over preindustrial levels by 2100. The pessimistic scenario corresponds to "SSP3: Regional Rivalry (A Rocky Road)," which depicts a world of resurgent nationalism, material-intensive consumption, and limited cooperation to preserve shared resources, resulting in warming of 2.8–4.6°C over preindustrial levels by 2100.

CH

CHAPTER

3

HOW DOES URBAN HEAT AFFECT CITIES AND RESIDENTS?

KEY MESSAGES

- Extreme heat—be it from the urban heat island effect, global warming, or the combination of the two negatively affects every aspect of urban life.

- Extreme heat makes cities less economically productive by reducing the capacity of workers, machinery, and infrastructure. Cities may face average gross domestic product (GDP) losses of over 5 percent by 2100 because of increasing temperatures, with the worst-impacted cities losing over 10 percent of GDP.

- Extreme heat is responsible for over 100,000 excess deaths per year in the East Asia region, a number that is projected to increase. It also affects livability by increasing rates of illness, accidents, crime, and violence.

- Extreme heat undermines environmental sustainability by increasing energy consumption and associated carbon emissions because of the increased need for mechanical cooling.

INTRODUCTION

Extreme heat—be it from the urban heat island (UHI) effect, climate change, or both combined negatively affects every aspect of urban life. This chapter summarizes the extensive evidence on the negative impacts of extreme heat on urban prosperity, livability, and environmental sustainability.

The chapter begins by providing a simple framework to understand the channels through which extreme heat may affect a city's productive capacity and surveying the evidence that relates to these different channels for the East Asia region. It goes on to discuss the toll of extreme heat exposure on the human body, resulting in over 100,000 excess deaths per year in East Asia as well as higher rates of illness, accidents, suicides, and violent crimes. It also explores the ways in which the negative impacts of extreme heat are felt disproportionately by the urban poor, elderly, and other already disadvantaged groups. Finally, it discusses the impacts of air conditioning, which is being rapidly adopted in the region and is accompanied by higher energy consumption and the outdoor release of heat—further worsening the UHI effect. To the extent possible, this chapter relies on evidence from East Asia but falls back on literature from other countries when the evidence base for East Asian countries is thinner.

EXTREME HEAT UNDERMINES URBAN PROSPERITY

EXTREME HEAT MAKES CITIES LESS PRODUCTIVE

In addition to its more well-known health impacts, which are discussed later in this chapter, extreme heat constrains every input into a city's productive capabilities. A city's real output (Y) depends on several factors: the number of hours worked by its workers (L); the amount of physical capital that its firms use in production (K); the supply of human capital (H) and the efficiency with which it is used (e); and a city's total factor productivity (A), which captures other factors, including technology, that affect a city's output.

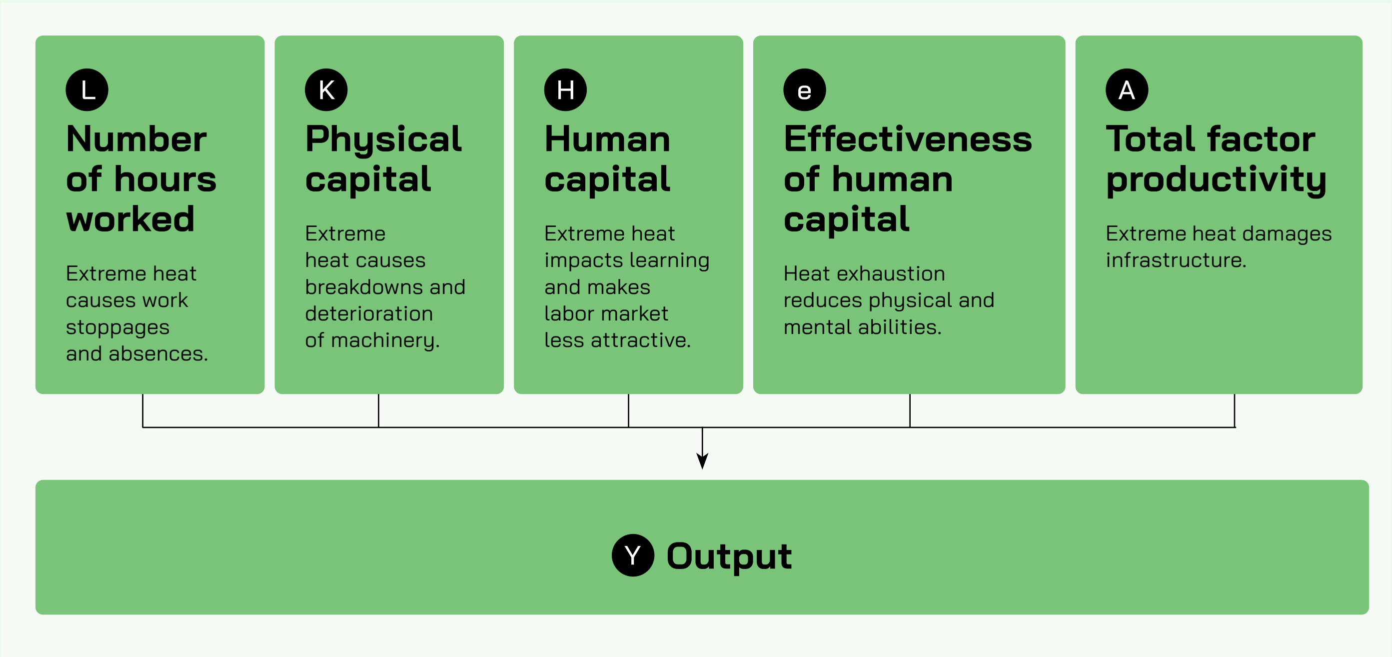
The dependence of a city's real output on these factors can be captured by its "production function," which provides a simple and convenient framework for thinking through the different potential channels through which extreme heat might affect a city's economy. Hence, a city's production function can be expressed as

$$Y=f(L,K,eH,A).$$

As shown also in figure 3.1, extreme heat—whether due to the UHI effect or climate change—can potentially reduce a city's real output by

- *Reducing the number of hours worked* (*L*) because of work stoppages and breaks taken during extreme heat as well as absences induced by heat-related illness;
- *Reducing physical capital inputs* (*K*)—for example, owing to heat-induced breakdowns and accelerated deterioration of machinery and physical inputs into production;
- *Reducing the effectiveness* (*e*) *of existing human capital inputs in the short run*—for example, through the effects of heat exhaustion on physical and mental abilities, which affect both manual labor and cognitive work;
- *Reducing the supply* (*H*) *of human capital in the long run* by negatively affecting educational outcomes (as further discussed below) and making a city less attractive to high-skilled workers;[1] and
- *Reducing total factor productivity* (*A*) owing to, for example, a diminished reliability of infrastructure services because of damage caused by extreme heat to roads, bridges, power plants, power lines, water pipes, and other forms of infrastructure.

Figure 3.1 Channels of Extreme Heat's Impacts on a City's Aggregate Real Output



SOURCE: World Bank elaboration.

REDUCTION IN WORKER PRODUCTIVITY

Heat already hurts manufacturing in the region, and the impact will increase with climate change. An extra day with temperature higher than 32 degrees Celsius (°C) decreases the output of Chinese manufacturing firms by 0.45 percent relative to an extra day with temperature of 10–16°C (Zhang et al. 2018). This temperature effect is driven by decreases in total factor productivity (TFP).[2]

The warming effects of climate change, not accounting for UHI, will result in reductions in output of 12 percent annually by midcentury (2040–59) for the average Chinese firm, assuming no further adaptation by firms (Zhang et al. 2018). If the output share of manufacturing remains at 32 percent of China's national gross domestic product (GDP), this loss translates to a 3.8 percent reduction in China's annual GDP. A 14-day heat wave in Nanjing, China, in 2013 reduced productive working time by 2.5 percent across all industries. Losses were highest (4.2–4.5 percent) in outdoor work (such as agriculture, mining, and construction) and lower (about 0.7 percent) in indoor work including manufacturing and services. The impact of the heat wave on health, work productivity, and capacity caused a total loss equivalent to 3.4 percent of the city's gross value of production in 2013. The largest share of this loss was in manufacturing (Xia et al. 2018).[3]

Heat stress can also reduce performance in cognitive tasks associated with knowledge work, although the mechanisms by which this occurs are not fully understood (Taylor et al. 2016). A review of 24 studies from around the world suggests that performance in office work increases with indoor temperatures up to 21–22°C and decreases when temperatures exceed 23–24°C. Average productivity of office work at an indoor temperature of 30°C is 9 percent below productivity at 22°C (Seppanen, Fisk, and Lei 2006).

DAMAGE TO URBAN INFRASTRUCTURE

Exposure to extreme heat can also damage urban infrastructure. For example, heat can damage transportation infrastructure by causing roads and rails to buckle owing to thermal expansion and by melting or softening paving material. It can also reduce the performance of electrical power lines and photovoltaic cells.

Moreover, heat can increase the risk of rupture of oil and gas pipes, cause geotechnical failures in embankments and earthworks, and damage underground communications infrastructure (Dodman et al. 2022). Infrastructure damage not only results in immediate risks, inconveniences, and costs but also further reduces a city's real output by reducing TFP (that is, *A* in the production function).

REDUCTION IN GLOBAL GDP

Several models suggest that warming due to climate change will also reduce global GDP:

- Burke and Tanutama (2019) estimate that tropical countries are already more than 5 percent poorer than they would have been had there been no warming since 2000.
- Burke, Hsiang, and Miguel et al. (2015b) estimate that global warming, if unmitigated, would reduce average global incomes by 23 percent by 2100.
- Kahn et al. (2019) find that an increase in the average global temperature of 0.04°C per year, in a worst-case scenario, would reduce global real GDP per capita by more than 7 percent by 2100. [4]

Crucially, these estimates consider only temperature increases due to climate change. In cities, the total economic damage from heat during the twenty-first century when the UHI effect is taken into account can be 2.6 times the magnitude of losses when it is not (box 3.1).

BOX 3.1 THE COMBINED IMPACTS OF THE URBAN HEAT ISLAND EFFECT AND CLIMATE CHANGE

Most discussions of projected temperature increase in coming decades focus exclusively on warming driven by global climate change. However, the urban heat island (UHI) effect will add significantly to the warming in cities.

Estrada, Wouter Botzen, and Tol (2017) estimate future temperature increases due to the combined effects of both UHI and climate change in the 1,692 largest cities in the world, all of which have a population of at least 300,000. They estimate that by 2050, the UHI effect will add 0.84°C to the temperature of the median city, and 2.08°C to the most populous 5 percent of cities, over and above the warming caused by climate change. The combined effect of UHI and climate change means that one in five cities could become more than 4°C warmer by 2050. One in four could become more than 7°C warmer by 2100.

Crucially, the combined economic impact of climate change and the UHI effect is likely to be greater than the sum of their individual impacts. This is because the impact of temperature on the economy is nonlinear: the negative effect of an increase in temperature of 1°C—from, for example, 35°C to 36°C—is greater than from an increase from 30°C to 31°C (Burke, Hsiang, and Miguel et al. 2015b).

Estrada, Wouter Botzen, and Tol (2017) estimate that warming due to climate change alone would reduce the gross domestic product (GDP) of the median city in 2050 by 0.7 percent in an RCP 4.5 scenario and by 0.9 percent in an RCP 8.5 scenario.[a] However, when combined with warming due to the UHI effect, these GDP reductions increase to 1.4 percent and 1.7 percent under RCP 4.5 and RCP 8.5, respectively. The worst-off city could face GDP losses of up to 10.9 percent in 2100.

The total economic damage from heat in cities during the twenty-first century when the UHI effect is taken into account can be 2.6 times the magnitude of losses when it is not.[b] If ignored, the economic impacts of the UHI effect could undo the benefits of efforts focused only on mitigating global climate change. In contrast to global warming, the UHI effect is furthermore a local negative environmental externality that can be attenuated through local policy actions without the need for global collective action.

a. Representative Concentration Pathways (RCP) are scenarios used by the Intergovernmental Panel on Climate Change (IPCC) to represent different possible future levels of global warming. RCP 4.5 represents an intermediate scenario, whereas RCP 8.5 represents a worst-case scenario.
b. This is based on the Dynamic Integrated Climate-Economy (DICE) model, which estimates the economic impacts of climate change. It estimates that 2.5°C of warming would lead to a welfare loss equivalent to 1.5 percent of GDP.

Economic losses from heat are projected to be greater in poorer countries. Burke, Hsiang, and Miguel (2015b) estimate that unmitigated global warming would widen income inequality between countries. However, this differential impact does not appear to be the result of any greater ability on the part of wealthier countries to adapt to extreme heat, since the differences in countries' adaptive capacity are insignificant, according to the authors.

Instead, the difference occurs mainly because poorer countries tend to have higher baseline temperatures, which means that further warming has a greater impact on their productivity than it does on wealthier, colder countries, where warming could even increase productivity. This differential impact on productivity relates to the importance of nonlinearities in the damage function, which means that the impacts of the UHI effect and climate change-induced warming can potentially compound each other (box 3.1).

GDP LOSSES ACROSS THE REGION

In several Southeast Asian countries, reduced labor productivity due to extreme heat induced by climate change is projected to cause GDP losses of 5.5–6 percent by 2030, not even considering the UHI effect. An International Labour Organization (ILO) study estimates that productivity loss due to heat stress cost Southeast Asian countries the equivalent of 3.1 percent of working hours (6.9 million full-time jobs) in 2015, mostly in agriculture and construction (ILO 2019).[5] Considering rising temperatures due to climate change and shifts in the economy, the productivity loss due to extreme heat in 2030 is projected to be the equivalent of 3.7 percent of working hours (13 million full-time jobs). Nearly 8.9 percent of working hours in construction and 3.9 percent of working hours in industry are projected to be lost because of extreme heat in Southeast Asia by 2030.

In proportional terms, the reduction in working hours due to heat stress in Southeast Asia in 2030 is projected to be highest in Cambodia (7.8 percent), Thailand (6.4 percent), and Viet Nam (5.1 percent). But in absolute terms, the highest projected losses are for Indonesia (equivalent of 4 million full-time jobs) and Viet Nam (3.1 million jobs). By comparison, China (not counted under Southeast Asia) is projected to lose a small proportion (0.8 percent) of working time but a large absolute amount (the equivalent of 5.5 million full-time jobs) by 2030.

Kjellstrom (2016), meanwhile, estimates that, in several Southeast Asian countries, reduced labor productivity due to extreme heat will cause GDP losses of 5.5–6 percent by 2030, including 6 percent (US$250 billion) in Indonesia, 5.9 percent (US$85 billion) in the Philippines, and 5.7 percent (US$85 billion) in Viet Nam. Heat-related GDP losses in China in 2030 will be smaller in terms of proportion (0.8 percent) but larger in absolute terms: US$450 billion.[6]

Again, these projections crucially neglect the UHI effect, which means that they likely underestimate, perhaps substantially, the productivity losses in cities (box 3.1). New analysis conducted for this study suggests that in large Southeast Asian metros as well as in warmer cities in the rest of East Asia during the summer, the negative economic impacts of warmer-than-average temperatures is significant enough to be visible in the intensity of nighttime lights, a widely used proxy for economic activity (box 3.2).

BOX 3.2 IMPACTS OF EXTREME HEAT ON URBAN ECONOMIC ACTIVITY ACROSS EAST ASIAN CITIES

News stories about extreme heat disrupting economic activity have become increasingly common in recent years. For example, the British Broadcasting Corporation (BBC) reported news of trains being cancelled and rail services disrupted in the United Kingdom after the country posted its hottest day on record in July 2022 (Nanji 2022). The *Wall Street Journal* carried news of electricity and production shortages in China as a result of its worst heat wave in six decades in August 2022 (Xie and Li 2022).

To what extent, then, does extreme heat affect urban economic activity across East Asian cities in the short run? To answer this question, the analysis in this box employs spatially granular monthly data on temperatures as well as on nighttime lights—a proxy for a city's aggregate level of economic activity. By measuring extreme heat as a monthly temperature anomaly relative to each city's historical norm,[a] this analysis estimates how a city's nighttime light intensity changed during any month when the city experienced extreme heat between April 2012 and December 2020.

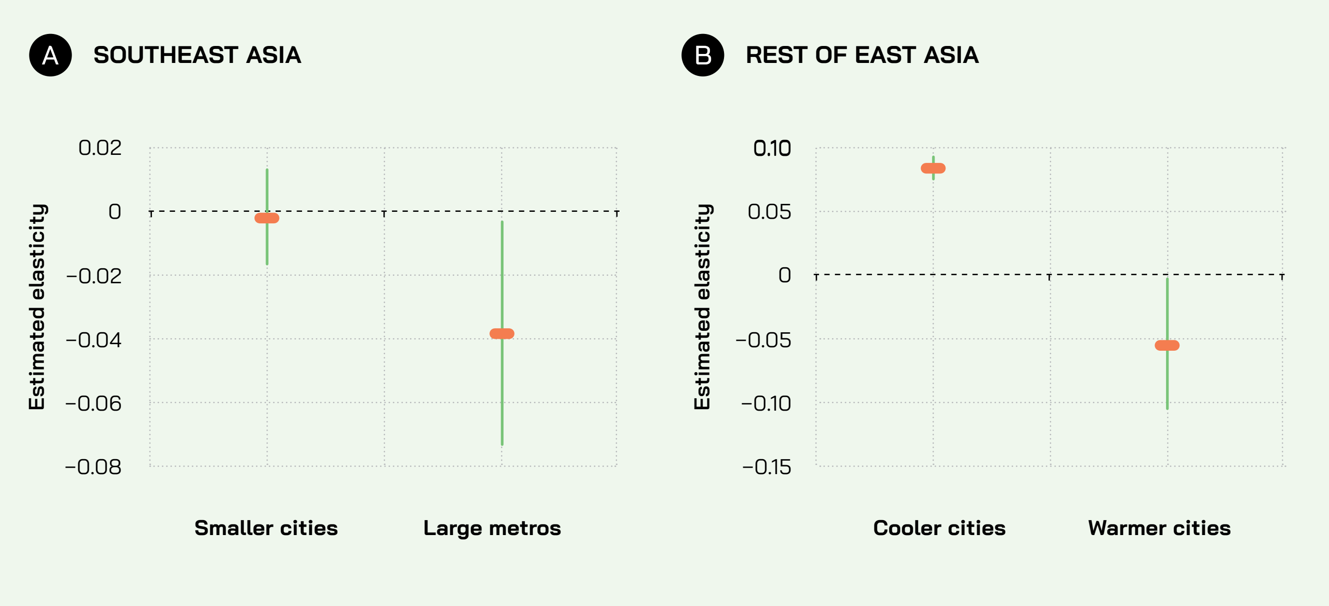
The results diverge across cities in different subregions. In Southeast Asia, where background climatic conditions are hot and humid all year round, extreme heat had severe negative estimated impacts on local economic activity in large metropolitan areas.[b] Those cities, including quite a few Indonesian secondary cities as well as national capitals of the region, darkened by nearly 4 percent on average in a month hit by extreme heat.[c] By contrast, the estimated impact is insignificant for smaller cities (figure B3.2.1, panel A). Although the exact mechanism behind this result requires further research, it is in line with a previous finding that cities with larger and denser populations are often under greater heat stresses because of larger-scale built environments and human activities (Liu et al. 2022).

The analysis of 536 other East Asian cities (excluding Southeast Asia) during summer months (June–August) reveals that cities with warmer baseline climates, including many manufacturing and financial hubs in China were affected by extreme heat quite significantly.[d] In a month hit by an extreme heat event, their nighttime light intensities dropped by an estimated 5.5 percent. By contrast, the estimated impact of extreme heat on economic activity for cities with cooler background climates is positive, perhaps reflecting the impacts of warmer, more pleasant evenings on outdoor economic activity (figure B3.2.1, panel B).

Given that gross domestic product (GDP) and the nighttime lights data do not perfectly correspond to each other, any estimates of changes in GDP derived from lights data must be treated with caution. That said, the range of the GDP-to-lights elasticity in the literature (0.3–1) suggests that the estimated percentage reduction in light intensity associated with extreme heat could be interpreted as a reduction in local GDP of 1.2–3.9 percent for large metropolitan areas in Southeast Asia and 1.7–5.5 percent for cities in the rest of East Asia cities with warm baseline climates.

Continued

Figure B3.2.1 Estimated Impacts of Extreme Heat Events on City Nighttime Light Intensity in East Asia, by Subregion, April 2012–December 2020



SOURCE: World Bank calculations based on the analysis of Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime lights monthly composites (https://payneinstitute.mines.edu/eog-2/viirs/) and monthly weather data from Climatology Lab, TerraClimate (https://www.climatologylab.org/terraclimate.html).

NOTE: Cities are defined as urban centers following the "degree of urbanization" methodology of the Global Human Settlement Layer (GHSL) Urban Centre Database. Each red marker shows the estimated impact of an extreme heat event, obtained by regressing the natural log of sum of lights in city *c* in month *m* on a dummy variable which takes the value 1 if temperature of city *c* in month *m* deviated from the city's long-run mean temperature for the month by at least +2 standard deviations; the dummy variable takes the value 0 otherwise. Vertical bars indicate the bounds of the 90 percent confidence interval associated with the corresponding estimated impact. Panel A is based on the analysis of 170 Southeast Asian cities. Panel B is based on the analysis of 536 cities in the rest of East Asia. The analysis of Southeast Asian cities (panel A) covers all 12 months of the year because monthly temperatures remain relatively warm throughout the year for those cities. In contrast, the analysis of cities in the rest of East Asia (panel B) covers only warm months, (June, July, and August) given their more variable climates.

a. For a detailed definition of extreme heat events, see chapter 1, annex 1A.
b. Southeast Asian countries included in the analysis are Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Thailand, and Viet Nam. Cities are classified as large metros (smaller cities) if they have a population of at least (below) 1.5 million as classified by the Organisation for Economic Co-operation and Development.
c. Indonesian secondary cities classified as large metropolitan areas include Surabaya, Bandung, Yogyakarta, Medan, Semarang, and others.
d. These East Asian cities include those in China (including Hong Kong SAR); Japan; the Democratic People's Republic of Korea; the Republic of Korea; Mongolia; and Taiwan, China. Cities with warmer (cooler) baseline climates are derived based on the top (bottom) half of the global distribution of long-run mean monthly temperature. Warmer cities include the Chinese cities of Guangzhou, Shanghai, Hangzhou, Wuhan, and Chongqing; Hong Kong SAR, China; and some cities from high-income economies including Osaka-Kyoto, Japan.

EXTREME HEAT HURTS EDUCATIONAL OUTCOMES

As with office work, heat stress impairs the ability of students to perform cognitive tasks. Heat affects both classroom learning and exam-day performance, with potential long-term impacts on productivity and earnings. Studies show that the number of hot school days is correlated with lower standardized test scores, both in the United States (Park et al. 2020) and across 58 countries (Park, Behrer, and Goodman 2021). These studies show that hot nonschool days were not correlated with lower scores, suggesting a direct impact of heat on learning itself.

In the case of the United States, replacing a school day in the 60s on the Fahrenheit scale (roughly 15–21°C) with a hotter school day lowers achievement, with the extent of that damage increasing roughly linearly with temperature above 70 degrees Fahrenheit (21°C). According to a study on China (Zivin et al. 2018), exam-day temperatures affect test scores, with negative consequences for students' further educational opportunities. An increase of 1 standard deviation in exam-day temperature (3.3°C) during the Chinese National College Entrance Examination reduces the test score by 1.1 percent (0.096 standard deviations), which in turn reduces the probability of admission into a first-tier university by nearly 2 percent.

In terms of the production function discussed earlier, the effect of heat on education lowers the supply of skilled labor (H) and the effectiveness of each worker per hour (e). To the extent that skilled labor is an input into innovation, it could also slow the growth of total factor productivity (A).

EXTREME HEAT MAKES CITIES LESS LIVABLE

HEAT CAUSES ILLNESS AND DEATH

Over 100,000 people in the East Asia region die each year because of extreme heat, a number that is likely to increase. Studies of East Asian cities including Bangkok and Hong Kong SAR, China, estimate increases in mortality of 2–6 percent per 1°C increase in temperature above 29°C (Chan et al. 2012).

In a study of global deaths related to nonoptimal temperatures (hot and cold), Zhao et al. (2021) find that the average number of excess deaths related to heat per year was over 21,000 in Southeast Asia and nearly 80,000 in the Rest of East Asia. Surprisingly, however, the equivalent numbers of *cold*-related deaths were much higher (168,000 and 1.16 million, respectively). Rising temperatures due to climate change (a 0.26°C increase in daily mean temperature per decade from 2000 to 2019 in both regions) means that although heat-related deaths are increasing in these regions, they are far outnumbered by the decrease in cold-related deaths. This is particularly true in Southeast Asia, where heat-related deaths as a proportion of all deaths increased from 0.45 percent in the 2000–03 period to 0.73 percent in 2016–19, while the share of cold-related deaths decreased from 5.38 percent to 3.22 percent.[7]

By contrast, however, Bressler et al. (2012) project that in all middle-income countries in East Asia (and in the world as a whole), future warming during this century will increase heat-related mortality more than it decreases cold-related mortality in most scenarios, leading to a net increase in mortality, even adjusting for increased resilience due to income growth.

Extreme heat affects health in a variety of ways. Heat-related illnesses include dehydration, heat cramps, and heat stroke. Overheating also increases the likelihood of death from preexisting conditions such as respiratory and cardiovascular diseases (WHO 2018). High temperatures further reduce water quality by enabling the development of harmful algal blooms and toxic bacteria and the depletion of oxygen in urban water bodies. Spikes in the concentrations of waterborne bacteria and viruses can trigger outbreaks of diseases including cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio (USAID 2020).

Heat also kills and injures people indirectly, by increasing rates of accidents and suicides. The increase in accidents can likely be attributed to the impact of heat stress on cognition and attention (Park, Pankratz, and Behrer 2021). For example, although evidence for East Asian countries is sparse, research shows that in the United States, fatal car crashes increase by a significant amount (3.4 percent) on heat wave days (Wu, Zaitchik, and Gohlke 2018), which is also consistent with earlier cited findings of the impacts of heat on cognitive performance. Furthermore, a recent study using data from California in the United States finds that both indoor and outdoor workplace injuries rise with temperature, including injuries not usually associated with heat—for example, falling, being struck by a crane, or mishandling dangerous machinery (Park, Pankratz, and Behrer 2021). A day with temperatures of 29–32°C has a 5–7 percent higher injury risk than a day with temperatures of 15–21°C, while a day with temperatures above 38°C has a 10–15 percent higher injury risk.

Tragically, heat also correlates positively with suicide rates. Summer peaks in suicide rates have been observed since the nineteenth century, perhaps suggesting that global warming could lead to an increase in suicides. Burke et al. (2018) estimate that suicide rates rise by 0.7 percent in the United States and by 2.1 percent in Mexico per 1°C increase in monthly average temperature. Although the underlying mechanisms linking heat stress to suicide are not fully clear, the authors' analysis of temperature's effects on depressive language in social media posts suggests that it is associated with a direct negative impact of heat on mental well-being.

Although no studies examine links between heat and suicide in East Asia, Chen et al. (2023) study the relationship between exposure to extreme heat and increased depression in adults over the age of 45 in China. They find that symptoms of depression, such as sleeplessness, distractibility, and lack of motivation, are significantly correlated with the number of days in the preceding year that had extremely high temperatures compared to the local mean. This relationship is only significant among respondents over the age of 60, suggesting that the elderly may be particularly vulnerable to the effects of extreme heat on mental health. Notably, the authors find a stronger correlation between depressive symptoms and exposure to extremely *cold* days than to hot days, which means that the net impact of increased temperatures on depression may be positive or negative in a given location, depending on how the distribution of extreme hot and cold days changes over time.

EXTREME HEAT MAY EXACERBATE CRIME, VIOLENCE, AND CONFLICT

Despite the lack of much research on the link between heat and crime in East Asia specifically, international studies suggest that such a link exists. Using highly spatially granular data, Heilmann and Kahn (2019) provide credible causal evidence that in Los Angeles, excessively high temperatures lead to increases in violent crime in particular, with no significant relationship between heat and nonviolent crime. They estimate that violent crime increases by 5.7 percent on days with maximum temperatures above 85°F (29.4°C). The authors argue that the impact of heat on violent crime but not on nonviolent crime strongly supports the notion that the mechanism underlying this relationship is increased aggression rather than greater opportunities for crime on hot days due to reduced policing or increased crowds.

Bruederle, Peters, and Roberts (2017) find that in South Africa as a whole, an increase of 1 standard deviation in the daily *maximum* temperature within an average month of the year (an increase of 2.7°C) increases total crime by 3.7 percent, while an equivalent increase in the daily *minimum* temperature (1 standard deviation, also 2.7°C) increases crime by 5.3 percent. The study also finds that these effects are driven mainly by the impacts of heat on violent crime (particularly sexual violence) and burglary. The authors describe their findings as strongly supporting a "heat-aggression link," although the impact on burglary is less easily explained.

Similarly, a study of Madrid (Sanz-Barbero et al. 2018) found positive correlations between heat waves (temperatures above 34°C) and the incidence of intimate partner violence—a finding the authors describe as consistent with a model that explains aggression as the result of irritability and stress caused by high temperatures. Although further studies are needed to fully document and understand possible links between heat and crime, particularly in East Asia, the literature suggests that impairment of cognitive processes may result in increased crime.

A metastudy on the relationship between climate and conflict (defined as being usually but not necessarily violent) finds that a 1 standard deviation increase in temperature increases interpersonal conflict by 2.4 percent and intergroup conflict by 11.3 percent (Burke, Hsiang, and Miguel 2015a). While there appears to be a global relationship between heat and conflict, it is unclear whether this relationship holds in Asia. Mares and Moffett (2016) find that across 57 countries, a 1°C increase in annual mean temperature is correlated with a 5.9 percent increase in national homicide rates, while a 1 standard deviation increase is correlated with a 58 percent increase. However, these results vary by region within their sample, and the correlation between temperature and homicides in Asia is insignificant.

In general, the literature does not establish any universal temperature threshold above which the impacts of heat on health, productivity, or crime and violence kick in (box 3.3).

BOX 3.3 DO THE NEGATIVE EFFECTS OF HEAT KICK IN AT A SPECIFIC TEMPERATURE?

Adverse physiological impacts occur when extreme heat exceeds population-specific thresholds. Even small increases in temperatures beyond those for which a population is prepared increase the likelihood of illness and death. To some extent, the body can acclimatize to higher temperatures over time, which is why definitions of heat waves are often relative to mean local temperatures rather than universal temperature thresholds (see also the discussion in chapter 1 on this point).

Populations can also deacclimatize and reacclimatize to heat over the course of a year. This is why heat waves that take place earlier in the summer, before the population has had a chance to acclimatize, are associated with higher mortality than later ones (Anderson and Bell 2011).

For more indirect impacts—on, say, productivity, education, and crime—it is difficult to answer this question based on the existing literature because each study uses different temperature intervals and thresholds. For example, the studies discussed in this chapter report the impacts of heat

- Above 23–24°C on *office work* (Seppanen, Fisk, and Lei 2006);
- Above 27°C and above 32°C on *manufacturing work* (Somanathan et al. 2021; Zhang et al. 2018);
- Above 12–14°C, above 21°C, and above 27°C on *education* (Park et al. 2020; Park, Behrer, and Goodman 2021; Ziven et al. 2018); and
- Above 29°C *on crime and violence* (Heilmann and Kahn 2019).

These differences in intervals, rather than resulting from different underlying thresholds for these impacts, may simply be the result of varying research design choices; means of measuring temperature; which temperature measure is used (for example, air temperature versus land surface temperature); and data availability. It seems a priori unlikely that all the different impacts of heat that this chapter discusses—on physical labor, cognitive tasks, crime, health, and so on—would share a single temperature above which their effects are felt, though this intuition would need additional research to be confirmed.

Additionally, as earlier chapters have also discussed, other factors besides temperature itself affect the level of risk from extreme heat. As WHO (2018) states, "The precise threshold at which temperature represents a hazardous condition varies by region, other factors such as humidity and wind, local levels of human acclimatization and preparedness for heat conditions."

EXTREME HEAT MAKES CITIES LESS INCLUSIVE

At the local level, the burden of extreme temperatures on prosperity and livability is often felt disproportionately by the poor. Studies of China and Indonesia find that the adoption of air conditioning is significantly correlated with household income (Davis et al. 2021; Pavanello et al. 2021). This suggests that poorer urban residents are less likely to have access to air conditioning and thus are less able to self-protect against heat. The poor may also live in neighborhoods with less vegetation in the form of parks, street trees, and the like.

In eight large Indonesian metropolitan areas, more affluent neighborhoods (measured using educational attainment as a proxy) face less heat exposure than less affluent ones (Rossitti 2022). Additionally, Chan et al. (2012) find that in Hong Kong SAR, China, the relationship between heat and mortality is stronger in poorer districts. These two studies together suggest that (a) poorer neighborhoods may be more exposed to extreme heat, and (b) when exposed, these neighborhoods' residents are likelier than wealthier residents to die from that exposure. These results highlight the importance of both heat mitigation (reducing exposure to extreme heat) and adaptation (reducing the damage caused by exposure to extreme heat) measures in cities.

However, whether the UHI effect is more intense in poorer or wealthier neighborhoods varies by city. A study of 25 cities across world regions found that in most (18) of them, including Jakarta, Indonesia, poorer neighborhoods did experience higher temperatures (Chakraborty and Lee 2019).[8] Conversely, in the remaining 7 cities, including Beijing, Bangkok, and Manila, wealthier neighborhoods experience higher temperatures. The authors note that several aspects of urban development, such as a city's housing market and connectivity, affect whether more affluent residents live in the city centers where UHI intensity is generally higher. In addition to these direct impacts, exposure to extreme heat could impair the economic mobility of the poor because of the impact on their educational outcomes and economic productivity, as discussed earlier.[9]

Elderly residents, as well as those with disabilities and chronic medical conditions, are most at risk of the health impacts of heat. Vulnerability to heat-related conditions is significantly affected by respiratory and cardiovascular conditions, which make it harder for the body's cooling responses to function (see chapter 1, box 1.3). Infants and people over 75 are particularly vulnerable to heat waves.

The vulnerability of elderly people is particularly salient in the East Asia region, because the population of the region above the age of 65 is projected to double between 2020 and 2050 (UN DESA 2017). And for many of the region's countries, it is projected to triple or nearly triple (table 3.1). Varquez et al. (2020) project that in Jakarta, the proportion of the population in the 65+ age group will increase from 3.3 percent in the 2010s to 22 percent by the 2050s. They further project that the total number of heat-related elderly deaths in August will be 12–15 times higher in the 2050s than in the 2010s because of the combined effects of population aging and rising daytime temperatures.

Table 3.1 Elderly Populations in Selected East Asian Countries, 2020 (actual) and 2050 (projected)

COUNTRY	POPULATION AGE 65+, 2020 (THOUSANDS)	POPULATION AGE 65+, 2050 (THOUSANDS, PROJECTED)	POPULATION AGE 65+ (RATIO OF 2050 TO 2020)
Mongolia	142	534	3.8
The Lao PDR	310	986	3.2
Cambodia	811	2,555	3.2
Indonesia	17,130	52,495	3.1
Malaysia	2,325	6,894	3.0
Viet Nam	7,658	22,414	2.9
Philippines	6,040	17,045	2.8
Singapore	780	2,131	2.7
Myanmar	3,393	8,205	2.4
Timor-Leste	56	131	2.3
Korea, Rep.	8,096	17,831	2.2
Thailand	9,045	19,546	2.2
China	172,263	365,636	2.1
Japan	35,916	39,881	1.1
East Asia total[a]	271,616	572,498	2.1

SOURCE: United Nations Department of Economic and Social Affairs (UN DESA) Population Division, World Population Prospects 2019 custom online data.

a. The East Asia total includes all countries classified by UN DESA in this dataset as belonging to "Eastern Asia" and "South-Eastern Asia."

EXTREME HEAT INCREASES ENERGY USE FOR COOLING

Air conditioner (AC) ownership is rising rapidly across the region, primarily in cities. It varies across the region, with less than 10 percent of households in Indonesia, the Philippines, and Viet Nam owning ACs. However, energy use for air conditioning in Association of Southeast Asian Nations (ASEAN) countries has increased 7.5 times over the past 30 years and is expected to continue to increase as incomes and temperatures in the region rise (IEA 2019b).[10]

In China, AC use has grown rapidly since 2000. The country accounted for about one-third of global growth in cooling energy between 2000 and 2017. This was driven primarily by growth in AC ownership in cities. Over 60 percent of households in China now own an AC. This is projected to increase to 85 percent by 2030. Electricity consumption per capita for space cooling in China is still less than half of that in the Republic of Korea or Japan, suggesting that there is considerable room for growth (IEA 2019a).

Extreme heat increases energy consumption for mechanical cooling (especially air conditioning). This in turn raises carbon emissions from energy and contributes to global warming (further necessitating AC use). A 1°C rise in temperature increases annual electricity consumption by 3–4 percent in Singapore and 4–5 percent in Hong Kong SAR, China (Ang, Wang, and Ma 2017). However, such annual electricity consumption figures underestimate the spike in electricity demand for cooling during the hottest periods. For example, in Shanghai, China, annual electricity consumption increases by 9 percent per 1°C increase in annual mean surface temperature, but *peak* electricity use increases by 36 percent per 1°C increase (Li, Pizer, and Wu 2019). This finding is reinforced in other regions. For example, simulations of Paris by Viguié et al. (2020) suggest that if ACs were used to cool all buildings in Paris down to 23°C during a heat wave, the energy required would be equivalent to 81 percent of the current average total daily electricity consumption.

Air conditioning further raises outdoor temperatures by contributing to the UHI effect and global warming. Although AC use cools indoor spaces, it further raises outdoor temperatures both directly and indirectly, creating a vicious cycle. ACs directly release heat into streets, raising outside air temperature by 2–4°C during intense heat waves (Viguié et al. 2020), further intensifying the UHI effect. By increasing energy consumption, especially on the scale of East Asian cities, AC use can also further contribute to carbon emissions (depending on the energy source) and therefore increase warming due to global climate change. Viguié et al. (2020) describe AC use as a "maladaptation" to extreme heat, because of its negative externalities.

SUMMARY AND CONCLUSION

Extreme heat negatively affects every aspect of urban life. The research reviewed in this chapter indicates that exposure to such heat has a range of negative impacts. Although the specific thresholds at which these negative impacts come into effect may vary (see box 3.3), increasing temperatures in the region in coming decades are likely to exacerbate several of these impacts.

Reduced labor productivity due to extreme heat induced by climate change alone is projected to cause GDP losses in several East Asian countries of 5.5–6 percent by 2030. In cities, the combined impacts of climate change and UHI could more than double the losses to city-level GDP that would be caused by either one on its own. In addition, evidence from East Asia and beyond suggests that exposure to extreme heat worsens educational outcomes; increases the rates of illness, mortality, injury, crime, and violence; necessitates higher energy consumption; and damages urban infrastructure.

Cities must act to mitigate the UHI effect and adapt to the increasing frequency and intensity of heat waves, using approaches discussed in the next chapter.

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NOTES

1 Cities potentially become less attractive to high-skilled workers through two channels: (a) by directly making the city a less pleasant place to live because of the associated thermal discomfort; and (b) by indirectly making the city a less attractive place to live and work in by reducing the marginal productivity of labor and therefore the real wages that a city's firms can pay workers in competitive markets.

2 TFP, as discussed by Zhang et al. (2018), may encompass the concepts described by both "A" and "e" in the production function introduced above (equation 3.1), because the authors do not separate out the effectiveness of human labor.

3 Studies for other Asian countries also report negative effects of heat on manufacturing output. Somanathan et al. (2021) find that in garment plants without climate control (centralized air cooling) in and around Delhi in India, an additional day with a maximum temperature above 35°C reduces average daily output that week by as much as 8 percent relative to if the temperature had remained below 19°C. Among weavers in India, the study finds that an additional day with a maximum temperature above 35°C in the six preceding days reduces output by about 2.7 percent because of lower on-the-job productivity and by an additional 1.4 percent because of absenteeism.

4 These figures correspond to the Intergovernmental Panel on Climate Change's Representative Concentration Pathways (RCP) 8.5 (worst case) scenario. For a further explanation of RCP scenarios, see box 3.1, note "a."

5 The ILO study calculates productivity losses as "the equivalent working hours lost owing to slower work or a complete stoppage of work when heat levels are too high for working" (ILO 2019, 91). In terms of the production function discussed earlier, this combines a reduction in effectiveness *e* ("slower work") with a reduction in labor input *L* ("complete stoppage of work"). Kjellstrom (2016) uses the same definition of productivity losses.

6 All dollar values in Kjellstrom (2016) are in purchasing power parity (PPP) constant 2005 US dollars.

7 Zhao et al. (2021) do not elaborate on why warm places would have a higher number of cold- than heat-related deaths. One potential explanation could be that people living in places that are usually warm are not prepared for cold weather and lack indoor heating, insulated homes, or warm clothes, resulting in more deaths during rare cold spells. Testing this hypothesis could be an important area for future research.

8 Chapter 2 also finds this to be the case for Bandung, Indonesia.

9 The impacts of heat on injury and crime also vary by income group. The study mentioned earlier of workplace injuries due to heat in the United States (Park, Pankratz, and Behrer 2021) finds that the risk of injury is five times higher for a worker from the bottom income quintile than for someone from the top quintile because of differences in the nature and conditions of the work performed by these groups. In turn, injury and illness due to heat result in lost income, which can throw a financially precarious household into crisis. The study of heat and crime in Los Angeles discussed earlier (Heilmann and Kahn 2019) also shows that the adverse impacts of high temperatures on crime are concentrated in the poorest quintile of city districts, which already have the most crime.

10 ASEAN member countries include Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

CH
CHAPTER

4

MITIGATING AND ADAPTING TO EXTREME URBAN HEAT: POLICY PRINCIPLES AND OPTIONS

KEY MESSAGES

This report's analysis points to three key principles—and associated options for action—to equip East Asian cities to combat the urban heat island effect and withstand heat waves:

Places: **Invest in vegetation, public spaces, and building design for a cooler city**

People: **Protect the health of vulnerable groups during heat waves**

Institutions: **Build a leadership coalition to drive attention to heat hazards across city and national agencies.**

INTRODUCTION

While heat stress presents growing risks to East Asia's urban populations, the challenge is one that the region's cities can address decisively and effectively. Working in tandem with national governments and neighborhood-level stakeholders, East Asian cities have at their disposal a wide range of policy and investment options to reduce heat exposure and help residents better anticipate and cope with extreme conditions. However, resilience to extreme heat is no ordinary policy challenge. At least three factors complicate the policy response, making new and innovative mindsets essential. Making a city resilient to heat requires the following:

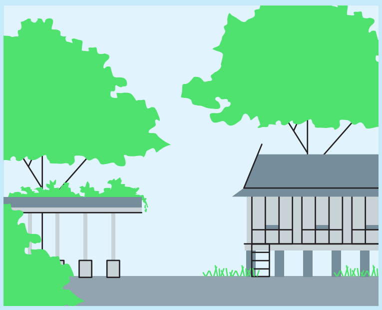
- *Access to an unusually wide variety of skills* from across government and the private sector. Contributions are needed from built environment disciplines (such as urban planners and forestry managers) but also from public health specialists, doctors, and emergency managers, architects, real estate developers and business owners.
- *Action across physical scales,* from changing the material of individual walls and roofs to rethinking areawide land use plans for increased greenery and wind flow.
- *New governance structures* to ensure both clear lines of authority and coordination of action. Established policy priorities such as transport, health, and education typically have accountability and resources vested in clearly defined agencies, but the authority and capability to reduce heat risks is highly fragmented among government entities.

Leadership is therefore crucial. To rise to the challenge of extreme heat and combat the urban heat island (UHI) effect, city leaders must establish an evidence base, articulate a vision for change, and build new coalitions for action.

A FRAMEWORK FOR ACTION: THREE PRINCIPLES, SIX ACTION AREAS

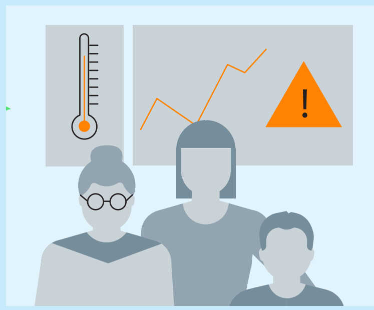
To help structure an effective response to rising heat stress in East Asian cities, this report proposes a framework for action based around three principles: cool the physical spaces of a city ("Places"), act during heat waves to prevent death and illness among vulnerable populations ("People"), and mainstream heat resilience into city strategies, operations, and budgets ("Institutions"). Addressing the three principles in tandem is important given their interlocking nature and requires concerted leadership by city and national authorities (figure 4.1).

Figure 4.1 The "Places, People, Institutions" Framework for Urban Heat Resilience



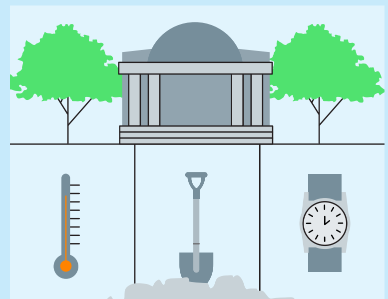
Places

- Advance urban greening through strategic planning
- Cool city spaces through wind, shade and design
- Engage building owners to tackle indoor heat



People

- Save lives through heatwave early warnings
- Protect heat-exposed workers



Institutions

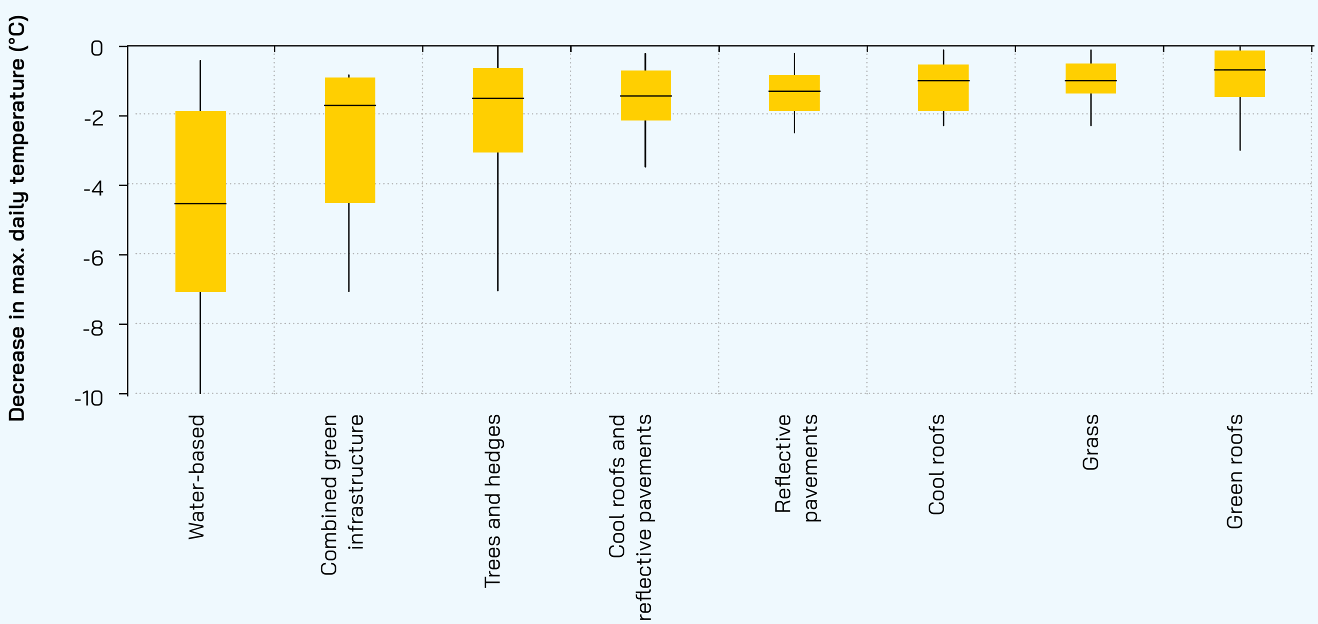
- Mainstream heat mitigation into city strategies and operations

SOURCE: World Bank.

Places. Heat stress is experienced in the physical *places* of a city, both indoors and out. Making streets, plazas, parks, factories, workshops, marketplaces, and homes cooler will reduce heat exposure, contributing to a competitive and inclusive economy and healthy population.

Temperature reduction from place-based cooling interventions—including urban greening and cool building materials—can be significant. Indeed, Santamouris et al. (2017) reviewed 220 studies of such measures and found that average daily temperatures at project sites fell by up to 2 degrees Celsius (°C) in approximately two-thirds of cases and by more than 2°C in the remaining cases. These temperature reductions are of roughly the magnitude needed to offset on a localized basis the UHI effects in many East Asian cities. Maximum daily temperatures, i.e. the hottest temperature recorded at any point during a 24-hour period, fell by more than 3°C in the proximity of tree and water-based interventions and by more than 5°C in some cases (figure 4.2).

Figure 4.2 Cooling Effects of Selected UHI Mitigation Strategies



SOURCE: Santamouris et al. 2017.

NOTE: The figure shows temperature reduction in degrees Celsius (°C) from interventions to mitigate urban heat island (UHI) effects, based on a review of performance data from 220 projects. The temperature reduction figures represent decrease in daily maximum temperatures (i.e. the hottest temperature recorded in any 24 hour period) at each project site compared with measurements taken in a control period. For each category of intervention, the yellow shaded box and accompanying whiskers illustrate the range of temperature reduction benefits that were recorded. The top, middle and bottom of the yellow shaded box represents the 25th percentile, 50th percentile, and 75th percentile respectively, while the black lines extend out to the minimum and maximum temperature reduction values that were recorded.

People. But heat waves are also time-bound emergency situations that endanger *people*—particularly elderly people, children, heat-exposed workers, and those with health vulnerabilities. Identifying the groups that are disproportionately at risk and protecting them during heat waves is imperative. As discussed later in the chapter, experience shows that deaths during heat waves have fallen by double-digit margins after cities introduced heat wave alerts and associated measures to protect the most vulnerable during extreme temperatures.

Institutions. Finally, mainstreaming heat resilience across a city's *institutions*—its governmental departments and agencies as well as civil society and professional groups that play essential roles—is a necessary response to intensifying urban heat. By establishing coordination structures such as a citywide extreme heat task force and adopting a heat wave risk management. East Asian cities can put themselves on a sound institutional footing to protect citizens, infrastructure, and the economy against future temperature extremes.

The following sections present six strategic options for action to deliver on the "Places, People, Institutions" agenda for heat resilience. There is no one-size-fits-all solution given East Asian cities' differing climates, populations, and institutional starting points. However, by prioritizing needed interventions from across this set of action areas—with consideration of the detailed policy and investment options outlined in Annex 4A at the end of the chapter—each city can design an effective local response to cool its places and protect its population from rising heat stress.

STRATEGIC OPTION 1: ADVANCE URBAN GREENING THROUGH STRATEGIC PLANNING

Green assets such as trees, grass, and shrubs result in cooler city spaces, and, as the analysis of chapter 1 showed, the intensity of an East Asian city's average UHI effect is strongly positively correlated with its average level of vegetation. However, as illustrated in chapter 2 for the city of Bandung in Indonesia, vegetation levels also tend to be highly uneven between a city's neighborhoods. Prosperous residential areas tend to have better organized and resourced tree care and may have larger plot sizes, whereas central business districts and poor residential neighborhoods often lack greenery. Expanding the reach of urban nature, especially where trees and shrubs are in short supply, can increase shade and evapotranspiration, mitigating the UHI effect and reducing air temperatures. Urban greening is a key ingredient in heat resilience strategies and benefits diverse groups, including workers and shoppers who frequent dense city centers as well as the poorest residents whose neighborhoods may lack grass, shrubs, and trees.

The return on investment from urban greening can be high. Studies estimate that greening interventions can result in a median reduction in localized temperatures of 1.5°C (Santamouris et al. 2017). Planting at "microsites" (such as tree pits and on traffic medians) cools air locally, while planting at extensive sites (such as parks) can also generate a "park cool island effect" benefiting surrounding blocks, particularly in areas downwind of them. This cooling effect may extend up to 2 kilometers, depending on the characteristics of the nearby areas (Santamouris et al. 2017). Multiple pocket parks—small parks of around 1,000 square meters—may confer greater cooling benefits than a single large park of equivalent aggregate size, especially in high-rise tropical regions (Giridharan and Emmanuel 2018).

One study found that expanding tree cover on 10 percent of city land could yield a 1.5°C temperature reduction for 647,000 people in Seoul, 770,000 in Jakarta, and 2.2 million in Beijing respectively—at a cost of just US$1–3 per capita for each benefiting resident (McDonald et al. 2016). City leaders can consider using, or adapting, the so-called 3-30-300 rule: each resident should be able to see at least 3 trees from their home, have 30 percent canopy cover in their neighborhood, and live no more than 300 meters from a park or green space (Konijnendijk 2021).

Meeting ambitious goals such as the 3-30-300 target across East Asian cities will require resources and long-term planning. Indeed, greening of cities is easier said than done. Key challenges in urban forestry expansion include species selection; survival during the crucial first year after planting; tree maintenance and pruning; managing competition between tree roots and the needs of residents and infrastructure; and securing community support for planting and maintenance. Urban greening requires strategic planning across several physical scales to expand green assets on large and small sites as well as on publicly owned, commercial, and residential land (table 4.1). Forward planning with a timeline of at least a decade is particularly important for urban forestry given the speed at which trees grow.[1]

In this context, adopting dedicated urban forestry master plans is highly advisable. By setting a strategic vision for green assets in the city, such plans provide a powerful tool to (a) ensure that legislative frameworks and fiscal resources align with a city's future vision for trees and vegetation, and (b) track progress toward the goals.

Table 4.1 Actions to Create Cooler City Places, by Scale

ASPECT	BUILDING SCALE	BLOCK SCALE	NEIGHBORHOOD SCALE	CITY SCALE
Urban climate effect	Heat absorption and radiation, shading, ventilation	Street canyon dynamics: heating and cooling, pollutant circulation	Local heat island intensity, park cool island effects	Urban impact on weather patterns: air circulation, pollutants, fog
Relevant actors	Building owner, landlord, tenant	Residents' association, real estate developer	Neighborhood association, infrastructure or real estate developer	Urban planner, architects' association, national government
Example interventions	Cool roof, passive building design, green building elements	Public space design, arrangement of buildings, urban greening microsites	Urban greening: street trees, traffic medians, private land, pocket parks	Building code (such as cool roof mandate), planning incentives (such as FAR bonus), design guide, breezeway planning
Scale illustration				

SOURCE: World Bank.

PHOTOS: © Nicholas Jones / World Bank; further permission required for reuse.

NOTE: The figure shows urban climate effects, relevant actors, and feasible interventions across different physical scales of urban space, arranged from small to large scale. FAR = floor-area ratio.

STRATEGIC OPTION 2: COOL CITY SPACES THROUGH WIND, SHADE, AND URBAN DESIGN

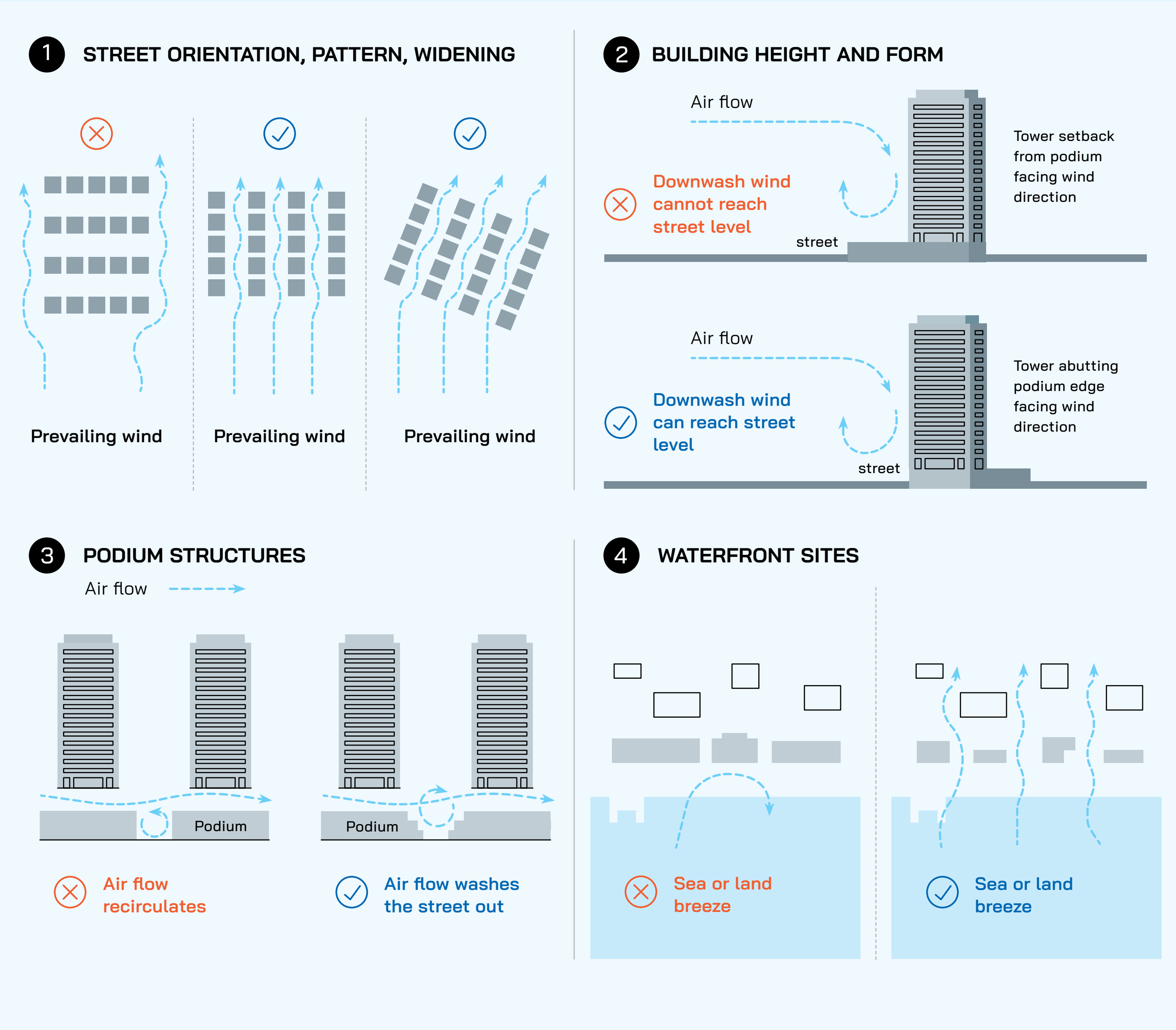
Increasing green cover in cities is important, but so too are interventions to preserve beneficial aspects of local climates—such as wind flow generated by the local topography—and promote cooler design of public spaces.

Wind effects. For coastal cities in particular, wind is a crucial resource. Sea breezes form because of pressure differentials when air above the city warms at a different rate than air above the sea. The resulting convection cools surfaces and disperses pollution. Indeed, in Singapore, air temperatures fall by 2°C when wind speed is 1.5 meters per second higher (Erell, Pearlmutter, and Williamson 2011).

However, urban construction can inhibit wind. Poor building design—such as lines of tall buildings directly on the water's edge that block sea breezes—have a detrimental effect on thermal conditions and air pollution levels for inland districts (Oke et al. 2017).[2]

East Asian cities that anticipate rapid growth of further tall buildings along the coast can learn from examples such as the air ventilation assessment in Hong Kong SAR, China (figure 4.3). Just as Hong Kong's urban design guidelines provide clear guidance on design features and requirements—such as stepped-back buildings, designated breezeways, and building arrangements to channel wind—designing cities "with the wind" may offer significant benefits (Ng 2009).

Figure 4.3 Recommended Site-Level Practices in Hong Kong SAR, China, to Safeguard Air Ventilation and Microclimates Considering Wind Flows



SOURCE: PlanD 2016.

Shade effects. In addition to wind, shade is a valuable commodity in hot climates. Urban planning documents and cooling action plans can promote increased shade in public places. In Freetown, Sierra Leone, an early initiative of the city's first chief heat officer was to install awnings in three public market places where some 2,300 mainly female market traders sold produce daily in hot conditions (Atlantic Council 2022). In Singapore, a distinctive network of covered walkways has become a hallmark of the urban landscape, adding to livability and promoting a vibrant commercial and business landscape that is more comfortably accessible to pedestrians given the city's hot and humid climate (box 4.1).

In promoting cooler urban designs, traditional building practices ("vernacular architecture")—which, in many East Asian regions, offers a wealth of architectural practices that promote ventilation, minimize heat storage in surfaces, and provide shade (Satwiko 1999)—offer an important potential source of inspiration.

BOX 4.1 COOLING SINGAPORE WITH TRADITIONAL TECHNIQUES AND DIGITAL TECHNOLOGIES

Planting trees to increase greenery coverage has been a key strategy to control urban temperatures since Singapore's independence in 1965. The government first launched a tree-planting campaign in 1963 to replicate tree-lined streets from overseas, and this was incorporated into the "Garden City" vision (announced in 1967 by Prime Minister Lee Kuan Yew), which accelerated tree planting. More recently the National Parks Board has since 2015 extended the Garden City vision to plant climbers and shrubs on bus shelter roofs, on covered walkways, at railway stations, and on noise barriers.

Covered walkways have been a key feature since at least the Town Plan of 1822, which set an essential framework for Singapore's spatial development. Today, the Urban Redevelopment Authority (URA) mandates that all commercial and mixed developments "shall provide covered walkways along the periphery of the building facing roads and pedestrian routes," with design specifications around roof height and minimum width. The Land Transport Authority launched the Walk2Ride program as part of the 2013 Land Transport Master Plan, setting further ambitions to expand the network of covered walkways.

In 2017, the government of Singapore launched a major research project entitled "Cooling Singapore," led by a university center with international partners. The project has conducted research on the urban heat island (UHI) effect, including heat stress mapping, identifying gaps in knowledge and technology, and establishing a task force to test intervention options. The project team tested and simulated alternative building designs, conducted surveys of residents' experiences and preferences, and developed a "digital twin" model to simulate local climates.

Cooling Singapore has also created an Urban Heat Vulnerability Index, which combines physical exposure with socioeconomic indicators to identify populations most vulnerable to extreme heat. It maps physical exposure indicators (measures of temperature and vegetation) as well as sensitivity and adaptive capacity indicators (share of elderly and infant population, unemployment rate, employment in construction, access to local medical facilities, and others) (Philipp and Chow 2020).

In 2019, an interagency working group led by the Ministry of Sustainability and the Environment (MSE) and the URA was launched to implement initiatives to mitigate UHI effects in Singapore. It identified three key strategies for UHI mitigation:

- *Understanding UHI effects* by expanding the network of climate sensors in the country to collect data and running computational simulation models
- *Simulating the effectiveness of UHI mitigation strategies* through the Cooling Singapore project
- *Implementing interim UHI mitigation measures* by partnering with industry and the public.

Urban design effects. With East Asian cities facing a hotter future, architectural and urban design practices have an important role to play in promoting the thermal comfort of urban landscapes. Among them, street depth and orientation are important considerations. The depth of street canyons—the ratio of building height to street width—can affect the amount of the sun's energy received by building façades during the day as well as influencing air flow. In Bangkok, a study showed that medium-depth street canyons (with a height-width ratio of 0.36 to 0.65) were hottest, providing neither sufficient shade nor unobstructed ventilation (Takkanon and Chantarangul 2019). The effect of street canyon depth varies over a 24-hour period, with more-enclosed spaces being cooler during the day owing to shade but warmer at night because of trapped heat.

Orientation of streets affects both shade and ventilation. Streets oriented roughly parallel to the flow of breeze (for example, perpendicular to the shore in a coastal city) have better ventilation and lower temperatures. Water bodies in urban areas can prove highly beneficial to thermal comfort (particularly in dry climates). Where water availability permits, features such as sprinklers, fountains, and misting devices have been implemented with success in cities such as Singapore to cool public spaces such as plazas, train stations, and children's playgrounds (Lai et al. 2019).

Urban design solutions are context specific—differing notably based on local climate, topography, and latitude—but city leaders can incentivize good architectural and design practices by publicizing the urban heat challenge, celebrating good local practices, and building essential considerations into local codes and design guidelines.

STRATEGIC OPTION 3: ENGAGE BUILDING OWNERS TO TACKLE INDOOR HEAT

Poorer neighborhoods often have higher outdoor air temperatures than wealthier ones, but when indoor conditions are also considered, the "thermal inequalities" loom even larger. Addressing indoor heat exposure is essential to reducing heat illness and sustaining labor productivity, since people spend much time indoors. The design and construction of buildings is a key entry point to address heat exposure.
City governments' policy leverage differs depending on building ownership and established planning procedures, and hot buildings cannot be transformed into cool

ones overnight. However, city authorities can systematically engage with building owners to promote cooler design and materials while looking out for "quick wins" that reduce harmful heat exposure of at low cost.

Passive cooling of buildings refers to architectural elements that reduce indoor temperatures without mechanical cooling. Before the advent of air conditioning, traditional building designs in warm regions featured passive cooling techniques by necessity. Although these may not be sufficient to ensure thermal comfort during the hottest times of the year, they still contribute to cooler temperatures and reduced air conditioning needs. Depending on the climate, passive cooling features may include various elements for shading (overhanging eaves, latticed façades, louvered shades, and others); courtyards; wind towers and other features for ventilation; water for evaporative cooling; the use of earthen surfaces and insulating materials on façades; and the use of materials that reflect the sun's energy rather than absorbing it (Srivastav and Jones 2009; Yoshino, Hasegawa, and Matsumoto 2007).

Building materials differ substantially in the proportion of incoming radiation, from the sun and other sources, that they reflect away. The fraction of incoming energy that a surface reflects is known as its albedo (table 4.2). City authorities can promote the use of high-albedo materials (including the application of white paint coatings to roofs) and other passive cooling interventions through a combination of "hard measures" (mandatory regulations and direct public investment) and "soft measures" (including incentives and information provision). Among hard measures, building codes and zoning requirements can be used to drive adoption of cooler building practices. A good example of this is India's 2016 building code, which specifies reflectivity and emissivity values required for new or substantially renovated roofs (ESMAP 2020).

City governments can also lead by example in their design or renovation of publicly owned facilities including those procured through public-private partnerships. Schools, clinics, government buildings, and sport facilities all provide opportunities to pilot solutions, establish design standards, build construction industry capacity, and create a local evidence base on the effectiveness of cool building measures (table 4.2).

Table 4.2 Albedo Value for Selected Building Materials

BUILDING MATERIAL	ALBEDO
ROADS	
Asphalt (fresh → weathered)	0.05–0.27
WALLS	
Concrete	0.10–0.35
Brick (red → white)	0.20–0.60
Limestone	0.40–0.64
ROOFS	
Tar and gravel, bitumen	0.08–0.18
Tile (old → fresh)	0.10–0.35
PAINTS	
Black	0.02–0.15
White	0.50–0.90

SOURCE: Adapted from Oke et al. 2017.

NOTE: The albedo value of a surface is the fraction of incoming radiation that it reflects. Albedo is scaled from 0 and 1. Surfaces with higher albedo reflect away a higher proportion of incoming solar radiation; for example, a white painted roof with albedo of 0.7 would reflect 70 percent of incoming radiation.

Given the limits of public budgets and building code enforcement, a broader set of tools including fiscal and planning incentives and concessional finance for cool building upgrades may be worth examining on a case-by-case basis. Hong Kong SAR, China; Singapore; and Tokyo are among the cities offering floor-area ratio bonuses—which permit larger buildings on a given plot size—if developers adhere to green building standards.

Property tax rebates for cool roof installations are another option. Cool roof programs reduce indoor heat gain through white paint coatings that reflect away the sun's energy. They represent one of the most cost-effective and scalable heat reduction measures. This is exemplified by Cool Roofs Indonesia, a program whose interventions have resulted in indoor temperature reductions as high as 10°C (Clean Cooling Collaborative 2022). Integrating cool roofs into public housing programs and incentivizing their adoption by commercial building owners can offer major benefits.[3]

STRATEGIC OPTION 4: SAVE LIVES THROUGH HEAT WAVE EARLY WARNINGS

Whatever incremental steps cities take to reduce heat exposure across indoor and outdoor settings year-round, the moment of truth for preventing heat-related deaths and illnesses is when a heat wave strikes. To a significant degree, deaths during heat waves are both predictable and preventable: they are concentrated in groups that have high *exposure* to heat—owing to factors such as housing quality or heat-exposed occupations—as well as high *vulnerability* to heat, whether because of age, occupation, or health status. The most effective measures to prevent a heat wave death are those taken by at-risk individuals or those closest to them: their family, health care providers, or employers.

Heat waves cause most deaths when they take populations by surprise by coming early in the season. As a substantial body of public health experience has shown, heat-health early warnings can save lives by informing people that their health faces an imminent threat—prompting individuals to take actions that preserve their health—as well as by activating protocols in health care, education, and workplace settings (Toloo et al. 2013).

To maintain credibility and trust, it is essential to issue warnings only when heat stress reaches a level that is known to predict significant adverse health impacts. Design of warning systems therefore requires collaborative work between meteorological agencies, public health specialists, and affected groups. Mortality data should be matched with meteorological information to design warning systems that will be activated when deaths would otherwise occur.[4] Effective heat wave early warning systems go beyond simply announcing high air temperatures to activating planned interventions that target the population subgroups known to be most at risk, as several examples illustrate:

- *In the United States*, the city of Philadelphia—which introduced one of the world's first population health-focused heat wave warning systems in 1995—defined a protocol for announcing a "heat health emergency" and accompanied such announcements with a suite of measures, from activating a "Heatline" telephone service to using libraries and swimming pools as cooling centers and increasing outreach to homeless people (Weinberger et al. 2018).
- *In Hanoi*, the Viet Nam Red Cross and Viet Nam Institute of Meteorology, Hydrology and Climate Change jointly implement warnings based on a combined measure of heat and humidity and guide vulnerable populations to assistance including mobile cooling centers (Jjemba et al. 2020).
- *In Japan*, a country with a hot summer climate, the government has developed and refined an extreme heat early warning system centered on the concept of "heat illness reduction." Alerts are issued by the Japan Meteorological Agency and disseminated via television and radio, private weather companies, email and social media channels, and local government—including via public loudspeakers (box 4.2).

BOX 4.2 HEAT ILLNESS PREVENTION IN JAPAN

In Japan, a country known for its generally mild climate, increased hot summers during the 1990s spurred recognition of the dangers posed by extreme heat to human health—and led to the development of a robust national framework for heat illness reduction.

An important early impetus for heat health policy was heatstroke among student athletes. In 1994, the Japan Sport Association published "A Guidebook for the Prevention of Heat Disorder During Sports Activities" (JSPO 1994), which, together with a public information campaign, helped to reduce cases of heat illness at sports facilities and among those 14 years old and younger.

Consecutive hot summers and preparations for the 2020 Tokyo Olympic Games prompted government action to develop and refine an alert system. The Heat Caution Notice system, introduced in 2011, provided alerts when air temperature was projected to exceed 35 degrees Celsius (°C). However, by neglecting humidity and radiation—two important aspects of heat stress—the alert system was found to correlate imperfectly with heat illness cases. The high frequency of alerts also raised concern for "alert fatigue."

An improved system of Heat Stroke Alert (Necchūshō keikai arāto), tested in Tokyo then rolled out nationally in 2021, provides citizens with alerts when the Wet Bulb Globe Temperature is projected to exceed 31°C (table B4.2.1). The alerts are usually issued by 5 p.m. on the previous day or, if a sudden temperature rise is expected, at 5 a.m. on the day of expected extreme heat. The Japan Meteorological Agency (JMA) issues alerts to media, local governments, and private weather forecasting companies to ensure widespread dissemination. These measures reach a large portion of the population, including through television news flashes and dissemination over local government loudspeaker systems (figure B4.2.1 panel A).

A hallmark of Japan's response to extreme urban heat has been cooperation across government departments, which was initiated through an Urban Heat Island (UHI) Ministerial Liaison Council convened by the Cabinet Secretariat in the early 2000s. Where heat illness reduction is concerned, high-level policy coordination has meant that alerts issued by the JMA link with health guidance developed by medical experts (notably the "Heat Illness Environmental Health Manual," first published in 2018) and are supported by public awareness measures (figure B4.2.1 panel B).

Heat wave alerts have benefited from the wide array of communication channels, which increasingly include social media. Of alert recipients who responded to an evaluation survey, 31 percent changed their behavior to stay indoors, 52 percent hydrated frequently, and 75 percent checked on family members (Japan MOE and JMA 2021). Collaborative actions across key heat-exposure settings—from school sports facilities to elderly care homes, construction sites, train stations, and private homes—have helped to avert heat illness and reduce pressure on the health system.

Table B4.2.1 Japan's Heat Stroke Alert System: Heat Stress Thresholds and Recommended Actions

COLOR	HEAT THRESHOLD (°C WBGT)	CATEGORY	MAIN ACTIONS RECOMMENDED
Red	Above 31	Dangerous	Exercise should be stopped.
Orange	28–31	Warning	Refrain from heavy exercise; frequent rest and hydration are strongly encouraged.
Yellow	25–28	Watch	Frequent rest and hydration are strongly encouraged during heavy exercise.
Sky blue	21–25	Caution	Hydration is encouraged.
Blue	Below 21	Generally safe	Appropriate hydration is suggested.

SOURCE: Japan Meteorological Agency.

NOTE: °C WBGT = degrees Celsius (Wet Bulb Globe Temperature).

Figure B4.2.1 Heat Health Early Warning System and Public Awareness Campaigns in Japan

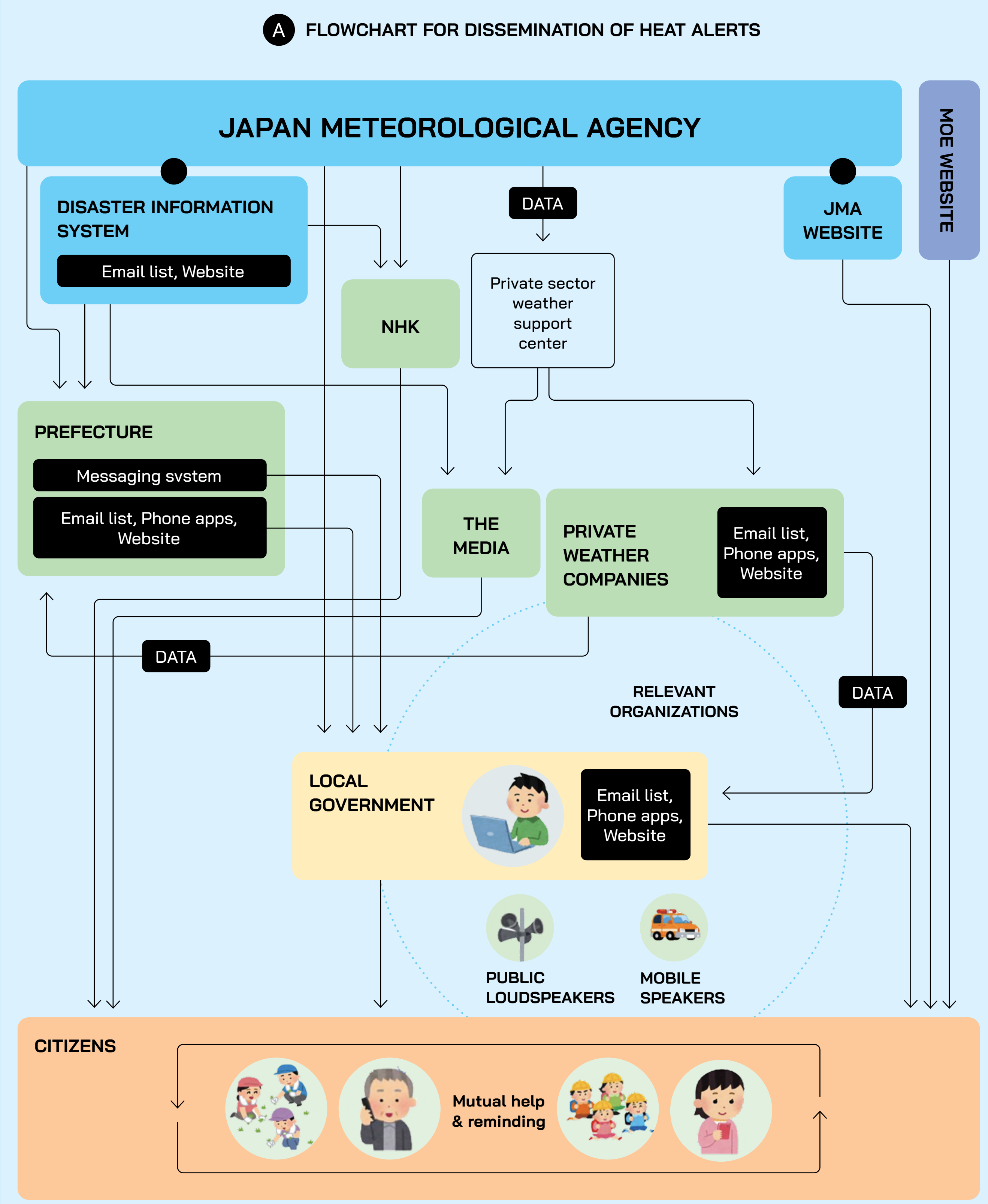


Figure B4.2.1 Heat Health Early Warning System and Public Awareness Campaigns in Japan

B HEAT ILLNESS PREVENTION CAMPAIGN PUBLICITY MATERIALS (ENGLISH LANGUAGE VERSION)

SOURCE: SOURCE: Panel (a): World Bank translation and elaboration based on Japan Meteorological Association and Ministry of Environment, 2021. Panel (b): Japan Ministry of Environment (n.d.).

A central requirement for heat wave early warning systems is to determine a trigger upon which such warnings will be issued. In Ahmedabad, one of India's hottest cities, all-cause mortality increased to three times its baseline level on the hottest day of the 2010 heat wave (Azhar et al. 2014). The tripling of citywide daily deaths proved a wake-up call for city leaders, who proceeded to implement South Asia's first Heat Action Plan, based around a "traffic light" warning system: citizens receive yellow, orange, and red alerts when temperatures exceed 41°C, 43°C, and 45°C, respectively. The thresholds for the alert system were designed by examining the correlation of daily deaths from all causes with temperatures from local weather stations. The Heat Action Plan, with the traffic-light alert system at its core, has been credited with helping to avoid around 1,100 deaths per year in the years immediately following its introduction (Hess et al. 2018).

Although more evaluations of heat wave early warning systems are needed, existing studies from across world regions already present compelling evidence of the benefits (table 4.3). Heat-related deaths fall into two categories: (a) exertional deaths, which occur when physical effort in hot conditions places body systems under extreme stress; and (b) nonexertional deaths, which occur most frequently at home and among individuals with comorbidities such as cardiovascular disease, reduced lung capacity, or diabetes (Cissé et al. 2022). In both cases, heat wave early warnings based on sound public health guidance can spur vulnerable individuals to hydrate, avoid heat, cool their bodies, and check on neighbors.

Table 4.3 Do Heat Wave Alerts Save Lives? Evidence from International Studies

CITY STUDIED	OBSERVED CHANGE IN MORTALITY	STUDY REFERENCE
Florence, Italy	The odds of mortality during a heat wave among the frail elderly population decreased by 9 percent after introduction of alert system compared with a counterfactual scenario.	Morabito et al. (2012)
Hong Kong SAR, China	Ischemic heart disease deaths among the elderly fell by 23 percent against expected baseline following the introduction of extreme heat warnings.	Chau, Chan, and Woo (2009)
Paris, France	Following the introduction of France's Heat Health Watch Warning System, mortality during the 2006 heat wave was 68 percent lower than expected based on past heat-mortality relationships.	Pascal et al. (2006)
Milwaukee, Wisconsin, United States	Heat wave deaths were 49 percent lower than expected levels after the introduction of a suite of heat-health measures, including an alert system.	Weisskopf et al. (2002)

SOURCE: World Bank.

Given East Asian countries' existing investments in weather forecasting capacities, the *direct* costs of implementing heat wave early warning systems in countries that currently lack them are likely to be low. They may include the costs of public health studies and community consultations to design warning systems, the cost for weather services to adapt existing forecasting products to locally defined needs, and the cost of city staff and communications specialists to issue warnings that effectively reach the most vulnerable groups.

However, the *secondary* costs may be more significant. An important priority is the strengthening of health care statistics and their use to fine-tune alert mechanisms. Lisbon, Portugal, is one example of a city where heat wave alerts are accompanied by detailed monitoring of disaggregated health statistics. Public health experts at the city's heat-health observatory (the ÍCARO (ICARUS) surveillance *system*)[5] monitor health outcomes by demographic group, providing insights that have proven valuable for refining the alert system (Leite et al. 2020).

Further costs associated with heat wave early warnings may include strengthening the readiness of hospitals, clinics, and ambulance crews to care for heatstroke patients. Ahmedabad's Heat Action Plan defined health sector protocols to be activated when "orange" or "red" alerts are issued. These include practical measures such as establishing heatstroke treatment stations in hospitals and equipping ambulance crews with ice packs and rehydration fluid. Even considering these secondary costs of establishing an action-oriented heat wave early warning system, the cost-benefit ratios of such systems is likely to be high (Rogers and Tsirkunov. 2011; Williams et al. 2022).

STRATEGIC OPTION 5: PROTECT HEAT-EXPOSED WORKERS

Exposure to heat stress varies by occupation. Workers in demanding outdoor occupations such as construction as well as road building and repairs are among the most exposed. Physical labor induces high heat production in workers' bodies that causes a rise in body temperature and subsequent illness. A large share of indoor jobs also entail heat stress due to physical intensity, building characteristics, exposure to indoor heat sources, and lack of ventilation or air conditioning. Many such roles skew toward a female workforce, particularly in industries such as garments and textiles, which play a key role in many East Asian economies. Indeed, females make up more than 70 percent of the textile and garment workforce in the Philippines, Thailand, and Viet Nam, and more than 80 percent in Malaysia and Myanmar (ILO 2022).

The physiological limits of human heat endurance—established through studies in military, sports, and occupational health and safety research—have motivated legislation in many countries that limits workplace heat exposure as measured by Wet Bulb Globe Temperature, a heat stress measure recognized by the International Organization for Standardization (ISO) for workplace applications (Kjellstrom, Holmer, and Lemke 2009). Although the devices required to monitor indoor heat stress are inexpensive, enforcement is nonetheless often lacking. However, a wide range of actions can reduce heat exposure during the working day, with employers, local government, and workers themselves each having a role to play (table 4.4).

Heat-exposed occupations vary greatly in their physical setting, labor market structure, and degree of supervision by employers or government. To identify the most efficient way to reduce heat stress across different occupations, consulting the workers themselves is therefore highly advantageous. In developing its Heat Action Plan, the city of Ahmedabad, India, convened consultations with heat-affected occupational groups including street vendors and traffic police (Knowlton et al, 2014). By hearing directly from heat-exposed workers, the plan's authors were able to incorporate practical measures into city guidelines while eliciting greater buy-in and awareness. A further benefit of such consultations is to establish sector-specific actions to be activated when alerts are issued by a heat wave early warning system (see Strategic Option 4).

Table 4.4 Examples of Actions to Protect Heat-Exposed Workers

CATEGORY	ACTION
Educational actions	• Inform heat-exposed workers about symptoms and risks of heat stress • Encourage behaviors that mitigate heat stress: drink water; eat less but more frequently; reduce caffeine and alcohol; seek medical attention when needed • Train workers to recognize heat illness symptoms and ensure that coworkers receive early intervention when needed ("buddy system")
Employer actions	• Organize work shifts to avoid exertion during hot afternoon periods • Schedule breaks if heat becomes too intense • Provide water and shade at work sites • Provide workers acclimatization time (for example, initial 50 percent workload) • Adapt uniforms and encourage wearing of light, breathable garments
Local government actions	• Consult heat-exposed workers to understand the risks they face and their needs for early warnings and working practice changes • Disseminate heat early warnings to employers, labor unions, and heat-exposed workers • Review and improve working practices for heat-exposed government staff and contractors • Strengthen enforcement of occupational health and safety legislation

SOURCE: Adapted from NRDC 2013.

STRATEGIC OPTION 6: MAINSTREAM HEAT RISK REDUCTION INTO CITY INSTITUTIONS AND STRATEGIES

Making cities resilient to extreme heat presents a distinct set of public policy challenges that call for an innovative, citywide response:

- *Managing across agencies.* The challenge of extreme heat in cities requires points of contact with an unusually large number of governmental agencies. From planning and parks departments to transit operators, and from health systems to meteorological agencies, effective action requires that many city and national entities work around the same table.
- *Managing across physical scales.* Making city landscapes cooler requires action across physical scales to change construction and design practices. From selection of roof and wall materials to the design of buildings and their surroundings, interventions are needed to incorporate green elements and cool materials into individual buildings and areawide plans.
- *Utilizing diverse policy instruments.* Heat stress interventions span a wide array of policy instruments—from direct public investments in school buildings or public plazas to "hard" legislative mandates (such as building codes) and "soft," bottom-up measures to incentivize action by building owners and residents (for example, tree stewardship schemes and public space design guides).

In contrast to established policy priorities like transportation, health, and education, no single city government agency is generally vested with the mandate and resources required to lead on extreme heat mitigation. Rather, the actions needed for effective heat mitigation are fragmented among many organizations and stakeholders. To make matters more complicated, city governments often lack a clear focal point for leadership on urban heat mitigation. Without an obvious leadership figure or an agreed-upon, long-term vision and strategy, the staffs of city planning, transportation, health, emergency management, or other departments may pay limited attention to the issue despite having taken promising heat mitigation actions within their spheres of influence.

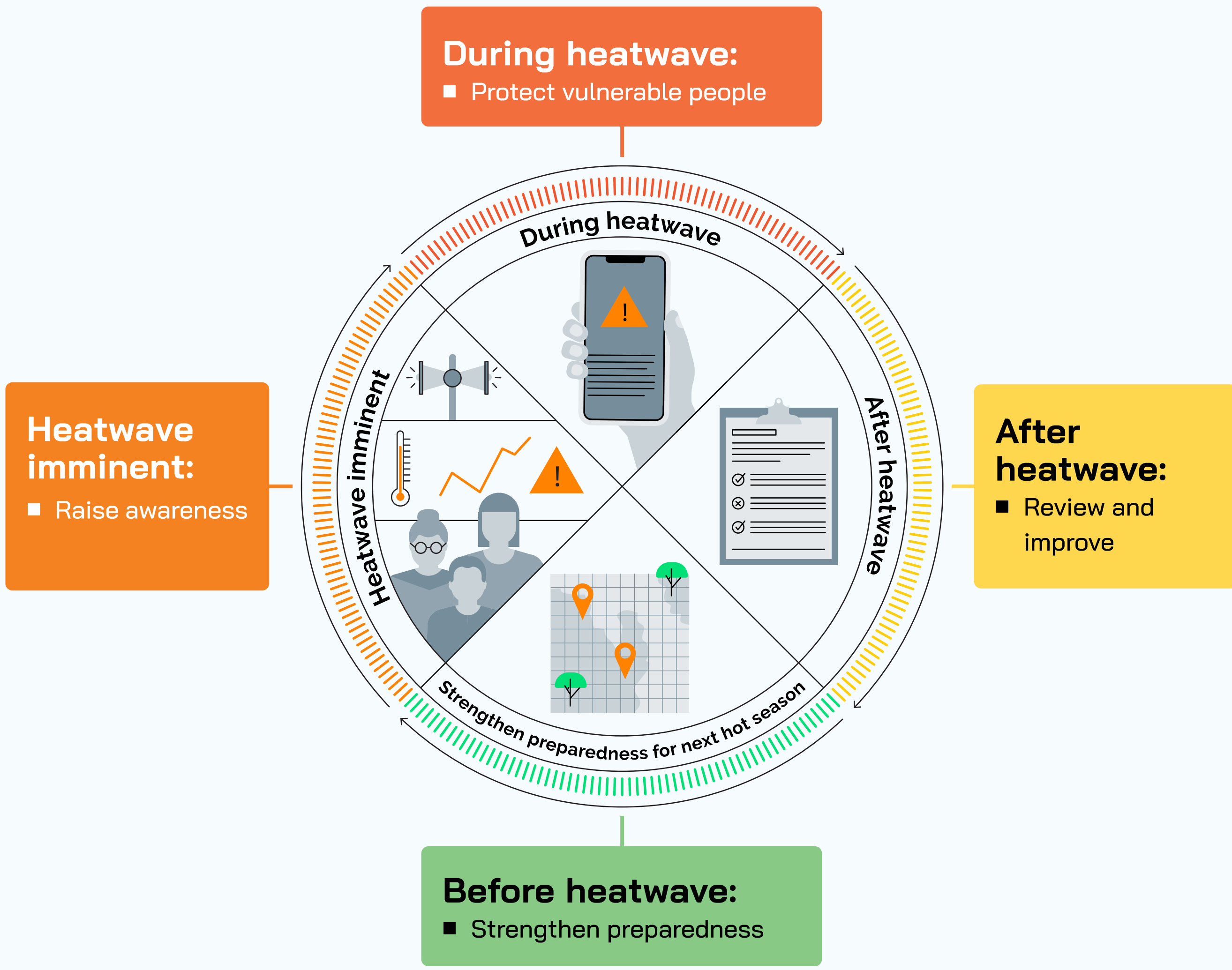
For cities that are beginning to recognize the need to act on this issue, a wise step might be to establish an extreme heat task force mandated to review evidence on extreme heat, gather and analyze data, consult affected groups, and recommend actions. In Tokyo, systematic action to respond to the UHI effect dates back at least to 1998, when the issue was first raised in the Tokyo Metropolitan Assembly, leading to the setting up of a study group within the Tokyo Metropolitan Government's Bureau of Environment (Yamaguchi 2013). The group raised awareness and secured buy-in from other branches of municipal and national government, leading to an expanding set of legislative initiatives and direct public investments in the following decade.

More recently, a growing number of cities worldwide have taken the step of appointing an individual official—sometimes designated as chief heat officer—to lead citywide actions. Whether led by a task force or an individual officer, a key objective should be to increase the visibility of the issue and secure buy-in from stakeholders on whose part action is needed. For example, after appointing its first chief heat officer in 2022, the city of Santiago, Chile, followed a consultative process before introducing the country's first extreme heat response protocol, which combines color-coded alerts with an information campaign to protect vulnerable groups and heat-exposed workers.

For cities that are at an early stage in addressing the UHI effect, taking stock of existing evidence and action on heat mitigation is an important starting point, but strengthening the evidence base through approaches such as heat mapping and public health assessment can help to build momentum. Community-based mapping approaches—such as the vehicle-based "citizen science" campaign conducted in Bandung, Indonesia, for this study (see chapter 2)—can also help to increase visibility and support. Building a partnership with relevant stakeholders inside and outside government, or a "cool city coalition," can advance heat reduction actions (annex 4A).

Because hot weather follows an annual seasonality, heat wave preparedness and response should also follow an annual seasonality—by strengthening preparedness in the run-up to the hot season, activating protocols when a heat wave is imminent, acting to protect the vulnerable during extreme heat events, and conducting after-action reviews before recommencing the cycle (figure 4.4).

Figure 4.4 The Heat Wave Risk Management Cycle



SOURCE: World Bank elaboration based on Singh et al. 2020.

SUMMARY AND CONCLUSION

Extreme urban heat—arising from the combination of the UHI effect and climate change—represents a significant and growing drag on the economic competitiveness of many East Asian cities while also contributing to cities that are less healthy, livable, and inclusive. To rise to the urban heat challenge, leaders in East Asian cities can adopt a "Places, People, Institutions" framework corresponding to three key principles: making places cooler; protecting vulnerable populations; and mainstreaming heat mitigation measures into city departments, operations, and budgets. By acting now, East Asian city leaders can help make their cities not only cooler but also more prosperous, inclusive, and livable.

ANNEX 4A

Mainstreaming Heat Resilience into City Institutions and Strategies: Suggested Phases for a City Extreme Heat Task Force with Suggested Key Questions and Actions

PHASE

	1. TAKE STOCK	2. BUILD THE EVIDENCE BASE	3. BUILD A "COOL CITY COALITION"	4. INVEST, MONITOR, MAINSTREAM
Activities	▪ Review knowledge, strategies, and actions relating to extreme heat	▪ Strengthen understanding of heat hazards, vulnerability, and impacts	▪ Review the organizational setting for heat action; enlist stakeholder support	▪ Prioritize investments and policy actions; integrate into core budgets; monitor and communicate
PLACES				
Key questions	▪ Have urban heat island studies been carried out already? ▪ What do city government and other stakeholders already do to promote cooler city spaces? Are the interventions working? ▪ How could heat mitigation actions contribute to existing city strategies and commitments?	▪ How does heat intensity differ between city neighborhoods? ▪ Do differences in building materials and vegetation density expose some residents to more heat? ▪ What opportunities exist to increase green cover, make buildings cooler, integrate shade and water into urban design, and improve wind flow? ▪ How does heat affect experience of public facilities including schools, hospitals, buses and trains?	▪ Which government departments and other stakeholders can be effective champions for cooler city spaces? ▪ Which departments and agencies could use their core operations, staff, and budget to promote greener streets and cooler buildings? ▪ Could residents' associations, professional bodies, employers, trade unions or botanical gardens support design and upkeep of green assets and cool buildings?	▪ Which place-based cooling interventions offer the most immediate, high-impact benefits? ▪ Should city agencies' design and procurement standards or operational handbooks be revised to integrate cooling considerations? ▪ Does the city monitor heat-related deaths each year and adjust hot-season planning based on the trends?
Supporting measures	▪ Map urban greening stakeholders ▪ Map cool building stakeholders ▪ Conduct desk review on policies and strategies for cool city places	▪ Conduct urban heat island studies using remote sensing, in situ measurements, and/or climate models ▪ Pilot cooling interventions (such as cool roofs on schools or public housing) to evaluate potential investment options ▪ Study impacts of buildings on wind to identify options for improved ventilation ▪ Conduct a baseline assessment of urban forestry, including tree health, green cover disparities, and species suitability for future climate	▪ Engage citizens through participatory heat mapping, focus groups, and surveys ▪ Consult forestry stakeholders on options to preserve and increase green cover ▪ Engage building owners and construction industry on indoor heat reduction options	▪ Short-list investment options for cooler and greener city spaces ▪ Identify options to integrate passive cooling measures into building codes and zoning regulations ▪ Identify options to strengthen markets for cool building designs and materials through public procurement ▪ Identify opportunities to mainstream heat mitigation into existing city department strategies ▪ Initiate prefeasibility study for prioritized investment options

PHASE

	1. TAKE STOCK	2. BUILD THE EVIDENCE BASE	3. BUILD A "COOL CITY COALITION"	4. INVEST, MONITOR, MAINSTREAM
PEOPLE				
Key questions	■ Do residents currently receive information about upcoming extreme heat? ■ How do doctors and hospital workers prepare for the hot season? ■ Does the national meteorological agency provide anticipatory heat stress forecasts for the city?	■ How do deaths and hospital admissions vary with heat? ■ Which socioeconomic groups have a higher rate of death, illness, or hospital admission during extreme heat? ■ Do current weather forecasting products meet the city's needs for protecting residents' lives during heat waves?	■ Which groups of workers have highest heat exposure? ■ What health and economic losses could be suffered in the future if workers are not protected? ■ Which stakeholders need to disseminate information for vulnerable groups to reduce heat exposure and receive needed support?	■ What actions to protect vulnerable people would prevent deaths and illnesses at the lowest cost? ■ At what heat stress threshold should alerts be issued?
Supporting measures	■ Map public health and early warning system stakeholders ■ Conduct desk review of policies and strategies to protect lives during heat waves	■ Conduct a study of how daily all-cause mortality varies with heat stress ■ Identify heat stress thresholds associated with increased mortality and morbidity ■ Assess the impact of current and future heat stress for workers and school children	■ Consult vulnerable groups on how they receive climate and health information ■ Engage doctors to raise awareness of heat-related illnesses and prioritize response actions ■ Consult heat-exposed workers on their safety needs	■ Initiate the design and implementation of a heat wave early warning system ■ Identify response actions to accompany heat wave alerts in the health sector, in schools, and in heat-exposed workplaces ■ Plan public information actions with input from health professionals and affected groups

CROSS-CUTTING ACTIONS

1. Establish leadership: Designate a city official with accountability for delivering heat mitigation outcomes
2. Plan: Establish a multiyear plan with a vision, goals, and targets (integrate into existing strategies or develop a dedicated heat action plan)
3. Coordinate: Convene city departments to coordinate short-run actions (responsibilities during heat emergencies) and long-run actions (investments for a cooler city)
4. Communicate: Drive behavior change through communication ahead of each hot season

SOURCE: World Bank.

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NOTES

1 Medium- and long-term strategic planning for urban forestry is also important considering two global environmental threats. First, newly introduced pathogens and pests (for example, Dutch elm disease) have decimated tree populations in the past. Second, rising global temperatures are causing suitability zones for individual species to shift, year by year, in a poleward direction. Planning on a multidecade timeline can address these challenges by fostering tree stock genetic diversity and ensuring that newly planted trees are suitable for the future climate. For an overview of key issues in urban tree management, see Roloff (2016).

2 For further discussion of these issues, see chapter 4 ("Airflow") in Oke et al. (2017).

3 For information on both "hard" and "soft" policy interventions to promote cooler cities, see ESMAP (2020) and Ruefenacht and Acero (2017). Based respectively on global experience and Singapore's local experience, these reports each provide a typology of measures with discussion of their applicability and factors for successful implementation.

4 The World Meteorological Organization has published important guidance on heat-health early warning system development, including varieties of heat threshold definition and monitoring mechanisms (McGregor et al. 2015).

5 ÍCARO both translates to Icarus—who, in Greek mythology, perished by flying too close to the sun—and is an acronym for *Importância do Calor: Repercussão nos Óbitos ("Importance of Heat: Impact on Deaths").*

UNLIVABLE

Amid continuing urban growth and the accelerating effects of climate change, East Asian cities suffer from more extreme temperatures than surrounding rural areas—being up to 2 degrees Celsius hotter on average. This urban heat island (UHI) effect is caused by cities' relative lack of vegetation, the prevalence of impervious surfaces, construction of buildings in locations that block breezes, releases of heat from cars and machinery, and other features of the urban environment. In the decades ahead, the UHI effect will interact with climate change in ways that make cities even more prone to heat waves—already increasing in frequency and intensity—especially among East Asian cities in tropical zones and in low- and middle-income countries.

Extreme heat not only lowers the economic competitiveness and livability of cities in the region but also increases the risk of death and illness. Groups such as low-income residents, outdoor workers, and the region's growing elderly population are the most vulnerable to extreme heat. The poor are also more likely to bear the brunt of these harms: certain urban neighborhoods, particularly poorer ones, may be several degrees hotter than others within the same city.

Unlivable: What the Urban Heat Island Effect Means for East Asia's Cities uses satellite data, on-the-ground data collection, and a review of economic literature to shed new light on the magnitude of the UHI effect and its impacts on East Asian cities. Using a "Places, People, Institutions" framework, the report provides practical suggestions to help policy makers to rise to the extreme urban heat challenge. These actions—such as promoting urban greening, adopting heat-resilient urban design, and implementing heat wave early warning systems—can help to protect East Asia's urban residents from the impacts of extreme heat, contributing to cities that are more competitive, livable, and inclusive.

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