Two Degrees

The Built Environment and Our Changing Climate

Foreword by Amory Lovins

Alisdair McGregor, Cole Roberts, and Fiona Cousins

ROUTLEDGE

18

GUIDELINE CHAPTER

Designing for Hotter and Drier Climates

Cole Roberts

I met a traveller from an antique land
Who said: Two vast and trunkless legs of stone
Stand in the desert. Near them, on the sand,
Half sunk, a shattered visage lies, whose frown,
And wrinkled lip, and sneer of cold command,
Tell that its sculptor well those passions read
Which yet survive, stamped on these lifeless things,
The hand that mocked them and the heart that fed.
And on the pedestal these words appear:
"My name is Ozymandias, king of kings:
Look on my works, ye Mighty, and despair!"
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.

Percy Bysshe Shelley, "Ozymandias"

What majesty is the desert storm coming on a plain. Seen from afar, mountainous forms of gray frame the flat and dimensionless blue sky. Winds rush through the brittle grasses. The air is energized. Like a train barreling through town, the hard pounding of raindrops and hail strikes charge the ground. With it comes the smell of water, vegetation, wetted earth, and life. And then it's gone. Left behind, dappled pools evaporate in the resurgent Sun. Saline soil may leach into the pools, and as the water evaporates, a taste of salt lingers. It as though the land has wept swollen tears. It is then that you can sense the mournful nature of deserts. Explosively alive, tenuous, and thirsting.

Deserts are among the most inspiring environments of raw beauty in all the world. They attract recreation, art, tourism, and agriculture. They are a retirement destination for many, a harrowing passage for others. They are both fragile and dangerous.

To those of us who choose to live in the hot and dry climates of the world, life is one of extremes. Temperatures may swing 60°F (33°C) in 24 hours. A year of poor precipitation can mean water rationing and the threat of ravaging wildfires. Consecutive years (or decades) of poor precipitation can mean disaster. If welcome rains do come, they can fall so hard and fast that minutes later and miles away, amid bright sun and cloudless skies, dry riverbeds can flash flood and carry lives away.

Climate change will have great impact on the hot and dry climates of the world, partly because of the direct changes in climate and partly because of the indirect threats to culture and economy.

Many deserts of the world appear to be entering periods of extreme, prolonged drought, and yet the people and plants living in these regions have grown complacent during periods of relative wetness. During this time, population has been expanding. Will cities such as Phoenix, Arizona, see dramatic outflows of residents as the number of days of extreme heat increase, water becomes scarcer, and gasoline costs rise, or will technology and adaptation be sufficient bulwarks to maintain livability?

This chapter explores the climate change predictions, risks, and design guidelines for successful adaptation in hot and dry climates. It is intended to be read in conjunction with Chapter 16 and also to function independently as a ready reference for those living or working in hot and dry regions. Although not all of this chapter will be immediately relevant to all hot and dry regions, the content serves as a starting point for forming a suitable adaptation response. As you read, consider how your region compares, imagine the people you know choosing (or failing) to act, and imagine the plausible futures that are even now being shaped.

RISK ACCUMULATION

Hot and dry climates are characterized by a unique combination of risks (i.e., sequential hazards or concatenated threats).

High Temperatures, Water Scarcity, and Nonresilient Urban Form

The default response to high temperatures in dry climates is to consume more water (for drinking, irrigating, and evaporative air-conditioning). As temperatures rise, the increased demand for water further strains already threatened resources. The intensity of this threat is exacerbated by the remarkably poor development of many cities for passive cooling and water efficiency. Many desert cities have been built whole or significantly expanded within the past fifty years, during a period when modern design and planning paid little attention to water efficiency, solar lot orientation, and thermally massive construction. The result is that the resilient form of old cities

Complacency along the Colorado

The next time you take a sip of coffee in the morning, imagine you're drinking a bit of the 5.4-million-year-old muddy Colorado River. Your single sip would consume roughly 250,000 years of the river's history. To sip the last 100 years, you would be rationed to less than a tenth of a drop. Not even enough to wet your tongue. Yet, it is this less-than-a-tenth-of-a-drop that forms the basis for southwestern U.S. water law and the 1922 Colorado River Compact—the agreement that apportions the river's water to its various dependents. When signed in 1922, the estimate of river water flow was 16.4 million acre-feet (maf) per year. Since then, flow has varied by a factor of five, from about 5 maf (1977) to 25 maf (1984). Tree ring studies have shown that average flow over the past three centuries has been 13.5 maf and varies widely from 4.4 maf to over 22 maf. Most recently, the 2000–4 drought was the most severe multiyear drought on record, with an average annual flow of 9.6 maf over those five years. Since actual depletions (use plus evaporation) are now about 14 maf annually, and given that some states' apportionments are still not fully consumed, the river's flow is already overapportioned and those who depend on it are likely faced with reductions in Colorado River supply of up to 75 percent during periods of extreme extended drought!

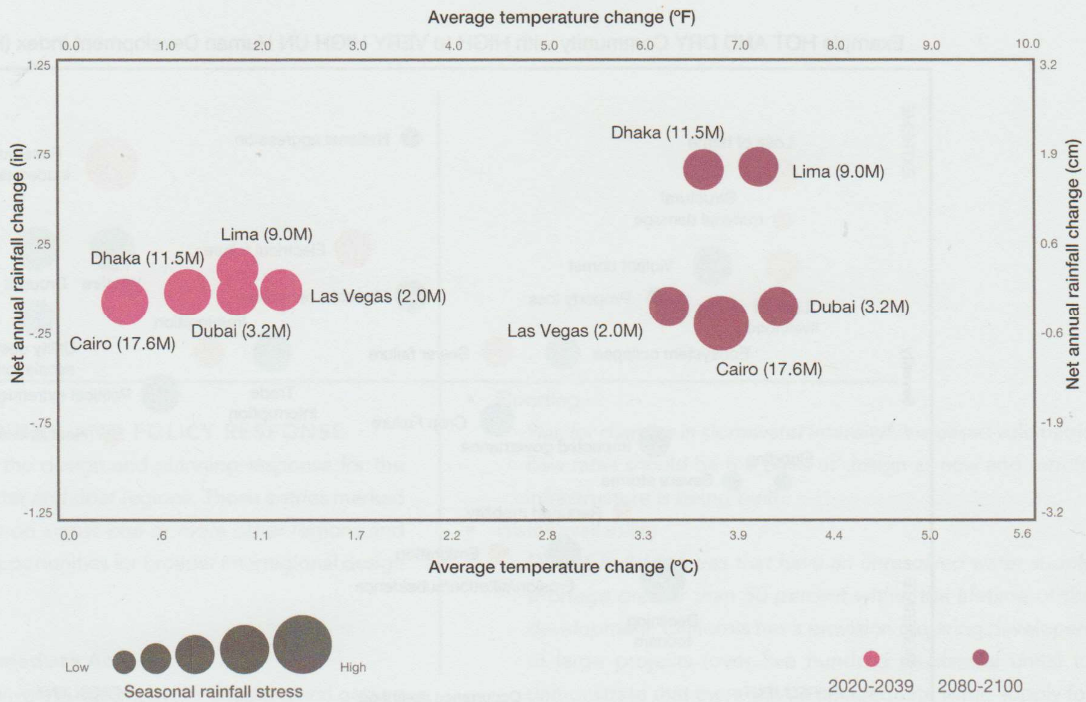
In 2007, a committee of scientists convened by the National Research Council published "Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability."[1] In the report, the committee highlighted the historical "normality" of severe droughts in the Colorado River basin. It went on to predict more severe droughts than the tree ring record due to "temperature trends and projections," referring to progressively warmer future climate in the basin, which would lead to reduced snowpacks, earlier snowmelt, greater evapotranspiration, and lower streamflows. The effects of this warming will be superimposed on the natural variability described by the tree ring data, worsening the impact of "normal" drought. In effect, creating a new "normal" of variable flow and extreme drought.

Between 2000 and 2006, the seven states of the Colorado basin added five million people, a 10 percent population increase. Without changes in current management practices, there is as much as a 50 percent chance of fully depleting all of the Colorado River reservoir storage by 2050, according to a scientific study coauthored by NOAA-funded scientists. And 2050 is as near as the 1970s are fresh in our memory—just four decades separate us. The buildings and infrastructure planned and constructed today will certainly be around to see it, as will many of us.

18.1 The Central Arizona Project is designed to bring about 1.5 million acre-feet of Colorado River water per year to Pima, Pinal, and Maricopa Counties
Image: Tim Roberts Photography/Shutterstock.com

2020 - 2100 Changes

(Rainfall and Temperature)



18.2 Changes in rainfall and temperature anticipated for five sample cities and their populations (in millions)
Graphic: Arup,
Data: World Bank Climate Change Knowledge Portal

is the exception rather than the rule. New city design has resulted in wide roads, dark (heat-absorbing) and impervious surfaces, and buildings poorly prepared for higher temperatures.

City Growth during the Age of the Automobile

The second combination of risks lies in the growth pattern of hot and dry cities—growth that has occurred during a period of low fuel costs and a cultural shift away from mass transit and dense urban form toward the automobile and sprawling development. As a result, hot and dry cities have a vulnerability to wildfires (due to proximity to combustible vegetation) and a uniquely high dependency on automobiles for transportation and access to necessities like food, health care, and employment. As fuel costs rise and public transit is hamstrung by low density, vulnerability will increase disproportionately among the elderly, young, pregnant, and disabled. Transportation will also take a greater proportion of the income of lower-income wage earners, including teachers, service staff, and the part-time employed.

Energy, Water, and/or Food Import Dependence

The third combination of risks originates from the dependency of hot and dry cities on imports of energy, water, and/or food for their economic life blood. A leading reason for the collapse of island civilizations of the past (including Greenland, Easter Island, and the Pitcairn Islands) was because they were cut off from their sources of trade. Similarly, desert cities often feel more like islands than oases. As energy, water, and food stress occur in trade partner cities, desert cities are expected to incur consequentially greater stresses.

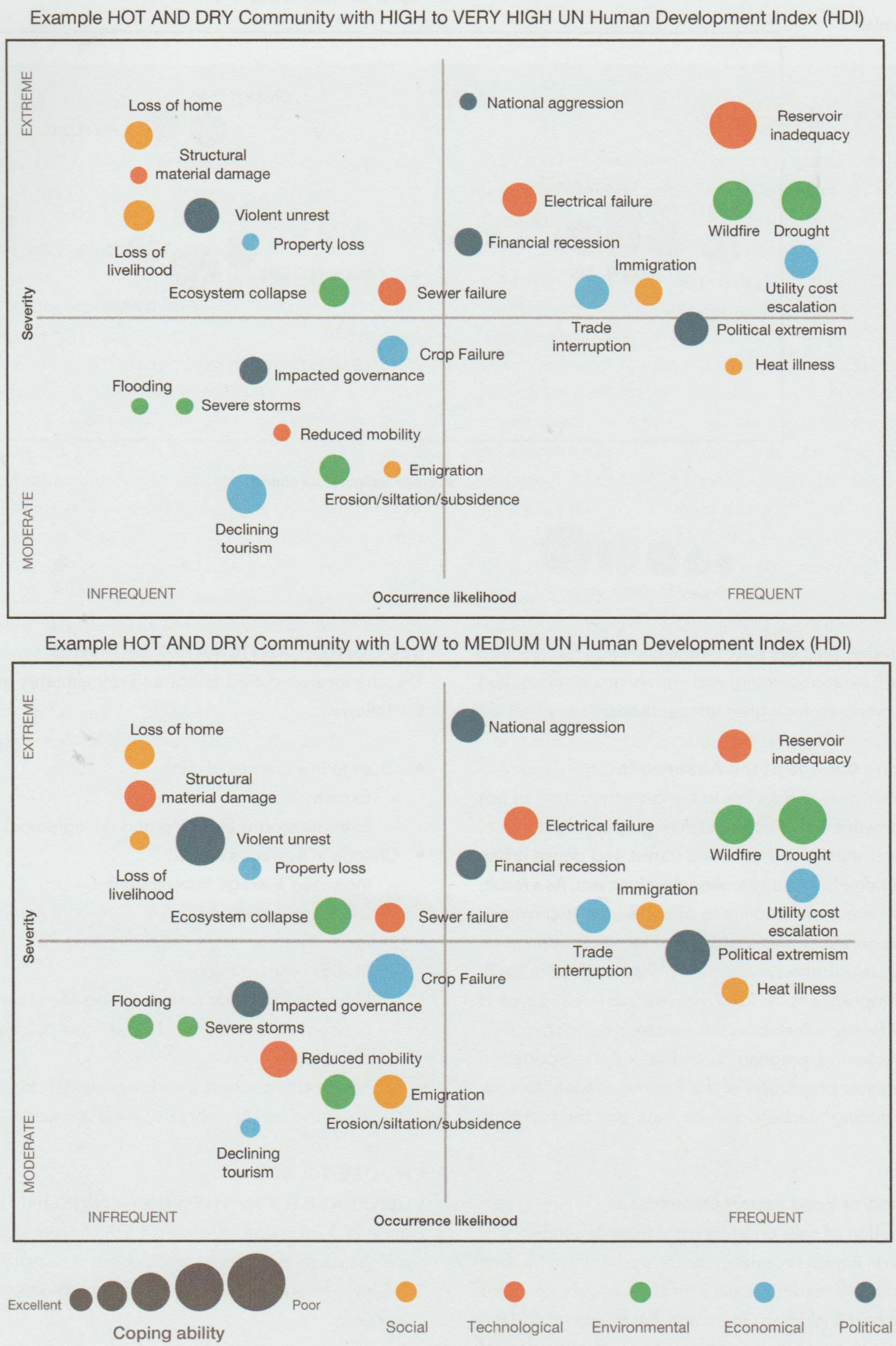
RECOGNIZE: ANTICIPATED CHANGES

The changes predicted in hot and dry climates generally include the following:

- Change in extremes (direct):
  - Extreme heat
  - Extreme storms (flooding and dry lightning)
- Change in averages (direct):
  - Increased average temperature
  - Decreased average rainfall
- Indirect changes:
  - Rising commodity prices
  - Enhanced evaporation and drying of soils and wetlands
  - Economic downturn and social and political stress due to risk accumulation
  - For locations reliant on snowpack melt for water resources, water availability may become less reliable.

CHOOSE TO ACT: VULNERABILITY IN THE BUILT ENVIRONMENT

Figure 18.3 (overleaf) illustrates a selection of potential risks and coping capacity for the built environment in hotter and drier regions. They have been plotted on a Vulnerability Map for an example community.



18.3 An example Vulnerability Map illustrating risk (the product of severity and likelihood) and coping capacity factors; the UN HDI has been used as a basis for coping ability—actual vulnerability will vary significantly within a community, and it is critical that assessments are of adequate rigor to account for such differences

Graphic: Arup

ACT SUCCESSFULLY: THE DESIGN, PLANNING, AND POLICY RESPONSE

Below is a summary of the design and planning response for the built environment in hotter and drier regions. Those entries marked by an asterisk are common across one or more other regions and may therefore provide opportunities for broader interregional design integration.

1. Build Capacity (Immediate Action)

Before anything is built, invest in making better decisions and getting more useful information.

- Educate and plan
  - *Climate adaptation plan** Prepare a draft plan that summarizes the risks, vulnerability, known information, and potential measures for adaptation in your region or regions. This can be a part of a broader climate change planning effort, or a separate process focused solely on adaptation.
  - *Climate adaptation training** Roll out programs to educate your community or organization on the implementation of the adaptation plan.
  - *Establish policy direction** Pilot, expand, and optimize policy to support a long-term process of improving adaptation.
- Decision making
  - *Value water in life-cycle analysis* Only air can compete with water for a form so highly prized but little valued. To ensure good decision making in hot and dry climates, it is an imperative that system choices consider direct and indirect water consumption impacts. Life-cycle cost analysis should include the value of water consumed by each alternative. Where water costs are artificially depressed in value due to the sunk investment of large infrastructure projects (as in Arizona) or politically stabilizing subsidized pricing (as in Saudi Arabia), a reasoned estimate of the true value and marginal cost of securing new supplies should be considered for inclusion in the analysis.

2. Select the Right Site (Immediate Action)

Once the decision to build has been made, the location selected for development should be suitable.

- Flooding
  - *Plan for changes in stormwater intensity** Increased volumetric flow rates should be the basis of design as new and retrofit infrastructure is being built.
- Water availability
  - *Do not build in areas that have an unresolved water supply shortage greater than 50 percent within the lifetime of the development* California has a provision requiring developers of large projects (over five hundred residential units) to demonstrate that there will be an adequate water supply for twenty years before a building permit is issued. (Note this measure does challenge the majority of new nonreplacement development in the world's hot and dry climates.)
- Fire danger
  - *Do not build in areas susceptible to wildfire* (Note this measure does challenge the majority of suburban/rural development in the world's hot and dry climates, especially those in forested subregions.)

3. Build In Passive Survivability (Immediate Action)

After the project has been sited, pursue opportunities that don't require active interventions to be successful.

- Planting and water features
  - *Water efficient (xeric) plantings should be instituted into law* This is not the "zero"-scape of rock lawns and bright concrete patios, but an attractive native and adapted landscape that is drought tolerant and biologically active, and promotes local cooling through shade and evapotranspiration.
- Sun and shade
  - *Build in passive cooling** Incorporate the multitude of measures that allow buildings to compensate for the climatic extremes. These measures may include proper east–west orientation, reflective roofing, thermally massive materials, reduced glazing areas (especially on west faces), exterior window shades, shaded arcades, and high-performance glazing.
  - *Heat island reduction** Through urban planning and building design, temper the formation of heat islands, which artificially

Adapting to Change Down Under

If you're looking for a good example of adaptation planning for climate change, take some time to review the initiatives of the Australian government. The Australian government's position paper, "Adapting to Climate Change in Australia,"[2] sets out the government's vision for adapting to the impacts of climate change and proposes practical steps to realize that vision.

It outlines the Australian government's role in adaptation, which includes building community resilience and establishing the right conditions for people to adapt, taking climate change into account in the management of Commonwealth assets and programs, providing sound scientific information, and leading national reform.

The Australian government is supporting activities and financially investing to improve knowledge and build adaptation capacity. Highlights include:

- A $31 million Australian Climate Change Science Program
- A National Framework for Climate Change Science to set climate change research priorities
- $387 million for the Marine and Climate Super Science Initiative
- A $126 million Climate Change Adaptation Program helping Australians to better understand and manage climate change risks
- A National Climate Change Adaptation Research Facility
- $12.9 billion to secure Australia's water supply, in the single largest investment in climate change adaptation
- Support of Australian farmers as they adapt to climate change, through Australia's Farming Futures program
- The Caring for our Coasts policy, helping coastal communities prepare for and adapt to the impacts of climate change, including a national coastal risk assessment
- A Coasts and Climate Change Council established in late 2009 to engage with communities and stakeholders and to advise the government on key issues.

18.4 Australia is among the first governments to address the adaptation response to climate change at a national level
Image: Ian Woolcock/Shutterstock.com

raise the urban temperature. Shade hardscapes through building form and selective use of low water use trees. Select materials with a heightened reflectivity (albedo) and emissivity (ability to reemit captured heat). Focus heat island reduction efforts at the urban scale using vulnerability mapping, a process that highlights the locations of vulnerable populations.

- Rainwater and greywater
  - *Capture rainwater* Although not allowed in all regions, the local capture and use of rainwater in urban environments can be an excellent solution to both extend the available water for use and reduce the intensity of its flow in local stormwater networks.

4. Design Active Resilient Systems (25+ years)

Our built environment can't be entirely passive. Once the passive opportunities have been exploited, design in climate appropriate, low resource intensity systems that can withstand partial or complete disruptions.

- Building air-conditioning
  - *Consider compressor-based nonevaporative cooling* The energy efficiency advantage of evaporative systems when compared to air-cooled compressors is not as great as it once was. High efficiency compressor technology has advanced to close the gap.
  - *Select systems that have capacity to function in mixed modes (aka hybrid systems)** Such systems can more readily operate in a variety of modes, ranging from "off," to "on with natural ventilation," to "on with air-conditioned supply." They do not require the relatively cold air (55°F [13°C]) and water (44°F [7°C]) typical of most air-conditioning systems, thus dampening the severity of system disruptions due to compromised power or water supply. Examples include radiant cooling systems, underfloor air systems, and displacement air systems.
  - *Leverage low nighttime temperatures** The 30°F+ (17°C+) day-to-night temperature variation is uniquely appropriate for thermal energy storage strategies (ice, chilled water, or condenser water).
  - *Wet/dry cooling towers* Where evaporative cooling towers are put to use, they should be hybrid towers capable of running the majority of the time in a dry "fluid cooler" mode and only occasionally in "wet" evaporative mode for extreme conditions. The water savings of these towers can exceed 95 percent of a conventional cooling tower.
  - *Adopt future design conditions (corrected design day)** All systems should be specified in accordance with corrected climatic conditions appropriate to their system life (e.g., twenty-five years into the future for many heating, ventilation, and air-conditioning systems). The result may be slight increases to system size and shortened hours of natural ventilation modes during a typical year. Since many designers oversize systems already, a practice that can actually reduce performance, it is important that the system is right-sized for the future conditions, not simply further oversized.
- Building plumbing
  - *Design water-efficient systems* Flow rates on fixtures should be no greater than 1.5 gallons per minute.[3] Flush rates on toilets and urinals should be no greater than 1.28 and 0.125 gallons per flush, respectively. Hot water latency should be less than three seconds (achievable through a variety of measures), and where possible foot-operated faucets should be installed to free up hands during washing.
  - *Reuse greywater* To use water only once and send it down the drain is a profligate waste of opportunity. So unless there is a regional water balance initiative (as there is in Las Vegas, Nevada), which requires return water flows to the local water treatment plant, passive greywater redirection to local landscape can be a valuable strategy.
  - *Plan for local batch storage* Study cities like Delhi where water supply stress is acute and you'll see residences and office towers with on-site water storage. Given the limited hours that the municipal water supply service is turned on (in Delhi, one hour of flow twice a day), the small tanks (typically around five hundred gallons per household) serve to provide water for the hours when the municipal service is not flowing. They also provide a valuable emergency water source in the event of a disaster that may affect the municipal service for three or more days.

- Build to lessen wildfire danger
  - *Gutters* Eliminate gutters or design to minimize risk.
  - *Vented roofs* Avoid vented roofs or protect vents from ember entry.
  - *Specify low-combustible building materials* Class A roofing, with noncombustible decking and siding.
  - *Manage planting* Through distancing, plant selection, and other strategies lessen the impacts of planting on fire exposure.
- Create resilient infrastructure systems (create smart/resilient electrical and water networks that can suffer failures without ensuing cascading failures)
  - *Demand response** By shedding noncritical demands (electrical and water), the priority demands for life safety, economy, and environmental resilience can continue to be supplied in whole or in part.
  - *Diversify supply** Develop multiple supply sources (electrical and water), including the alternative supply "sources" of efficiency and closed-loop recovery, a failure in one supply can be compensated by another source.
  - *Informatics (making invisible information visible and visible information actionable)** By leveraging information technology and behavioral psychology, consumers and decision makers will have the opportunity to more effectively make decisions that enhance efficiency and cope with adversity.
- Plan resilient urban forms
  - *Establish, expand, and optimize diverse modes of transportation in concert with transit-oriented development** Diverse transportation modes supported by appropriate urban density create improved access to critical community services in the event of failures. They also support vulnerable populations, and encourage physical fitness. All of this can help minimize heat illness risks due to climate change while simultaneously improving general health, culture, and economic strength in our communities.
  - *Create urban vegetated space and community centers** These spaces provide alternatives for vulnerable populations facing heat illness threats. Air-conditioning in all climates and shade in dry climates in particular are among the best measures for reducing human mortality due to extreme heat.

5. Encourage Adaptable Buildings and Infrastructure (2+ to 200+ years)

Whatever decisions are made should be reasonably adaptable.

- *Design for how buildings learn**[4] By recognizing adaptability in layers, there is greater potential for building and infrastructure retrofits to be both lower cost and more effective. Where layers are crossed (e.g., embedded hydronic tubing in concrete structure), it is important that the lifespan of the layers is equal and/or that a retrofit strategy for the system with the shorter lifespan is anticipated.
- *Retrofit (i.e., teach) existing building stock** As our buildings age, capital reinvestment initiatives are an opportunity not only to beautify but to help the buildings better serve their occupants and owners. Examples include window retrofits, cool roofing, and air-cooled compressor-based air-conditioning.
- *Retrofit (i.e., teach) existing urban open space** To improve stormwater management and lessen urban heat islands, the street network should be gradually renewed with drought tolerant planting, cool materials, and pedestrian shade structures. Opportunities for stormwater capture and reuse should be explored.

6. Manage Settlement and Retreat (50+ years)

We only need to look back to the North American "dust bowl" of the 1930s to imagine what resettlement can look like. A false complacency stemming from a period of relative wetness had given rise to a belief that "rain follows the plow." When severe drought struck in 1933, the land blew away and economies collapsed. Within six years, 2.5 million Americans had relocated from nine U.S. states. On the other side of the globe and 60 years later, China has lost 2.6 million square kilometers to desertification since 1950 and faces accelerating desertification rates (currently at an additional 3,000 square kilometers per year). It is estimated that some 24,000 villages, 1,400 kilometers of rail lines, 30,000 kilometers of highways, and 50,000 kilometers of canals and waterways are subject to constant threat of desertification in China alone.[5]

Although land management and water use practices continue to improve, desertification and water availability are threats to limitless growth. Adaptation plans in hot and dry climates therefore need to make a reasonable effort to estimate their "right size" given available resources and scenario planning.

- *Managed settlement** As the carrying capacity of a region is approached, a variety of strategies may be used to manage growth while maintaining a strong economy. They include urban growth boundaries, development impact fees, and permit restrictions.
- *Passive retreat** As stresses increase, some resettlement will occur through market mechanisms. Commodity costs will increase. Water rights will be bought out by those willing to pay for them. This is likely to affect large water users (e.g., agriculture, golf courses, industrial users) most.
- *Active retreat** It is hard to judge if active retreat will be needed as in coastal regions. Presently, the authors assume that the question should continue to be posed even if the answer is yet unknown.

NOTES

1 Committee on the Scientific Bases of Colorado River Basin Water Management, National Research Council, Washington, DC: The National Academies Press, 2007.

2 Department of Climate Change, "Adapting to Climate Change in Australia: An Australian Government Position Paper," Canberra: Department of Climate Change, 2010; see also http://climatechange.gov.au/government/adapt.aspx.

3 Even at 1.5 gallons per minute, a typical shower will consume 15 gallons of water. In many modern global households (in e.g., Delhi, India or Kyoto, Japan), middle-class citizens wash with less than three gallons of water by using hot water containers and ladles. It helps if the bathing room is warm.

4 Stewart Brand, *How Buildings Learn: What Happens After They're Built*, New York: Penguin Books, 1995.

5 Dry lands occupy 43 percent of the world's land surface and are home to about 1 billion people. The science and case studies of desertification in North America, Australia, China, and Asia are presented in the United Nations report Y. Youlin, V. Squires, and L. Qi, *Global Alarm: Dust and Sandstorms from the World's Drylands*, Bonn: UNCCD, 2001.

"We have our challenge laid out—*Two Degrees* provides a well-structured guide in which anyone who designs or builds in the built environment can find lasting value."
—Ed Mazria, founder and CEO, Architecture 2030

"A beautiful book, logically and accessibly laid out. I value its positive approach and rational sequencing for responding to threats that feel overwhelming. But 'no decision' is a decision, and inaction oftentimes, but not always, does more harm than good; the case demands a thoughtful action plan. *Two Degrees* disentangles the threats and, in this doctor's mind, offers a 'treatment' plan that can save lives, environments, and resources."
—Richard J. Jackson MD, *Designing Healthy Communities*, former director of the Centers for Disease Control and Prevention's National Center for Environmental Health in Atlanta and former California Department of Public Health officer

"[*Two Degrees*] is a world-class book. There is a waterfall of ideas... Thoughtful. Clear. *Two Degrees* emerges from some of the best minds in sustainable practice. Enjoy!"
—Jim Cramer, Design Futures Council; chairman and principal, Greenway Group

"A truly unique approach to meeting the challenge of solving the complexity of global-scale climate change on a human scale, using practical, profitable, and sustainable approaches to developing buildings."
—Jeffrey R. Koseff, Perry L. McCarty Director of the Stanford Woods Institute for the Environment

"*Two Degrees* connects good science, professional practice, and people, with a dash of passion and optimism. A timely and important contribution, and an enjoyable book, well worth reading and sharing."
—Steve Selkowitz, Lawrence Berkeley National Laboratory, Building Technology & Urban Systems

The Earth's temperature has been rising. To limit catastrophic outcomes, the international scientific community has set a challenging goal of no more than 2 degrees Celsius (3.6 degrees Fahrenheit) average temperature rise. Economists agree we will save trillions of dollars by acting early. But how do we act successfully? And what's the backup plan if we fall short?

Setting politics aside, *Two Degrees* reviews the current science and explains how we can set practical steps to reduce the extent of warming and to adapt to the inevitable changes, all while improving the bottom line, beautifying our communities, and improving human health. The book is a practical guide intended for a broad audience of those who occupy and shape our built environment. The authors provide a clear framework for communities, policy makers, planners, designers, developers, builders, and operators to help manage the impacts and capture the opportunities of our changing climate.

Two Degrees is divided into three sections—Fundamentals, Mitigation, and Adaptation—covering a diverse array of topics ranging from climate-positive communities and low-carbon buildings to the psychology of choice and the cost of a low-carbon economy. After a foreword by Amory Lovins, more than 10 contributing authors share knowledge based on direct experience in all aspects of built environment practice. This book clarifies the misconceptions, provides new and unique insights, and shows how a better approach to the built environment can increase resilience and positively shape our future.

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