

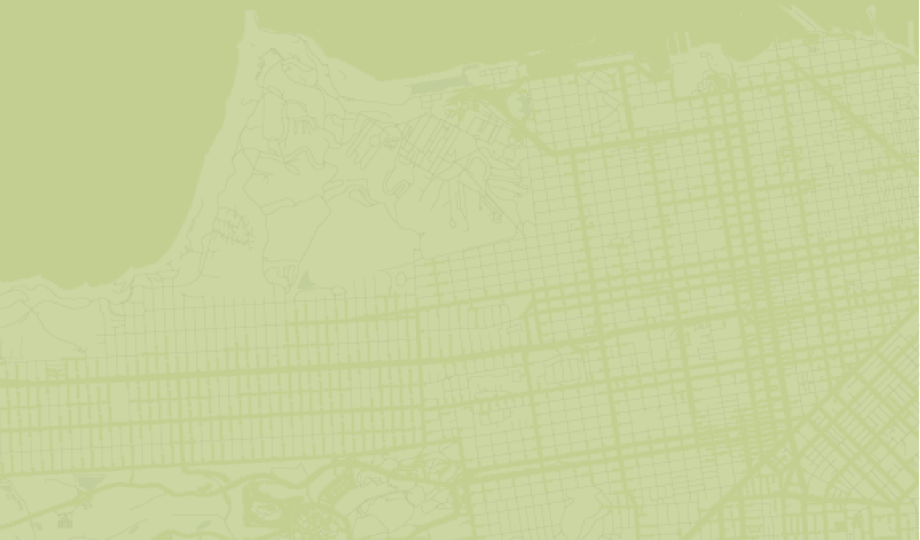
GREEN BUILDING AND CLIMATE RESILIENCE

Understanding impacts and preparing for changing conditions

University of Michigan
Larissa Larsen, Nicholas Rajkovich, Clair Leighton, Kevin McCoy, Koben Calhoun, Evan Mallen, Kevin Bush, Jared Enriquez

U.S. Green Building Council
Chris Pyke, Sean McMahon

With support from
Alison G. Kwok, University of Oregon



Taubman College of Architecture and Urban Planning, University of Michigan

U.S. Green Building Council

Suggested Citation

Larsen, L., Rajkovich, N., Leighton, C., McCoy, K., Calhoun, K., Mallen, E., Bush, K., Enriquez, J., Pyke, C., McMahon, S., and Kwok, A. *Green Building and Climate Resilience: Understanding Impacts and Preparing for Changing Conditions*. University of Michigan; U.S. Green Building Council, 2011.

Copyright

Disclaimer

None of the parties involved in the funding or creation of this document, including the University of Michigan, the U.S. Green Building Council (USGBC), its members, volunteers, or contractors, assume any liability or responsibility to the user or any third parties for the accuracy, completeness, or use of or reliance on any information contained in this document, or for any injuries, losses, or damages (including, without limitation, equitable relief) arising from such use or reliance. Although the information contained in this document is believed to be reliable and accurate, all materials set forth within are provided without warranties of any kind, either express or implied, including but not limited to warranties of the accuracy or completeness of information or the suitability of the information for any particular purpose.

As a condition of use, the user covenants not to sue and agrees to waive and release the U.S. Green Building Council, the University of Michigan, its members, volunteers, and contractors from any and all claims, demands, and causes of action for any injuries, losses, or damages (including, without limitation, equitable relief) that the user may now or hereafter have a right to assert against such parties as a result of the use of, or reliance on, this document.

Trademark

Contacts

Chris Pyke, Vice President of Research U.S. Green Building Council
2101 L Street, NW
Suite 500
Washington, DC 20037 Email: cpyke@usgbc.org

Larissa Larsen, Associate Professor
Urban and Regional Planning Program
A. Alfred Taubman College of Architecture and Urban Planning University of Michigan
2000 Bonisteel Boulevard
Ann Arbor, MI 48109
Email: larissal@umich.edu

Photo Credits

Left to Right:

Osbornb, “Green Roof” November 27th, 2009
via Flickr, Creative Commons License

Green Garage Detroit
A business enterprise, and a community of
people dedicated to Detroit’s sustainable future.
Peggy Brennan
Greengaragedetroit.com

Thomas Le Ngo, “P100808” July 27th 2006
via Flickr, Creative Commons License

Table of Contents

Appendices (Separate Document)

Acronyms and Abbreviations

CCAP	Center for Clean Air Policy
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2 / CO_2e	Carbon Dioxide / Carbon Dioxide Equivalent
EPA	U.S. Environmental Protection Agency
Gt	Gigaton (one billion tons)
HVAC	Heating, Ventilation and Air-Conditioning
ICLEI	ICLEI-Local Governments for Sustainability (formerly the International Council for Local Environmental Initiatives)
IEQ	Indoor Environmental Quality
IPCC	Intergovernmental Panel on Climate Change
kW/ kWh	Kilowatt / Kilowatt Hour
LEED	Leadership in Energy and Environmental Design Program
N_2O	Nitrous Oxide
NOAA	National Oceanic and Atmospheric Administration
ppm / ppb	Parts per million / Parts per billion
TMY	Typical Meteorological Year
USCCSP	U.S. Climate Change Science Program
USGBC	U.S. Green Building Council
USGCRP	U.S. Global Change Research Program

Preface

The majority of efforts to address climate change through green building are focused on reducing greenhouse gas emissions. This is reflected in the current U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) rating system, which allocates over 25 percent of available points for reducing greenhouse gas emissions associated with building systems, transportation, water, waste, and construction materials (U.S. Green Building Council, 2008). By definition, greenhouse gas emission reductions are climate change mitigation. Green buildings should include both mitigation and adaptation strategies if we hope to shape the built environment in a way that is both responsive and resilient to future climate extremes.

While LEED does not require climate change adaptation strategies to achieve certification, this report summarizes current technical and scientific data on the impacts of climate change on the built environment in an effort to support the work of building professionals in this emerging area of concern and to inform the selection of strategies and approaches. Within this document, we identify climate-related vulnerabilities at the regional level and prioritize design, construction, and operation strategies that will increase resilience and facilitate climate adaptation.

The mission of the USGBC is to enable an environmentally and socially responsible, healthy, and prosperous environment that improves quality of life. Following the formation of the USGBC in 1993, the organization's members quickly realized that the sustainable building industry needed a transparent system to define and measure "green buildings." The LEED rating system provides a third-party certification of buildings and neighborhoods designed to improve performance in energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, stewardship of resources and sensitivity to environmental impacts.

The LEED rating system has been modified over time in order to continue the advancement of green building performance. The most recent version, LEED Version 3.0, was launched in 2009 and provided a significant update to the LEED program. This report on climate adaptation strategies and other documents such as the Core Concepts Guide continue to advance green building practice and provide USGBC members with timely and accurate information.

1. Executive Summary

The USGBC has been active in addressing climate change since the early days of LEED. These efforts have focused on guiding green building professionals toward reducing the greenhouse gas emissions of a project, thus mitigating the contribution of the project to global climate change. However, world climate change experts such as the Intergovernmental Panel on Climate Change (IPCC), the U.S. Global Change Research Program (USGCRP), and the U.S. Environmental Protection Agency (EPA) have indicated that the world will almost certainly experience some degree of climate change no matter how quickly greenhouse gas emissions are reduced. This makes climate adaptation necessary. Because climate change is related to human behaviors, uncertainty remains around the degree of change and types of impact. The points of uncertainty are described in Appendix A: Key Terms.

As green building professionals, we need to understand the probable impacts of climate change on the built environment and to incorporate appropriate adaptation strategies into our practices so that the environments we design, build, and manage today will be suitable for a range of uncertain futures. While climate has always been integrated into the building professions, our codes, standards, and practices typically assume that the future will be similar to the past. Climate change requires that we update these codes, standards, and practices with the best available knowledge. Planning to adapt to the effects of climate change in the built environment involves first understanding how the regional climate is likely to change. Projections of change, by U.S. region, are included in Appendix B: Regional Climate Change Impacts. By understanding the probable impacts, design teams can set modified performance goals, diving deeper into project-specific changes at the building or neighborhood level, and then select strategies to increase the resilience and adaptive capacity of each project.

The body of this report summarizes the most recent research on the likely impacts of climate change at various scales: regional, neighborhood, and site or building. We report predicted climate changes by region, and wherever possible we present a range of predicted future characteristics in the categories of temperature, precipitation, coastlines, air quality, pests, and fires. We also explore how climate change mitigation and adaptation efforts at all scales interact synergistically, with a focus on how green building professionals can approach adaptation in the built environment.

Appendix C contains a set of specific strategies that can be used to enhance resilience and provide adaptive benefits. The strategies are divided into six categories: 1) envelope, 2) siting and landscape, 3) heating, cooling, and lighting, 4) water and waste, 5) equipment, and 6) process and operation. Several of the strategies presented are “no-regrets” strategies. A no-regrets strategy will generate social and/or economic benefits whether or not climate change occurs. A "resilient" strategy will allow a system to absorb disturbances such as increased precipitation or flooding while maintaining its structure and function.

To our knowledge, this report represents one of the first attempts to compile all research on the impacts of climate change on the built environment, and to link impacts with strategies for addressing them. The information and strategies presented here provide a solid baseline from which green building professionals can begin to address climate change adaptation in their projects. However, there is a great need for further research. Not all U.S. regions have received significant attention from climate change researchers. To date, the research has focused disproportionately on the heavily populated coastal areas. Of even greater concern is the significant lack of work focused on connecting climate research with practice. While this report represents a first step towards bridging this gap, building professionals will need significant future guidance to address the sizable climate change challenge. This report concludes with an analysis of current research needs and suggests resources to develop to bridge the research-practice divide.

2. Introduction

A changing climate presents a challenge to the planners and designers of the built environment. Building professionals will need to incorporate strategies that consider future climate change within their region. This contrasts with the current practice of basing building and neighborhood design decisions on historic climate data.

While ICLEI-Local Governments for Sustainability (ICLEI) encourages cities to plan for the effects of climate change by creating a comprehensive climate adaptation plan, building professionals need their own framework and tools for incorporating climate adaptation strategies in their projects. This section of the report describes climate adaptation planning, the primary ways that climate currently influences building and neighborhood design at a variety of scales, and the steps for incorporating climate adaptation strategies into a project.

The Challenge of a Changing Climate

The IPCC and the EPA report that some degree of climate change will occur regardless of whether we begin to significantly reduce our greenhouse gas emissions. The effect of climate change on neighborhoods and buildings will depend on the sensitivity and adaptability of these systems (US EPA 2011). Adaptation is defined as the adjustment of our built environment, infrastructure, and social systems in response to actual or expected climatic events or their effects. Adaptation includes responses to reduce harm or to capture benefits (IPCC 2007) as well as resilience, the ability of a system to absorb a climatic event without failing or changing state.

Until now, green building practice has focused primarily on lessening the built environment’s contribution to climate change through the reduction of greenhouse gas emissions. This is still a critical role for green building, as residential and commercial buildings contribute approximately 37% of the total greenhouse gas emissions in the United States (U.S. Energy Information Administration 2009). The next step is to understand the impact of climate change on the built environment and to incorporate appropriate adaptation strategies into green building practice so that the environments we design, build, and manage today will be suitable for a range of uncertain futures.

Emissions trends help us to understand why the climate is changing, but it is difficult to predict the long-term climate impacts of greenhouse gas emissions. Making exact predictions of how global average temperatures will change over time is complicated by factors such as population growth, economic growth, technological development, and energy efficiency improvements (Nakicenovic et al. 2000). These four factors result from human behaviors and policies and complicate any series of calculations.

For green building professionals, an integral part of adapting to climate change is the continued effort to reduce greenhouse gas emissions from the built environment while increasing adaptation strategies. Mitigation and adaptation strategies should not be seen as an "either/or" proposition. For example, renewable energy strategies will both reduce a building’s dependency on the electrical grid and reduce carbon emissions and potentially make the building more resilient to power outages. Therefore, green building strategies can often reduce greenhouse gas emissions while building resilience to the effects of climate change by enabling future adaptation.

The Role of Climate in Building and Neighborhood Design

Climate data is used to inform a number of different decisions in the design, construction, and operation of the built environment. These decisions include the selection of systems for heating, ventilation and air conditioning (HVAC), tree and plant species for landscaping, and appropriate building materials. Currently, climate-related decisions are based on historic climate data and past trends, with the inherent assumption that the climate will remain relatively stable in the future. Table 1 summarizes some of the ways climate data informs design decisions. Today’s building professionals should consider climate projections in conjunction with historic trends and current conditions as they make design, construction, operations and maintenance decisions.

Table 1: Examples of How Climate Data Informs Decisions in the Built Environment

System	Climate Considerations	Implications
HVAC & Building Energy Simulations	The size of a heating and cooling system (and its associated energy use) is estimated using typical meteorological year (TMY) data. TMY data provides various annual climate averages based on past weather data.	Designing HVAC systems based on historic weather data will make building systems vulnerable to future changes in climate. Building energy use will increase if climate extremes become the norm. Occupants may also experience thermal discomfort.
Transportation Infrastructure	Pavement design and engineering are affected by temperature, precipitation, freezing and thawing, and solar radiation.	Climate change, including changes in temperature and precipitation trends, may reduce the life expectancy of pavement that is designed based on past climate data.
Stormwater Management	Stormwater management systems, including retention and detention ponds, are sized using past precipitation data and current definitions of 50- or 100-year storm events.	Heavy precipitation events and storms may overwhelm stormwater management systems more frequently in the future. Major storm events may cause serious flooding if stormwater systems are not designed to handle greater quantity and intensity of precipitation.
Landscape Design	Landscapes are designed with current precipitation patterns, temperature patterns, and plant hardiness zones in mind.	Climate change, including changes in precipitation and temperature patterns, will affect landscape design, including native plants. Climate change will also shift plant hardiness zones northward, affecting plant selection.

This report provides information and resources for addressing climate change impacts in the built environment. Appendix B summarizes projected regional climate impacts and illustrates anticipated effects of climate change in nine geographical regions of the United States. Once climate change impacts are understood, a project team can evaluate the range of possible adaptation strategies to increase its system's resilience and capacity to adapt to climate change. The following sections of this report outline the steps for different scales and stages of planning and design.

Climate Adaptation Planning at the City Level

Many cities are engaging in comprehensive climate adaptation planning. These cities range in size and geographic location from small cities threatened by sea level rise in Alaska to larger cities with vulnerable, aging infrastructure such as Boston, Massachusetts. In 2010, ICLEI introduced a process for climate adaptation planning, similar to its process for climate change mitigation (ICLEI 2011). The five milestones of ICLEI's climate adaptation planning process, listed below, illustrate the broad scope and comprehensive nature of city climate adaptation plans. It is useful to note that the more specific adaptation strategies contained within this publication complement these broader action steps and may help local governments achieve their goals.

The five milestones below are part of ICLEI's Climate Resilient Communities program (ICLEI-USA 2011):

1. Conduct a climate resiliency study
2. Set preparedness goals
3. Develop a climate preparedness plan
4. Publish and implement the climate preparedness plan
5. Monitor and reevaluate resiliency

While different in scale from climate adaptation planning at the project level, a city-level plan is an important resource for understanding local impacts and identifying city-wide priorities for increased resiliency. For example, if a city's combined sewer and stormwater system is already overloaded and climate change impacts include increased precipitation, onsite stormwater management should be considered to increase a project's resiliency to storm events.

Primary Resources—Adaptation and Resilience

1. ICLEI – Local Governments for Sustainability provides technical and policy assistance, software training, climate expertise, information services, and peer networking to help members build capacity, share knowledge and implement sustainable development and climate protection at the local level. As part of their climate change guidance, ICLEI issued a document entitled "Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments" in 2007. The document can be downloaded from the Climate Impacts Group website at the University of Washington: http://cses.washington.edu
2. The ICLEI-USA Climate Resilient Communities program provides adaptation resources for local governments. More information and case studies can be found at http://www.icleiusa.org/
3. In a document that provides guidance for Canadian municipalities, ICLEI prepared guidelines and worksheets helpful for conducting an adaptation process. The ICLEI Canada are available from http://www.iclei.org/index.php?id=8708.

Incorporating Climate Adaptation into New Buildings and Neighborhoods

Green building professionals can integrate climate adaptation strategies into a project by using the following four-step process. The existing LEED Rating System and the LEED Reference Guides complement this process by identifying greenhouse gas mitigation strategies. Professionals aware of the predicted climate change impacts for their project's region can set performance goals for the future climate. For example, a project in a region expected to experience more intense rain events might set a goal of managing all stormwater runoff onsite. The team would then analyze predicted changes in precipitation for the region under multiple scenarios and select strategies that would achieve the goal throughout the design life and under multiple precipitation scenarios.

1. <u>Understand regional impacts:</u> Identify climate impacts for the project's region.
2. <u>Modify performance goals:</u> Incorporate possible impacts into performance goals for the building or neighborhood.
3. <u>Determine the range of effects on the local built environment:</u> Refine regional impacts to a smaller scale; anticipate how climate changes are likely to manifest in the local environment; present design team with a range of possible scenarios.
4. <u>Select a combination of no-regrets and resilient adaptation strategies:</u> Choose strategies that enable the project to achieve and maintain performance goals, under all possible futures, for the expected life of the project.

Incorporating Climate Adaptation into Existing Buildings

Green building and climate adaptation strategies must be applied to existing buildings as well as new building projects. Borrowing from the ICLEI process, the steps below describe how a project team can integrate adaptation strategies to existing buildings and sites.

1. <u>Understand regional impacts:</u> Identify climate impacts for the building's region.
2. <u>Evaluate current operation and maintenance targets</u>*:* Understand how the maintenance and operations perform under current peak climate conditions.
3. <u>Conduct a scenario analysis:</u> Analyze how the building will respond to projected climate impacts, modeling different system options under a variety of climatic conditions.

4. Implement adaptation strategies: Install adaptation strategies that provide passive or efficient responses to more extreme climate events in order to maintain occupant comfort while preventing increased energy use.

Additional Resources

1. The Center for Clean Air Policy (CCAP) helps policymakers around the world to develop, promote and implement innovative, market-based solutions to major climate, air quality and energy problems that balance both environmental and economic interests. As part of its climate change guidance, CCAP issued a document entitled "Ask the Climate Question: Adapting to Climate Change Impacts in Urban Regions" in 2009 (A. Lowe, Foster, and Winkelman 2009). The document can be downloaded from the CCAP website at http://www.ccap.org/docs/resources/674/Urban_Climate_Adaptation-FINAL_CCAP 6-9-09.pdf.

3. Understanding Climate Change: Global, Regional, and Local Impacts

The global climate is changing and the early effects have already been observed (USGCRP 2009). Key reports from the IPCC, the USGCRP, and the National Oceanic and Atmospheric Administration (NOAA) analyze the forces behind climate change and predict the future climate we are likely to face. Understanding these drivers is the first step toward understanding what a change in climate means for green building professionals operating at the city, neighborhood, and building levels.

This section of the report provides a broad overview of the science of climate change and describes the impacts expected at the regional, neighborhood, and building scales. Appendix A complements this section by defining key terms used in the literature. Appendix B lists specific impacts for each region of the United States, and outlines related impacts on the built environment.

Greenhouse Gases

The accumulation of greenhouse gases in the atmosphere is driving the increase in global temperature and other climatic changes. There are both natural and anthropogenic sources of greenhouse gases. Transportation, commercial and residential building, and industrial sources all contribute significant amounts of greenhouse gases. In the U.S. they contribute 36%, 37%, and 28%, respectively (U.S. Energy Information Administration 2009). These heat-trapping gases include carbon dioxide, methane, nitrous oxide, tropospheric ozone, chlorofluorocarbons (CFCs), water vapor, and aerosols (Forster et al. 2007). A low level of radiated heat from greenhouse gases is a natural phenomenon. However, since the industrial revolution, which began in the mid-1700s, concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere have increased significantly and caused an increase in global average temperature (USGCRP, 2009). Today, atmospheric concentrations of these three gases are higher than at any time in recorded human history and are increasing at exponential rates, as illustrated in Figure 1.

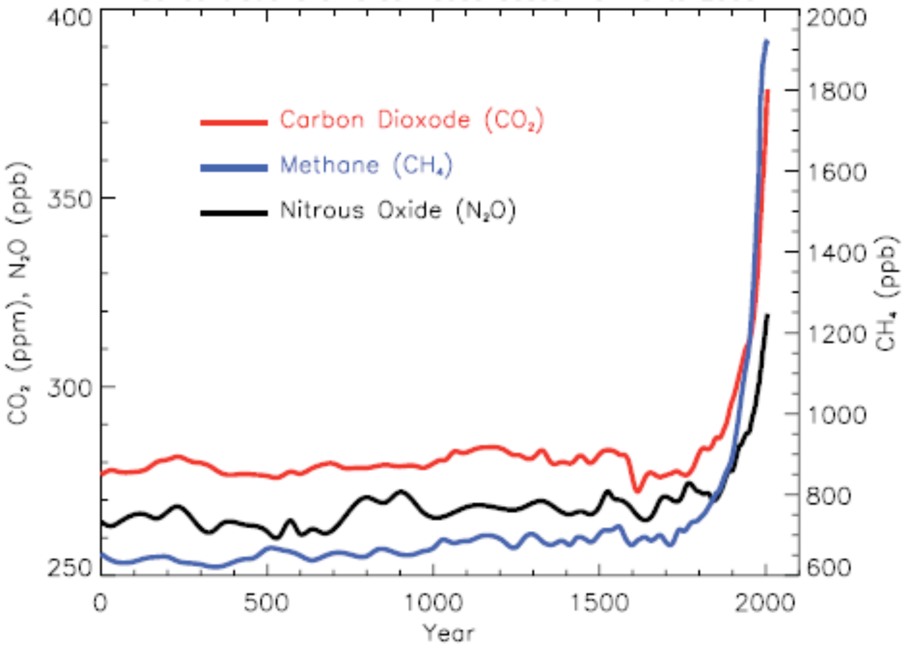


Figure 1: Concentrations of Atmospheric Greenhouse Gases over the Last 2000 Years (Source: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-2-1-figure-1.html)

Of these gases, CO_2 is the greatest total contributor to warmer temperatures because of its high concentration in the atmosphere, strong radiative forcing (restriction of outgoing infrared radiation), and long life span (Forster et al. 2007). Atmospheric concentrations of CO_2 are believed to have remained between 200 and 300 parts per million (ppm) for 800,000 years, but then rapidly increased to approximately 387 ppm in recent years (The World Bank 2010). CO_2 levels have increased by 35 percent since the start of the industrial revolution (USGCRP 2009), and concentrations continue to increase at an accelerated rate in the atmosphere (The World Bank, 2010), where CO_2 persists for up to 200 years (Snover et al. 2007).

The atmospheric concentration of CO_2 is affected by the natural cycle of release and uptake. Oceans, vegetation, and soil can absorb CO_2. However, this “carbon sequestration” is only temporary, and these “sinks” may lose capacity as the climate continues to warm. For example, thawing permafrost will likely release CO_2 that has been tored for thousands of years, potentially initiating a feedback loop in which more carbon is released to the atmosphere (USGCRP 2009).

There is a growing consensus in global policy and scientific circles that stabilizing emissions at a level associated with a 2ºC (3.6ºF) average warming is required to prevent the most severe impacts of climate change to human and natural systems (The World Bank 2010). In order to stay within this 2ºC limit, in the long term, CO_2 concentrations need to stabilize near current levels (USGCRP 2009).

To help envision the range of possible futures, the IPCC developed 40 baseline emissions scenarios showing different paths for greenhouse gas emissions from 2000 to 2100, based on variations in climate change factors. These scenarios assume no international policies to mitigate emissions (Nakicenovic et al. 2000) and they indicate that annual emissions could increase or decrease from today's level of approximately 40 gigatons of carbon dioxide equivalents (CO_2e) to anywhere between 30 and 140 gigatons. Temperature increases associated with these emission levels range from 1 to 7 degrees Celsius (Bernstein et al. 2007).

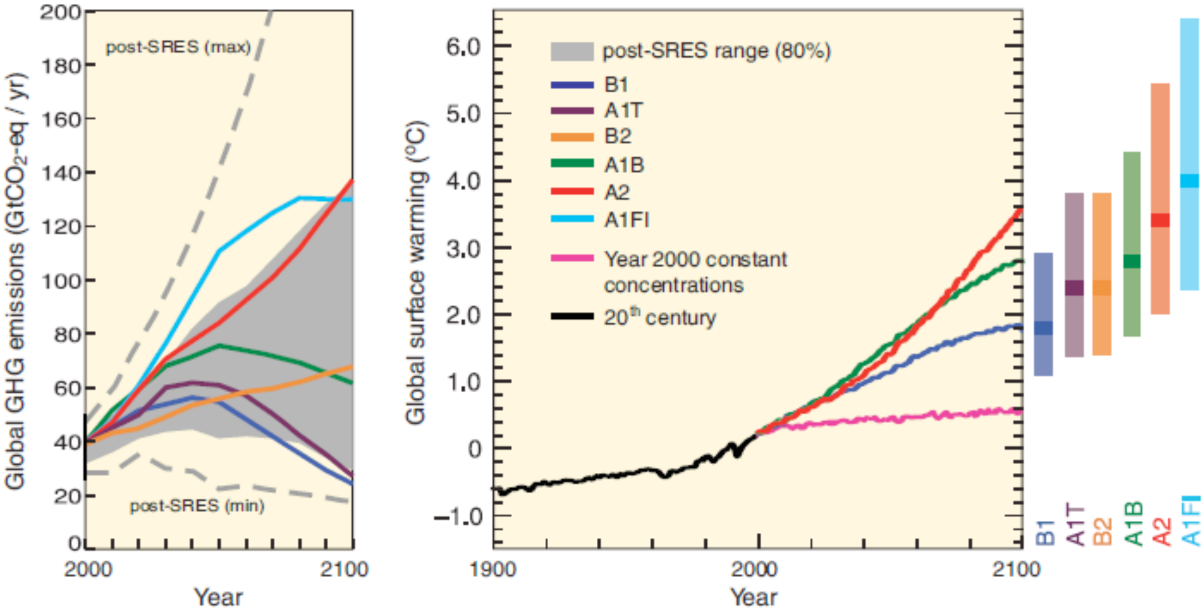


Figure 2: Scenarios for Greenhouse Gas Emissions from 2000 to 2100
(Source: http://www.ipcc.ch/publications_and_data/ar4/syr/en/figure-spm-5.html)

Observed and Predicted Global Climate Change Impacts

The early effects of global climate change can already be observed in changes to weather related hazards, hydrology and water resources, coastal processes, biological systems, agriculture, forestry, and human health (C. Rosenzweig et al. 2007). Some examples of observed effects include (relative to historical norms):

- Higher temperatures
- Increase in the number and size of drought-prone areas
- Higher intensity of storms
- Sea level rise
- Accelerated rates of coastal erosion
- Increased water salinity and suspended solids
- Increased river runoff

The effects of climate change will likely be more extreme than what we have observed so far. With each additional increase in the global mean annual temperature, the severity of effects are likely to worsen. However, the impacts of climate change will not be equally distributed among all locations (USGCRP 2009). Because of this, it is important for green building professionals to understand how climate change will impact the regions where they work.

U.S. Regional Climate Change Impacts

Understanding how global climate change is likely to affect the region where a project is located is an important first step in anticipating effects on the built environment, modifying project outcomes, and selecting appropriate response strategies. Regional climate impacts fall into six general categories:

1. Temperature
2. Water/Precipitation
3. Coastal Effects
4. Air Quality
5. Pests
6. Fire

These impacts have been the topic of significant research, compiled most recently by the USGCRP in 2009, and reported in detail by region in Appendix B of this report. The direction and degree of these impacts vary significantly by region and will result in a diverse set of challenges across different regions of the U.S. The USGCRP divides the nation into eight regions (plus coasts) as indicated in Figure 3. In this report, we include coastal impacts within the regions where they are located.

Figure 3: Regions of the United States (Source: http://www.globalchange.gov/)

Rising average temperatures are predicted in all U.S. regions and will influence many other climate change impacts, such as precipitation patterns. Higher temperatures will likely lead to more extremely hot days (over 90 degrees Fahrenheit) and an increasing frequency and intensity of heat waves. In many regions, these effects will likely be felt most during the summer months. Precipitation patterns are also likely to change as a result of higher temperatures, but the effects will vary widely by region. The Southwest is likely to see a decrease in overall precipitation and to experience longer, more frequent, and more severe droughts. Meanwhile, the Midwest is likely to experience less frequent but more intense storms, and an associated increased risk of flooding. In general, researchers are much less certain how climate change will impact precipitation patterns than average temperatures (USGCRP 2009).

Coastal areas are especially vulnerable to the effects of climate change due to rising sea levels, falling lake levels, and more intense tropical storms. As temperatures rise and polar ice melt accelerates, sea levels are predicted to rise, resulting in potentially disastrous effects for low-lying areas. Of particular concern is the vulnerability of coastal areas to inundation from storm surges during severe tropical storms and hurricanes. Rising sea levels will not affect all coastal areas equally. In general, the Atlantic Coast and Gulf Coast are more vulnerable due to their relatively flat topography and high rates of land subsidence in some areas. Sea level rise is less of a concern in some parts of the Pacific Northwest where land is rising due to tectonic activity. In the Midwest, inland and Great Lakes water levels are predicted to decline due to reductions in winter ice cover and increased evaporation, despite a predicted increase in total rainfall (USGCRP 2009).

Climate change will likely result in many more diverse and region-specific impacts including increased risk of wildfires, invasions of pests, and degradation of surface air quality. These and other impacts are often linked. For example, warmer winter temperatures may be contributing to the death of Pacific Northwest pine forests as more insects survive winter conditions (Ryan 1991). The increased number of dead trees within the pine forests may also result in more frequent and intense wildfires that could threaten nearby buildings and degrade air quality.

While changes in average precipitation and temperature patterns are important information for projecting impacts, the primary concern for green building practice is the impact that increasing severity and variability of weather patterns and climate will have on the local built environment. Appendix B contains important quantitative estimates of change in these affected categories through the end of the century. Please refer to this resource for more details on region-specific climate change predictions. Whenever possible, we report numbers as a range of possible changes. The most relevant numbers for design will be the upper and lower bounds, which represent the most extreme possibilities within the plausible range.

Determining Impacts at the Neighborhood or Building Level

Climate is the long-term average weather conditions of a region or place. Regional climate change predictions are useful for understanding general changes in weather and climate-related conditions, but more information is often needed to determine how these forces will affect a specific site or project. Local features (like a mountain or a large lake) can significantly influence weather patterns, and local features such as topography or distance from a coast can have important implications for climate change predictions (Wilby et al. 2004). Two types of resources are available to green building professionals who seek finer-grained detail on climate change impacts: downscaled climate models and historical analysis of severe weather events. When available, downscaled state/local climate change assessments are the best sources of this information.

Downscaling is a statistical process used to convert global or regional models to smaller geographies and to account for local features. Climate scientists have only recently begun producing downscaled climate models at the local level with sufficient accuracy to be useful to building professionals. Few cities have devoted the significant resources required to create locally downscaled climate change projections – instead, local climate action plans usually rely on the same regional sources cited by the USGCRP and used in this report. Some states (e.g. California) have developed resources that may reduce the uncertainties reported in the regional assessments. Finer resolution data at the metropolitan level may be available in the near future, and these data may further narrow uncertainty about climate impacts. However, some uncertainty will always exist because of natural weather pattern variability and because many climate change drivers are influenced by human behavior.

Regardless of whether downscaled local climate change predictions are available, additional work may be needed to assess neighborhood- and site-level vulnerability. One strategy is to use local knowledge of recent events. When ICLEI (see section 2.3) works with local governments to help them plan for sustainability and climate change adaptation, it recommends focusing on past extreme weather events and anecdotal accounts. When combined with regional climate change predictions, local historical accounts enable governments to envision how prepared they would need to be to respond to similar future events that are more frequent or more severe (ICLEI-Canada, 2010). Green building professionals should follow a similar process but tailor their approach to the specific concerns at the neighborhood or building level.

Additional Resources

1. The IPCC Working Group 2 Summary for Policymakers, approved in April 2007, is the formally adopted statement of the IPCC concerning the sensitivity, adaptive capacity and vulnerability of natural and human systems to climate change, and the potential consequences of climate change: http://www.ipcc-wg2.gov/AR4/website/spm.pdf.
2. The 2010 World Development Report says that advanced countries, which produced most of the greenhouse gas emissions of the past, must act to shape our climate future. The report argues that if developed countries act now, a "climate-smart" world is feasible, and the costs for getting there will be high but still manageable: http://go.worldbank.org/45FTJL7UP0.
3. The U.S. Global Change Research Program (USGCRP) coordinates and integrates federal research on changes in the global environment and their implications for society. The USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which called for "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." For more information from the program, see: http://www.globalchange.gov/.
4. A primary resource for additional information regarding regional impacts of climate change is the United States Global Change Research Program (USGCRP) Global Climate Change Impacts in the United States (GCCIUS) Assessment: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/download-the-report.
5. The California Climate Change Portal contains information on the impacts of climate change on California and the state's policies relating to global warming. It is also the home of the California Climate Change Center, a "virtual" research and information website operated by the California Energy Commission through its Public Interest Energy Research (PIER) Program: http://www.climatechange.ca.gov/.

4. Climate Change Impacts on the Built Environment

Distinct climate change impacts are associated with the regional, city, neighborhood, and site scales. This section of the report reviews literature that focuses on anticipated climate change impacts and the quantitative effects of these impacts on the built environment. Given the regional nature of both climate change impacts and urban systems and development, further localized research is needed on the impacts and effects of climate change on the built environment.

Regional Scale Impacts

The regional scale involves the broader urban area(s) and the various systems implemented in support of the social, economic, and environmental well-being of the area. While numerous elements are susceptible to climate change impacts, discussions of regional effects tend to focus on energy, water, and transportation systems. These three regional systems provide cities, neighborhoods, and buildings with essential services and permit movement and connection. Climate change will have a significant impact on the effectiveness of regional systems. More resilient regional systems will maintain efficiencies across systems and limit conflict.

Energy Systems: Climate change impacts on energy systems will affect both energy supply (generation, transmission, and distribution) and demand. Given increased variability in temperature, climate change could result in a need to increase energy supply capacity (Amato, Ruth, Kirshen, and Horwitz 2005). At the regional scale, climate change impacts on the delivery of energy may affect the siting of new facilities and infrastructure and disrupt the transmission of energy (USCCSP 2008). In particular, sea level rise, land subsidence, increased storm severity, and storm surges may constrain the location of future energy infrastructure sites (Perez 2009; USCCSP 2008).

The impacts of climate change on energy generation vary significantly by fuel source. However, the USCCSP states that fossil fuel and nuclear energy generation are inextricably tied to reliable and adequate supplies of water for cooling. Additionally, renewable energy sources, particularly hydroelectric and solar thermal systems, are highly dependent on water and are therefore very susceptible to climate change (USCCSP 2008).

Climate projections indicate warming trends during both winter and summer seasons. As a result, effects on energy demand will include small reductions in space heating but substantial increases in space cooling (Crawley et al. 2008; Huang 2006; USCCSP 2008).

A study of the Chicago region projects a 30 to 60 percent increase in annual Cooling Degree Days (CDD) by 2070 for lower and higher emission scenarios respectively (Perez 2009). Additionally, Franco and Sandstad (2006) find that energy models for California predict increases in annual electricity and peak load demands in all climate scenarios. In particular, the A1FI or "high emissions scenario" for the 2070 to 2099 timeframe shows an increase in annual electricity of 20.3 percent and a peak demand increase of 19.3 percent (Franco and Sanstad 2006). The resulting increase in demand, when combined with a strain on existing generation assets, may increase costs and reduce the reliability of regional energy systems.

<u>Water Systems:</u> Existing research on the impacts of climate change on water have primarily focused at the regional level because of the size and intricacies of these systems. The primary effects of climate change on regional water systems are increasing variability in the quantity and timing of streamflow runoff, increased risk of flooding, and diminished water quality (Barlage et al. 2002; Barnett et al. 2004; Hamlet and Lettenmaier 1999; Wilby 2007). The impacts of climate change on regional water systems will intensify conflicts between essential and non-essential water uses, and require regional management to ensure an increase in the quality and reliability of water resources (Barlage et al., 2002).

Water supply reliability is one of the most important and therefore most extensively researched effects of climate change on both natural systems and human populations. Projected water resource capacity is highly dependent on regional climate impacts and the existing water system balance between supply and demand. Anticipated changes in precipitation vary dramatically by region. Projections indicate increased precipitation at higher latitudes, rising intensity and frequency of low-precipitation periods for areas prone to droughts, and significant changes in runoff patterns for watersheds dependent on snow-fed rivers.

Significant research has focused on climate change impacts on streamflow and water reliability at the regional scale. While a majority of the studies have focused on the western region of the United States, many of the basic tenets and lessons can be applied to areas anticipating similar climate threats. A study on the effect of climate change on water resources in the West concludes, “by mid-century we see that the Colorado River Reservoir System will not be able to meet all of the demands placed on it, including water supply for Southern California" (Barlage et al. 2002). The variability in water supply levels will result in difficulty meeting domestic, industrial, and agricultural demand; maintaining energy production; and supporting natural systems.

Stormwater management is a second fundamental concern when analyzing the impacts of climate change on regional water systems. The increased intensity and frequency of high-precipitation events will likely result in increased runoff and flooding (Wilby 2007). Additionally, future development locations and land use decisions play influential roles in determining future stormwater runoff impacts regionally. Analyzing future regional stormwater runoff patterns involves considering climate change impacts in conjunction with urban development patterns. One such study, performed on the Rock Creek Basin in Oregon, indicates that, given climate change projections, sprawling development patterns increase annual runoff by 5.5 percent compared to the baseline model, while a more compact development scenario results in increased annual runoff by 5.2 percent (Franczyk and Chang 2009). The researchers conclude that while regional development patterns have a significant impact on streamflow and water runoff, climate change is expected to have a greater impact on streamflow than land use change (Barlage et al. 2002; Chang 2003; Franczyk and Chang 2009). As water runoff has a strong connection to flood risk and damage in urban areas (Ashley et al. 2005), as well as impacts on the health of natural watersheds (Barlage et al. 2002), considering the future effects of climate change is extremely important.

Transportation Systems: Transportation via land, air, or water plays an integral role in connecting urban areas internally and externally. Distinct climate threats exist for each transportation sector, and they vary significantly by location. Region-specific climate impacts will primarily affect transportation infrastructure. The climate change impacts of concern for transportation infrastructure include high precipitation events, extreme weather, sea level rise, thawing permafrost, and reduced ocean and lake ice cover (Transportation Research Board 2008). Therefore, climate change can affect transportation systems by decreasing reliability and safety, and by significantly increasing the cost of both operation and maintenance.

Neighborhood Scale Impacts

Neighborhoods connect individual building sites to the broader city and regional contexts. Furthermore, the neighborhood level is the primary scale at which building professionals can begin to address impacts of climate change. Because there is little existing research on the impacts of climate change at the neighborhood scale, our analysis focuses on applying information gathered through site or regional studies. In evaluating climate impacts at the neighborhood scale, the elements of location, design, and pattern are important to consider.

Location is a critical issue, especially in regards to the anticipated climate change impacts of sea level rise, increased frequency and intensity of flooding, and higher incidences of wildfires. While each of these impacts is more common in certain regions, every project team should consider these location-specific climate impacts when making development decisions.

<u>Sea Level Rise:</u> Factors that should be considered before building in coastal areas include anticipated sea level rise, potential changes in storm surge, and land subsidence. The range of projections, both high and low, for anticipated rises in sea level should be evaluated for specific locations. While general changing sea level projections are valuable, knowledge of local geology and tidal patterns is necessary for a full understanding of potential risks. For example, a study of the potential impact of hurricanes on sea level rise reports a mean global sea level rise projection of between 19 and 60 cm, with a high emissions scenario resulting in an 80.0 cm rise (Mousavi et al. 2010). Given variability in projections and coastal systems, regional studies and research are necessary to define local effects.

It is also necessary to analyze projected changes in storm surge associated with rising sea level. While changes in sea level help identify better location options, a more in-depth measure of risk relates to the potential impact of storm surge. This is especially important for areas currently (or projected to be) affected by hurricanes. Finally, research regarding land subsidence is an element in identifying the climate change risk regarding sea level rise for a specific location. An analysis of projected sea level rise, changing storm surge, and the amount of land subsidence allows for an informed decision when evaluating location choices in coastal areas.

<u>Flooding:</u> With increasing frequency and intensity of precipitation due to climate change, the risk of flooding increases. Flood risk is assessed primarily when determining the appropriate location for a specific project or in planning for urban growth. The most effective way to begin

accounting for the impacts of increased flooding is to identify the effect of precipitation projections on flood plain calculations and flood event probabilities. Consideration of flood risk when siting a project should identify changes in the planning of ‘at risk’ areas, and in particular how climate change will affect floodplains for 1-in-10, 1-in-50, and 1-in-100 year events. Two elements to consider when assessing climate change impacts on future flooding include changes in precipitation under future climate scenarios and changes to the landscape that could either reduce or increase stormwater run-off. Projections indicate increasingly frequent and intense precipitation events for most regions. Additionally, models taking into account land use planning processes generally show increased runoff resulting from sprawling development patterns and increased use of impervious surfaces (Marsh 2005). Therefore, the combination of more frequent and intense precipitation and continued land development will result in increased flood risk throughout urban areas (Barlage et al. 2002; Chang 2003; Franczyk and Chang 2009). Recent research predicts that flood risk will increase by a factor of at least two (Ashley et al. 2005). Furthermore, direct damage to buildings due to flooding is projected to increase by factors of 2.5, 3.8, and 9.8 for three different rivers within one watershed (Schreider, D. I. Smith, and Jakeman 2000). The variation in risk is due to the specific natural and built environment characteristics of the sub-watersheds. This example illustrates why more location-specific research will be extremely important when considering future development sites.

Wildfires: A final consideration when making location decisions is the rising threat of wildfires due to changing precipitation patterns and expanding urban areas. Generally, “climate change that results in drier, warmer climates has the potential to increase fire occurrence and intensify fire behavior” (Y. Liu, Stanturf, and Goodrick 2010). In particular, the incidence of wildfires is highly linked to low-precipitation and low-snowpack climate patterns (Barnett et al. 2004). Furthermore, the sprawling nature of urban areas has led to “the rapid growth of housing in and near the wildland-urban interface (WUI), [which has led to] increases in wildfire risk to lives and structures” (Massada et al. 2009). Thus, with further anticipated growth of urban metropolitan areas, as well as projected climate change conditions that are likely to increase the frequency of wildfires, it is reasonable to assume that fire will pose a growing risk to the built environment. Design teams should consider the projected regional climate impacts that may result in more frequent and intense wildfires when locating buildings, sites, and neighborhoods.

Neighborhood Design and Form

The design and pattern of neighborhoods that combine to form our cities play an important role in amplifying or dampening climate effects. For example, neighborhood design and development patterns could help mitigate changes in heat and stormwater runoff. In particular, neighborhood design that significantly increases the amount of impervious surfaces while adding little to no vegetation will only exacerbate the effects of anticipated climate change. Research on the regional impacts of climate change identifies compact development as a means of addressing climate change impacts on the built environment.

Urban Heat Island Effect: Urban heat island (UHI) effects and extreme heat events are the primary threats resulting from the increasing temperature associated with climate change. Urban neighborhood patterns have a distinct effect on the thermal comfort of local inhabitants during high heat events. Research on the UHI effect shows that higher density development exacerbates extreme heat events, resulting in additional stressors in urban areas (Coutts, Beringer, and Tapper 2010; Hamin and Gurran 2009; Harlan et al. 2006). The design of urban neighborhoods, including large areas of impervious surfaces, lack of shade-producing vegetation, lower albedo materials, and higher concentrations of waste heat sources all magnify the impact of heat events (Bowler et al. 2010; Coutts et al. 2010; Hamin and Gurran 2009; Smith and Levermore 2008; Wilby 2007).

Research also indicates that higher UHI effects impact both higher density urban areas and lower density sprawling urban areas (Oke 1981; Smith and Levermore 2008; Stone, Hess, and Frumkin 2010). Higher density and compact development often result in an “urban canyon” pattern that can trap daytime heat and limit the ability of wind and cooler temperatures to reduce heat (Oke 1981; Wilby, 2007). Similar to high-density urban form, a low-density sprawling development pattern has been shown to exacerbate the UHI effect due to extensive impervious and lower albedo surfaces, and a lack of vegetation (Stone et al. 2010). While issues of thermal comfort and heat stress are primarily addressed at the building and site levels, by beginning to identify the impact of neighborhood patterns on UHI effect, a design team can achieve a more holistic approach to address the impacts of heat-related climate change.

Stormwater Runoff: Extensive use of impervious surfaces in urban areas amplifies the impacts of extreme precipitation events. As high precipitation events become more frequent and intense, the associated impacts on urban areas and natural watersheds increase greatly. Neighborhood design and material selection have a distinct impact on the level of stormwater runoff. Specifically, largely impervious surfaces and limited vegetation dramatically decrease water's ability to infiltrate, thereby increasing runoff. The extent of the impact is supported by studies reporting that urban patterns of low-density sprawling development have a larger impact on flooding and stormwater runoff than high-density compact development (Franczyk and Chang 2009; Jacob and Winner 2009). Given anticipated changes in climate patterns, professionals should begin to consider the effect neighborhood patterns have on stormwater runoff and flooding.

Site or Project Scale Impacts

In assessing the impacts of climate change at the site and building level, it is important to draw connections to associated effects at the neighborhood, city, and regional scales. While climate change may have a distinct impact on the built environment at a specific level, many of the associated effects apply across scales. For instance, the primary neighborhood-level effects of increased urban heat island and stormwater runoff will influence site and building performance. Eight significant site-level impacts include landscape, water, stormwater, energy, indoor environmental quality, building materials, increased risk of flood events, and expanding pest ranges.

Landscapes: Research indicates that changes in plant hardiness zones will occur as a result of increasing temperatures, more intense and frequent heat and precipitation events, and longer periods between storm events (Parmesan and Yohe 2003). A recent study on the effects of climate change on global natural systems predicts an average systematic habitat shift of 6.1 km per decade towards the poles (Ibid.). Changing precipitation patterns, length of seasons, and average ambient temperature will all be determining factors to consider for climate adapted landscape design. Plant selection will also affect habitat opportunities.

A secondary issue relates to the use of greenspace in addressing stormwater runoff and urban heat effects as elements of green infrastructure. Significant research has focused on the effect of landscaping strategies on climate change impacts, particularly on-site stormwater runoff strategies and the urban heat island mitigation effects of shade and evapotranspiration (Berndtsson 2010; Bowler et al. 2010; Gill et al. 2007). Since landscape design and greenspace can lessen the future impacts of climate change, projected changes in landscape infrastructure design and plant species selection will be crucial site-level adaptation strategies.

Water: Research assessing the impacts of climate change on water systems has had a regional focus, with little emphasis on the site level effects on human systems. To assess site impacts, our analysis focuses on the projected regional effects and studies on site level water management. At the site level, climate change will primarily affect water consumption patterns and management of stormwater runoff.

Consumption Patterns: Water consumption patterns are projected to change in response to increasing temperature, more frequent and intense extreme heat events, and longer droughts (Smith, Howe, and Henderson 2009). If regional streamflow patterns change as anticipated, site level water availability will become increasingly unpredictable. Given increasing demand for and decreasing reliability of water supplies, the potential exists for longer periods of drought and growing controversy over water supply priorities (Wilby 2007). Therefore, great emphasis should be placed on site level water consumption reductions to help balance projected growth in demand with a less reliable supply.

Stormwater Runoff: As discussed in the regional and neighborhood sections, climate change will lead to more intense and frequent precipitation, thereby increasing stormwater runoff. While most research focuses on the impacts of stormwater runoff at a city or regional scale, there are site level effects as well. While regional or neighborhood systems can be designed to address stormwater runoff, the primary is site level damage and a localized risk of flooding (Ashley et al. 2005).

Warmer Temperatures; Increased Frequency and Intensity of Extreme Heat Events: Building level energy use is likely to change as a result of rising temperatures. As average temperatures increase, cooling degree days will also increase. Energy demands for heating will decrease slightly, but energy demands for cooling will increase significantly (USCCSP 2008), especially on extremely hot days (over 90˚F). Extremely hot days are already major drivers of energy use in buildings, and as extreme heat events become more frequent and severe, energy use will rise proportionately because increases in exterior heat and interior heat gains have a linear relationship (Coley and Kershaw 2010).

Increasing energy demands have important implications for building design and operations. Although energy demands are not predicted to increase in the short term (Huang 2006), long-term impacts could be quite different. One study suggests that climate change could increase California's annual electricity usage by 20% by century's end (Franco and Sanstad 2006). Such an increase would impose significantly higher costs for building operations. Designers should take care to incorporate higher cooling demands into building designs. While all buildings are likely to experience higher heating loads as a result of increasing temperatures, the degree to which they require additional energy for cooling is related to the design of the building envelope and systems (Coley and Kershaw 2010). Special consideration should be given to design solutions that do not increase building carbon emissions, such as high albedo roofs, green roofs, and enhanced building envelope strategies.

Increased Vulnerability to Extreme Heat Events: The frequency and severity of extreme heat events is likely to increase significantly as a result of climate change, affecting building occupant comfort. HVAC systems are currently designed to provide sufficient cooling capacity for the historic climate pattern. If extreme heat events increase dramatically, cooling systems may not be able to continue providing sufficient power to maintain comfort levels. Designers should consider an increased frequency and intensity of extreme heat events when determining needed cooling loads. In particular, designs that allow for future expansion may be prudent.

Decreased Ability For Natural Ventilation: Natural ventilation, such as opening a window, is a common way for building occupants to exercise control over personal comfort levels. Ventilation is also used as a natural supplement to forced-air cooling systems, and for low-energy night cooling of buildings. However, as both daytime and nighttime temperatures are predicted to rise, natural ventilation will be a less effective strategy for reducing indoor air temperatures in buildings. Further complicating matters, ground-level ozone concentrations are predicted to increase as daytime temperatures rise and the number of extreme heat events increases. A study of 50 U.S. cities estimated that ozone risk days will increase by 68% per year (Bell et al. 2007).

The combination of rising temperatures and the human health risks related to high ozone concentrations may make traditional natural ventilation of indoor spaces a less viable strategy. A UK study estimates that London office buildings and mixed use buildings that rely on natural ventilation will overheat more frequently (5-25% increase for a 1960s-era office building in 2080, and 1.4-3.7% for a more modern mixed-use building in 2020). However, the same study estimated that buildings with advanced natural ventilation may experience no increase in overheating through 2080 (Hacker and Holmes 2007).

Building Materials: There are few comprehensive studies on the projected impacts of climate change on building materials. However, some region specific reports focus on certain climate threats. Existing literature and reports indicate that building materials will be most affected by more intense and frequent storms, increased flooding, and changing regional pest ranges (Roberts 2008; Wilby 2007). The durability, design, and testing of building materials are primary considerations when accounting for anticipated climate change.

Increased Frequency and Intensity of Storms: We can look to the extensive research on the impact of storms, primarily hurricanes in the Southeastern region of the U.S., to begin assessing the affects of climate change on building materials. A detailed report following Hurricane Ike identifies roofing and wind-driven water as primary threats to building materials. The report outlines specific roofing recommendations, including the need "to assess actual performance of roofing products and systems in order to improve material production and installation specifications." Furthermore, recommendations regarding wind-driven water call for better water intrusion management, "through a combination of structural improvements and more realistic testing" (Institute for Business and Home Safety 2009). The report provides detailed roofing and envelope strategies to address the impacts of high wind and extreme precipitation resulting from intense storm events. While the Hurricane Ike report is a region-specific response to a single weather event, it exemplifies the type of research useful in determining the region-specific impacts of climate change on building materials.

Increased Risk of Flood Events: While location choices and neighborhood patterns play an important role in alleviating flood risk, building material decisions will also be affected. In anticipation of increased site level flood risk, recommendations include choosing building materials that are more durable and resistant to water, less susceptible to water intrusions, and relatively inexpensive and easy to replace if flooding occurs (Roberts 2008).

Expanding Pest Ranges: Finally, climate change will impact building materials as the warming climate is projected to increase the current climate range for insects (USCCSP 2008).

In particular, the increased range for termite habitat will raise the risk of damage to building materials. The range for termites is projected to spread as temperatures increase, especially with anticipated shorter winter seasons when ground freezing helps eliminate termite population (Peterson,2010). Regions with limited termite populations should consider increasing pest issues and damage to wood-based building materials as the climate warms.

5. Current Knowledge Gaps

According to the USGCRP, there is currently limited knowledge about the ability of communities and regions to adapt to a changing climate. To address this shortfall, research on climate change impacts and adaptation must begin to include complex human dimensions such as economics, management, governance, behavior, and equity. As part of this effort, interdisciplinary research on adapting to climate change in the built environment must take into account the interconnectedness of natural and human systems.

Climate change research has typically focused on how changes in temperature and precipitation will affect national and regional systems. Only a handful of studies have examined the effects of climate change at the neighborhood or building scale, and most of these studies are assessments of how upstream changes in natural systems (e.g., snow pack, precipitation rates, stream flow) may eventually impact human settlements (Chang 2003; Vogel, Bell, and Fennessey 1997; Wilby 2008). More research is needed to understand the direct impacts of temperature and precipitation change on neighborhoods and buildings.

To understand the impacts of climate change on neighborhoods and buildings, additional downscaling of climate models will be necessary. While the downscaling of climate models is becoming a common practice in the atmospheric sciences, only a handful of studies have attempted to translate data from these models into formats useful for planning and building professionals. One immediate need is "future" TMY files for building energy modeling, but other examples include data on precipitation to determine the size of stormwater systems.

The downscaling of climate models introduces a high level of uncertainty; these new data will have significant limitations. Working together, atmospheric scientists and building professionals can help to convey this uncertainty and explain the risk of action or inaction to building owners and the public. This may help to open a broader dialogue on how to prioritize resources to respond to climate change, and build support for local mitigation and adaptation efforts. An interdisciplinary approach will also be important for reframing climate change mitigation and adaptation as complementary rather than conflicting goals.

While Appendix C of this report outlines a number of adaptation strategies that building professionals can implement to make their projects more resilient, more research is necessary to understand the benefits, costs, and efficacy of each strategy. This could be accomplished by linking data from downscaled climate models with building energy or environmental performance models, but it will also require evaluation of long-term maintenance costs and the effective useful life of each strategy. In addition, little is known about how the interactive effect of multiple strategies might increase or decrease resilience and/or the capacity to adapt.

In the last decade, regional analysis of climate change in the United States has focused on the Northeast and California. This has created a wealth of data that has helped cities such as Boston and San Francisco to initiate climate adaptation efforts. Because climate change will affect all of North America, additional research should be encouraged in other regions as well. Special attention should be paid to places where the population may have a limited capacity to adapt. Coordinated efforts to capture lessons learned from the Northeast and California may also allow for rapid advances in local knowledge, and allow for best practices in resilience and adaptation to flourish across the United States.

Finally, there is limited research on how climate impacts will affect plant selection for landscape design and shifting pest zones. Building professionals should encourage researchers in these areas to evaluate the possible effects on the built environment. If these potential impacts are ignored, climate change could negatively affect what is otherwise a resilient design. For example, plants are an important component of landscape design for stormwater management. Plants that previously thrived in an area may be vulnerable to new pests that migrated to there because of changes in temperature or precipitation. The most resilient buildings will adapt not only to water and temperature impacts, but also to storm, pest, landscape, and fire impacts. As climate adaptation is incorporated into building design, case studies and lessons learned will help answer these questions and fill gaps in knowledge.

6. References

Adger, Neil, Shardul Agrawala, M Monirul Qader, C Conde, K O'Brien, J Pulhin, R Pulwarty, B Smit, and K Takahashi. 2007. *Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC*. Edited by M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson, *Change*. Cambridge, UK: Cambridge University Press.

Amato, Anthony D., Matthias Ruth, Paul Kirshen, and James Horwitz. 2005. Regional Energy Demand Responses To Climate Change: Methodology And Application To The Commonwealth Of Massachusetts. *Climatic Change* 71:175-201.

American Water Works Association. 2009. *Climate Change and Water; International Perspectives on Mitigation and Adaptation*. Edited by J. Smith, C. Howe and J. Henderson: IWA Publishing.

Ashley, R M, D J Balmforth, a J Saul, and J D Blanskby. 2005. Flooding in the future - predicting climate change, risks and responses in urban areas. *Water science and technology: a journal of the International Association on Water Pollution Research* 52:265-73.

Barlage, Michael J., Paul L. Richards, Peter J. Sousounis, and Andrew J. Brenner. 2002. Impacts of Climate Change and Land Use Change on Runoff from a Great Lakes Watershed. *Journal of Great Lakes Research* 28:568-582.

Barnett, Tim, Robert Malone, William Pennell, Detlet Stammer, Bert Semtner, and Warren Washington. 2004. The Effects of Climate Change on Water Resources in the West: Introduction and Overview. *Climatic Change* 62:1-11.

Bell, Michelle L., Richard Goldberg, Christian Hogrefe, Patrick L. Kinney, Kim Knowlton, Barry Lynn, Joyce Rosenthal, Cynthia Rosenzweig, and Jonathan a. Patz. 2007. Climate change, ambient ozone, and health in 50 US cities. *Climatic Change* 82:61-76.

Berndtsson, Justyna Czemiel. 2010. Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering* 36:351-360.

Bernstein, L., P. Bosch, O. Canziani, Z. Chen, R. Christ, O. Davidson, W. Hare, S. Huq, D. Karoly, V. Kattsov, Z. Kundzewicz, J. Liu, U. Lohmann, M. Manning, T. Matsuno, B. Menne, B. Metz, M. Mizra, N. Nichols, L. Nurse, R. Pachauri, J. Palutikof, M. Parry, D. Qin, N. Ravindranath, A. Reisinger, J. Ren, K. Riahi, C. Rosenzweig, M. Rusticucci, S. Schneider, Y. Sokona, S. Solomon, P. Stott, R. Stouffer, T. Sugiyama, R. Swart, D. Tirpak, C. Vogel, and G. Yohe. 2007. Climate Change 2007: Synthesis Report.

Blanco, H, M Alberti, A Forsyth, K Krizek, D Rodriguez, E Talen, and C Ellis. 2009. Hot, congested, crowded and diverse: Emerging research agendas in planning. *Progress in Planning* 71:153-205.

Bowler, Diana E., Lisette Buyung-Ali, Teri M. Knight, and Andrew S. Pullin. 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning* 97:147-155.

Brooks, Nick. 2003. Vulnerability, risk and adaptation: A conceptual framework. In *Event (London)*.

Brooks, N, WN Adger, and M Kelly. 2004. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change* 15:151-163.

Chang, Heejun. 2003. Basin Hydrologic Response to Changes in Climate and Land Use: the Conestoga River Basin, Pennsylvania. *Physical Geography* 24:222-247.

Coley, David, and Tristan Kershaw. 2010. Changes in internal temperatures within the built environment as a response to a changing climate. *Building and Environment* 45:89-93.

Coutts, Andrew, Jason Beringer, and Nigel Tapper. 2010. Changing Urban Climate and CO2 Emissions: Implications for the Development of Policies for Sustainable Cities. *Urban Policy and Research* 28:27-47.

Crawley, Drury B, Jon W Hand, Michaël Kummert, and Brent T Griffith. 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and Environment* 43:661-673.

Forster, P., V. Ramaswamy, P. Artaxo, T. Bernsten, R. Betts, D. Fahey, J. Haywood, J. Lean, D. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. VanDorland. 2007. Changes in atmospheric constituents and in radiative forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In *Climate change*. Cambridge, United Kingdom and New York, USA.

Franco, Guido, and Alan H Sanstad. 2006. Climate Change and Electricity Demand in California. California Energy Commission.

Franczyk, Jon, and Heejun Chang. 2009. The effects of climate change and urbanization on the runoff of the Rock Creek basin in the Portland metropolitan area , Oregon, USA. *Hydrological Processes* 23:805- 815.

Fussel, H.M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science* 2:265-275.

Gill, S.E, J.F Handley, A.R Ennos, and S Pauleit. 2007. Adapting Cities for Climate Change: The Role of the Green Infrastructure. *Built Environment* 33:115-133.

Hacker, Jacob N, and Michael J Holmes. 2007. Thermal Comfort: Climate Change and the Environmental Design of Buildings in the United Kingdom. *Built Environment* 33:97-114.

Hamin, Elisabeth M., and Nicole Gurran. 2009. Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. *Habitat International* 33:238-245.

Hamlet, Alan F, and Dennis P Lettenmaier. 1999. Effects of Climate Change on Hydrology and Water Resources in the Columbia River Basin. *Journal Of The American Water Resources Association* 35:1597-1623.

Harlan, Sharon L, Anthony J Brazel, Lela Prashad, William L Stefanov, and Larissa Larsen. 2006. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine* 63:2847-2863.

Hayhoe, Katharine, Mark Robson, John Rogula, Maximilian Auffhammer, Norman Miller, Jeff VanDorn, and Donald Wuebbles. 2010. An integrated framework for quantifying and valuing climate change impacts on urban energy and infrastructure: A Chicago case study. *Journal of Great Lakes Research* 36:94-105.

Huang, Joe. 2006. The impact of climate change on the energy use of the US residential and commercial building sectors. Lawrence Berkeley National Laboratory.

ICLEI. *ICLEI - Local Governments for Sustainability*. Available from http://www.iclei.org/.

ICLEI-Canada. *Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation* 2010. Available from http://www.iclei.org/index.php?id=8708.

ICLEI-USA. *ICLEI Climate Resilient Communities* 2011. Available from http://www.icleiusa.org/programs/climate/Climate_Adaptation.

Institute for Business & Home Safety. 2009. Hurricane Ike: Nature's Force vs. Structural Strength. http://www.disastersafety.org/content/data/file/hurricane_ike.pdf.

IPCC. *IPCC Publications and Data*. Available from http://www.ipcc.ch/publications_and_data/publications_and_data.shtml.

———. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. v. d. Linden and C. E. Hanson. Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Jacob, D, and D. A. Winner. 2009. Effect of climate change on air quality. *Atmospheric Environment* 43:51-63.

Kirshen, Paul, Matthias Ruth, and William Anderson. 2007. Interdependencies of urban climate change impacts and adaptation strategies: a case study of Metropolitan Boston USA. *Climatic Change* 86:105-122.

Liu, Yongqiang, John Stanturf, and Scott Goodrick. 2010. Trends in global wildfire potential in a changing climate. *Forest Ecology and Management* 259:685-697.

Lowe, Ashley, Josh Foster, and Steve Winkelman. 2009. Ask the Climate Question: Adapting to Climate Change Impacts in Urban Regions. In *Environmental Protection*.

Marsh, William M. 2005. *Landscape planning : Environmental Applications*. 4th ed. Hoboken, NJ: Wiley.

Massada, Avi Bar, Volker C Radeloff, Susan I Stewart, and Todd J Hawbaker. 2009. Wildfire risk in the wildland–urban interface: A simulation study in northwestern Wisconsin. *Forest Ecology and Management* 258:1990-1999.

Moser, SC. 2009. Good Morning, America! The explosive US awakening to the need for adaptation. Santa Cruz, CA.

Mousavi, Mir Emad, Jennifer L. Irish, Ashley E. Frey, Francisco Olivera, and Billy L. Edge. 2010. Global warming and hurricanes: the potential impact of hurricane intensification and sea level rise on coastal flooding. *Climatic Change*.

Nakicenovic, N., O. Davidson, G. Davis, A. Grübler, T. Kram, E. Lebre La Rovere, B. Metz, T. Morita, W. Pepper, H. Pitcher, A. Sankovski, P. Shukla, R. Swart, R. Watson, and Z. Dadi. 2000. IPCC Emissions Scenarios.

Northeast Climate Impacts Assessment (NECIA). *Northeast Climate Impacts Assessment*. Available from http://www.northeastclimateimpacts.org/.

Oke, T.R. 1981. Canyon Geometry and the Nocturnal Urban Heat Island: Comparison of Scale Model and Field Observations. *Journal of Climatology* 1:237-254.

Parmesan, Camille, and Gary Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37-42.

Perez, Pat. 2009. Potential Impacts of Climate Change on California's Energy Infrastructure and Identification of Adaptation Measures. California Energy Commission.

Peterson, Chris J. 2010. Termites and climate change: Here, there and everywhere? In *Earth Magazine*.

Roberts, S. 2008. Effects of climate change on the built environment. *Energy Policy* 36:4552-4557.

Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, and P. Tryjanowski. 2007. *Assessment of observed changes and responses in natural and managed systems. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, *Spring*. Cambridge, UK: Cambridge University Press.

Ryan, K. 1991. Vegetation and wildland fire: Implications of global climate change. *Environment International* 17:169-178.

Safety, Institute for Business and Home. 2009. Hurricane Ike: Nature's Force vs. Structural Strength.

Schreider, S.Yu., D.I. Smith, and A.J. Jakeman. 2000. Climate change impacts on urban flooding. *Climatic Change* 47:91-115.

Smith, Claire, and Geoff Levermore. 2008. Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world. *Energy Policy* 36:4558-4562.

Snover, Amy K., Lara WhitelyBinder, Jim Lopez, Elizabeth Willmott, Jennifer Kay, D. Howell, and J. Simmonds. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Oakland, CA.

Stone, Brian, Jeremy J Hess, and Howard Frumkin. 2010. Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? *Environmental Health Perspectives* 118:1425-8.

The World Bank. 2010. *Development and Climate Change*. Washington, DC.

Tomlan, Michael. 2011. Historic Preservation Education : in Academia Alongside Architecture. *Journal of Architectural Education* 47:187-196.

Transportation Research Board. 2008. Potential Impacts of Climate Change on U.S. Transportation. In *Asia-Pacific journal of public health / Asia-Pacific Academic Consortium for Public Health*. Washington, D.C.

U.S. Census Bureau. *2009 Population Estimates*. Available from http://www.census.gov/popest/estimates.html.

U.S. Energy Information Administration. 2009. Emissions of greenhouse gases in the United States. Washington, DC.

U.S. EPA. *EPA Green Building Website* 2011. Available from http://www.epa.gov/greenbuilding/.

———. *U.S. Environmental Protection Agency Climate Change Adaptation* 2011. Available from http://www.epa.gov/climatechange/effects/adaptation.html.

U.S. Green Building Council. 2008. LEED 2009 Credit Weighting Overview.

———. 2010. Green Building and LEED Core Concepts Guide.

USCCSP. 2008. *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. Edited by M. J. Savonis, V. R. Burkett and J. R. Potter, *Systematics*. Washington, D.C.: Department of Transportation.

———. 2008. Effects of Climate Change on Energy Production and Use in the United States. *U.S. Climate Change Science Program*.

USGCRP. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change.

———. 2009. Global Climate Change Impacts in the United States. New York.

———. *USGCRP Program Overview* 2010. Available from http://www.globalchange.gov/.

Vogel, Richard M, Christopher J Bell, and Neil M Fennessey. 1997. Climate, streamflow and water supply in the northeastern United States. *Journal of Hydrology* 198:42-68.

Wilby, RL, SP Charles, E Zorita, B Timbal, P Whetton, and LO Mearns. 2004. Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods. *Analysis*:1-27.

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

Wilby, Robert L. 2008. Constructing climate change scenarios of urban heat island intensity and air quality. *Environment and Planning B: Planning and Design* 35:902-919.

Wilson, Alex, and Andrea Ward. 2009. Design for Adaptation: Living in a Climate-Changing World. *Environmental Building News*:1-9.

APPENDIX A: Defining Key Terms

Just as the term green building has different meanings to different people, terms related to climate adaptation and climate mitigation have varying meanings in the literature. The variation is often driven by a difference in scale and time frame. The definitions below highlight the variations in meanings in order to clarify how green building and climate adaptation intersect at the local level.

Green Building

Green building is the effort to change the way the built environment is designed, constructed, and operated. Green building takes an integrated, interdisciplinary approach from the early planning stages to the operation of individual buildings, neighborhoods, and entire communities (U.S. Green Building Council 2010). This holistic approach considers the entire supply chain from siting to design, construction, operation, maintenance, renovation, and deconstruction. Green building is concerned with air quality, energy and water use, human health, waste reduction, pollution, and environmental degradation (U.S. EPA 2011). Therefore, green building is poised to incorporate climate adaptation strategies in order to lessen the negative effects of future climate impacts.

Climate and Climate Change

The novelist Robert Heinlein once wrote, "Climate is what you expect, weather is what you get." Climate includes longer-term weather patterns, and variations in elements such as temperature, precipitation, and humidity. *Climate change* is evaluated by the statistically significant change in the mean state or variability of climate measurements that persists for decades or longer (IPCC 2001). Past climate data is used in the planning and design of the built environment. Climate change will require building professionals to consider both past climate data and projected regional climate impacts.

Uncertainty

Planning for climate adaptation and increasing the adaptive capacity of a system inevitably involves some uncertainty. Both the IPCC and the U.S. Global Change Research Program are transparent about the level of *uncertainty* in their assessments and projections (IPCC 2007;

Nakicenovic et al. 2000). The level of uncertainty is presented as a range of likelihoods ranging from very unlikely to very likely (Nakicenovic et al. 2000). The IPCC probabilities are based on quantitative analysis or expert views (IPCC 2007). Similarly, the U.S. National Assessment classifications are based on the collective judgment of the National Assessment Team (USGCRP 2009). Building professionals must accept some uncertainty about climate change as they make design and planning decisions that will be resilient to future conditions.

Scenarios

One of the best ways to understand uncertainty and make decisions when effects are unknown is through the use of projected future scenarios (USGCRP 2001). The IPCC presents different *scenarios* of emissions projections considering a range of possible changes in population, economic growth, technological development, and improvements in energy efficiency. The use of scenarios acknowledges that there is uncertainty in the factors that contribute to climate change. Scenarios are an important component of an assessment because they paint a picture of possible alternative futures, incorporating current knowledge and uncertainties (Nakicenovic et al. 2000). Scenarios are an effort to inform decision makers as they attempt to balance risks and costs.

Mitigation

Mitigation strategies for climate change are different from strategies to “mitigate” or lessen the effects of climate change. In this document, "mitigation" means actions that aim to reduce greenhouse gases, for example by increasing the percentage of renewable energy or increasing energy efficiency. In the United States, buildings contribute 39 percent of national CO_2 emissions. Green building is an important strategy to reduce CO_2 emissions by reducing the energy demand of buildings and increasing the efficiency of energy use (U.S. Green Building Council 2010). Mitigation efforts are important because they will reduce the magnitude of climate change, but they should be coupled with adaptation strategies to lessen the impacts of extreme weather events. Mitigation and adaptation can act in *synergy* so that their combined effect is greater than the effects of efforts were implemented separately (Adger et al. 2007).

Adaptation

Adaptation is the adjustment of our built environment, infrastructure, and social systems in response to actual or expected climatic events or their effects. Adaptation includes responses to reduce harm or capture benefits (IPCC 2007).

The IPCC outlines three different types of adaptation:

- *Autonomous adaptation* is a normal response to relatively stable, average climate and the natural variable climatic conditions that were common in the recent past (Moser 2009). Future climatic conditions will likely have more extreme variation and autonomous adaptation may not be able to respond within the time frame that change is occurring. This type of adaptation is also referred to as "normal adaptation" (Moser 2009) or "spontaneous adaptation" (IPCC 2007).
- *Anticipatory adaptation* or proactive adaptation includes actions taken before climate change impacts are observed (IPCC 2007). Anticipatory adaptation is best understood at the local scale as a planned response to a discrete climate event (Brooks, Adger, and Kelly 2005).
- *Planned adaptation* is the result of policy decisions that are motivated by an awareness that conditions have changed or are about to change (IPCC 2007). It includes additional efforts to examine, plan, and implement strategies for climate adaptation (Moser 2009). Present and projected climate change information is used to review how currently planned practices, policies, and infrastructure will respond to the expected change. Effective planned adaptation requires an awareness of the climate impacts, availability of effective adaptation measures, information about these measures, and availability of resources and incentives for implementation. Planned adaptation strategies can be evaluated not only by their potential to reduce current and future climate risks but also by how they support other policy objectives for sustainability (Fussel 2007).

Vulnerability

Vulnerability is the degree to which a system is susceptible to and unable to cope with the negative effects of climate change. Vulnerability of a building or other parts of the built environment is the result of age, condition or integrity, proximity to other infrastructure, and level of service (specifically for a roadway) (CCSP 2008). The impacts of a climate event on a system or piece of infrastructure are mediated by its vulnerability.

Risk

Risk is commonly defined as the magnitude of an impact and the probability of its occurrence (Blanco et al. 2009). For example, the risk posed to a structure by sea level rise depends on the rate of sea level rise, the structure's existing vulnerability, and the rate at which the structure can adapt from a behavioral and mechanical perspective. The ability to reduce the risk to a system will depend on the timescale for both implementing adaptation measures and the evolution or occurrence of the hazard (Brooks 2003). Risk is inherently connected to vulnerability, and both terms are complicated by the lack of a common metric for assessment (Blanco et al. 2009).

Adaptive Capacity

Adaptive capacity takes adaptation one step further by considering the opportunities and barriers to adaptation. Adaptive capacity is a measure of a system's ability to adjust its characteristics or behavior in order to respond to existing and future climate variability. Increasing adaptive capacity may require investment in a system and/or the creation of strategies to respond to future climate conditions (Brooks, Adger, and Kelly 2005). A system's adaptive capacity may be restricted by outside factors such as financial constraints and political challenges.

Resilience

Resilience is the measure of a system to buffer negative climate effects while maintaining its structure and function (IPCC 2007). A resilient system is the converse of a vulnerable system. A resilient system is not sensitive to climate variability and change and has the capacity to adapt (Blanco et al. 2009). In the context of future climate change, a resilient system would be able to operate at its normal capacity given more extreme climate effects such as higher or lower temperatures, greater wind speeds, and increased or decreased precipitation levels.

General Circulation Models

General circulation models (GCMs) are the most comprehensive models of the Earth's climate system. These models include the global atmosphere, the oceans, the land surface, and sea ice and snow cover. GCMs are tested by their ability to model existing and historical climate conditions, a process sometimes referred to as "backcasting" (USGCRP 2001). Uncertainties of

GCMs include the inability to model physical processes at the appropriate scale, and the difficulty of simulating various feedback mechanisms, for example water vapor and warming, and clouds and radiation (Nakicenovic et al. 2000). The IPCC and the US National Assessment Program use GCMs to provide geographically and physically consistent estimates of regional climate change and the associated potential effects (Nakicenovic et al. 2000; USGCRP 2001). These regional climate change projections can be used to select appropriate climate adaptation strategies.

Additional Resources

The preceding concepts primarily relate to green building and climate adaptation, but there are a number of other terms related to climate change. The following resources provide additional clear and concise definitions:

- *Pew Center on Global Climate Change Website:* The Pew Center on Global Climate Change brings together business leaders, policy makers, scientists, and other experts to bring new approaches to climate change. Its website offers a glossary of key terms at *www.pewclimate.org/global-warming-basics/full_glossary/glossary.php.*
- *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4):* The IPCC is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide a clear scientific view on the current state of knowledge in climate change and its impacts. A new assessment report of climate change is prepared every five to six years. A glossary for the last report in 2007 can be found at www.ipcc.ch/publications_and_data/publications_and_data_glossary.htm.
- *Federal Highway Administration (FHWA) Regional Climate Change Effects: Useful Information for Transportation Agencies:* The FWHA is committed to improving transportation mobility and safety while protecting the environment, reducing greenhouse gas emissions, and preparing for climate change effects on the transportation system. As part of recent assessment of climate change on the U.S. transportation system, it prepared a glossary of key terms found at www.fhwa.dot.gov/hep/climate/climate_effects/effects05.cfm.

References

Adger, Neil, Shardul Agrawala, M Monirul Qader, C Conde, K O'Brien, J Pulhin, R Pulwarty, B Smit, and K Takahashi. 2007. *Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC*. Edited by M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson, *Change*. Cambridge, UK: Cambridge University Press.

Blanco, H, M Alberti, A Forsyth, K Krizek, D Rodriguez, E Talen, and C Ellis. 2009. Hot, congested, crowded and diverse: Emerging research agendas in planning. *Progress in Planning* 71:153-205.

Brooks, Nick. 2003. Vulnerability, risk and adaptation: A conceptual framework. In *Event (London)*.

Brooks, N, WN Adger, and M Kelly. 2004. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change* 15:151-163.

CCSP. 2008. *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. Edited by M. J. Savonis, V. R. Burkett and J. R. Potter, *Systematics*. Washington, D.C.: Department of Transportation.

Fussel, H.M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustain Sci* 2:265-275.

IPCC. 2007. *Climate Change 2007: Imacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. v. d. Linden and C. E. Hanson. Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Moser, SC. 2009. Good Morning, America! The explosive US awakening to the need for adaptation. Santa Cruz, CA.

Nakicenovic, N., O. Davidson, G. Davis, A. Grübler, T. Kram, E. Lebre La Rovere, B. Metz, T. Morita, W. Pepper, H. Pitcher, A. Sankovski, P. Shukla, R. Swart, R. Watson, and Z. Dadi. 2000. IPCC Emissions Scenarios. In *Group*.

U.S. EPA. *EPA Green Building Website* 2011. Available from http://www.epa.gov/greenbuilding/.

U.S. Green Building Council. 2010. Green Building and LEED Core Concepts Guide. Washington, D.C.

USGCRP. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. In *Environmental Conservation*. Cambridge, UK.

———. 2009. Global Climate Change Impacts in the United States. In *Society*. New York.

APPENDIX B: Regional Climate Change Impacts

The predicted effects of climate change vary significantly by region. In order to design resilient and adaptable green buildings and neighborhoods, it is essential that green building professionals understand how climate change is likely to impact a region, and how these changes will manifest in the built environment. The tables that follow summarize regional climate change impacts drawn from the literature. The information also suggests potential effects on the built environment and ways to measure these effects.

The climate impacts presented here are taken primarily from the United States Global Change Research Program (USGCRP; formerly known as the Climate Change Science Program (CCSP)). Mandated by Congress in 1990, its mission is "to build a knowledge base that informs human responses to climate and global change through coordinated and integrated federal programs of research, education, communication, and decision support" (USGCRP 2010). The USGCRP includes 13 U.S. departments and agencies, ranging from the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF), to the Department of Energy (DOE) and the Department of Defense (DOD).

The USGCRP's 2009 report, *Global Climate Change Impacts in the United States,* is the most comprehensive source for information on regional climate change impacts in the United States. It compiles the results of the CCSP's 21 previous Synthesis and Assessment Products (SAPs), each focused on a key climate change issue.

Another important input to the USGCRP report is the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. The IPCC is the world's leading organization for the compilation, review and dissemination of the current "state of the knowledge on climate change" (IPCC 2010). The USGCRP report draws upon many additional external peer-reviewed sources such as the Transportation Research Board, the Arctic Climate Impact Assessment, the National Center for Atmospheric Research (NCAR), and regional climate change impact studies. In a collaborative effort led by NOAA, the report was written and reviewed by a group of highly respected scientists in federal agencies, private consulting firms, research universities and Department of Energy national laboratories. Figure B1 shows the flow of research and information that inform the USGCRP report, the source for many of the climate change impacts reported here.

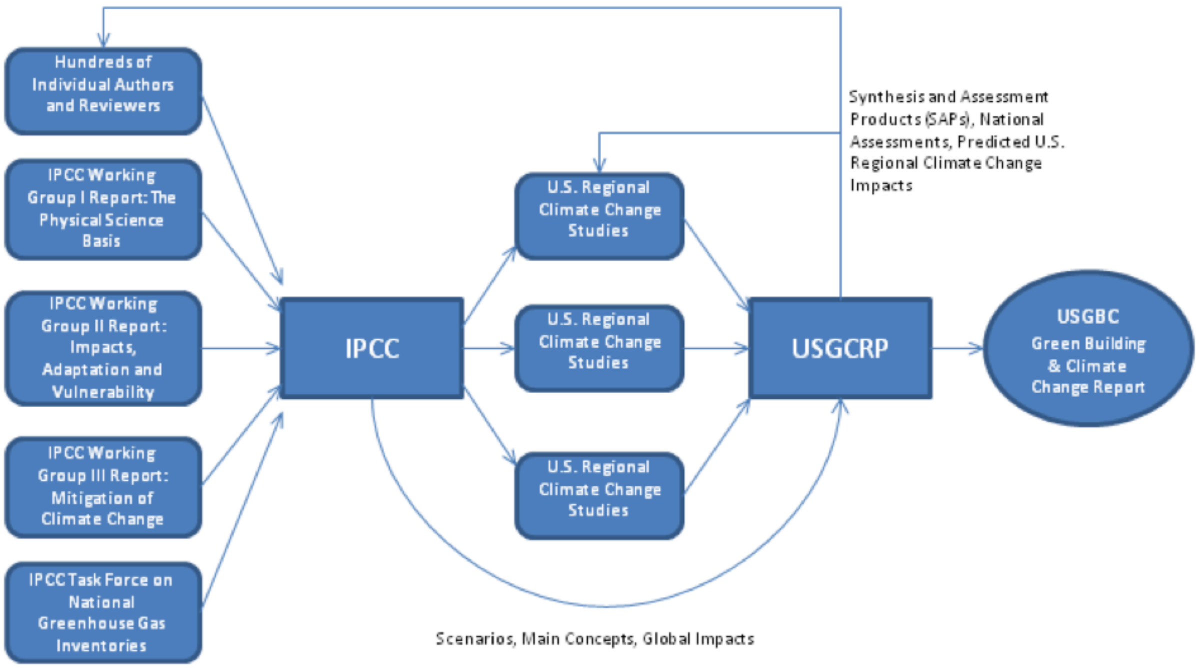


Figure B-1: Sources of Data for Climate Change Impacts Presented in Appendix B

Structure of the Climate Impacts Tables

The following tables list predicted climate impacts by region. Impacts are presented by category (e.g., temperature, precipitation) and in four time frames: observed by 2010, near-term (2010-2040), mid-term (2040-2070), and long-term (2070-2100). These tables provide predictions about future climate; however, these impacts are by no means certain. Future climate depends on an extremely complex set of variables, some of which are linked to human behavior. Therefore, future climate characteristics are uncertain and often studied using two or more emissions scenarios reflecting different possible futures. Some impacts are reported as a range of values, reflecting the uncertainty inherent in predicting future climate. These tables are designed as reference tools to provide green building professionals with a “first look” at the challenges regions will face under climate change. However, regional impacts may not provide the level of resolution needed to respond to all the risks that climate change poses at the local level. It may be necessary for green building professionals to seek out additional local sources of climate change data and impacts to supplement these data.

Northeast Region Climate Change Impacts

The Northeast can expect continued warming and associated climate change effects. Correlated impacts of warming will likely include the following (USGCRP 2009):

- Increasing frequency and intensity of extreme heat events
- Shorter winters with fewer cold days and more precipitation
- Short-term droughts as frequently as once each summer
- Sea level rise that exceeds the global average
- Increased flooding from more frequent and intense rain events
- Reduced snow cover, affecting stream flows

The associated impacts of climate change on the Northeast region will likely have substantial economic, social, and environmental ramifications. In addition, the Northeast region contains several major urban areas located in coastal or watershed areas. New York City, Boston, and Philadelphia are the 1st-, 5th-, and 8th- largest Combined Statistical Areas, respectively, in the United States (U.S. Census Bureau, 2009). Thus, the climate impacts of sea-level rise and more intense precipitation will have a substantial impact on the urban centers of the Northeast.

Predicted Climate Change Impacts: Northeast Region

	Climate Change Impacts	Relative To†	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 1.5 degrees F	↑ Increase of 1.3 to 3.8 degrees F‡	↑ Increase of 1.9 to 6.8 degrees F‡	↑ Increase of 3 to 12.5 degrees F‡	↑ Increased summertime HVAC energy usage (kWh), ↓ Decreased wintertime HVAC energy usage (kWh)
	Average summer air temperature	1961-1979	n/a	↑ Increase of 1.3 to 3.7 degrees F‡	↑ Increase of 1.8 to 6.9 degrees F‡	↑ Increase of 2.7 to14.1 degrees F‡	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)[1]	1960-1990	n/a	↑ 50% to 100% increase	↑ 300% - 700% increase	↑ 300% - 1200% increase	↑ Increased number of cooling degree days (cooling degree days); ↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of extreme heat events (yearly likelihood of event occurring)	5% yearly chance (20-year event recurrence)	n/a	↑	↑	↑ 50% - 100% yearly chance (1-2 year event recurrence)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Average winter air temperature	1961-1979	n/a	↑ Increase of 0.9 to 4.7 degrees F‡	↑ Increase of 1.8 to 7.9 degrees F‡	↑ Increase of 3.5 to 12.8 degrees F‡	↓ Decreased wintertime HVAC energy demand (kW), ↑ Increased winter rainfall (inches as rain), ↑ Increased risk of freeze/thaw damage (freezing rainfall events)
WATER/PRECIPITATION	Snowpack[1]	2010	n/a	↓	↓	↓ 4 to15 less snow-covered days in Northeast, ↓ 25% to 50% decrease in North, ↓ up to 89% decrease in South	↑ Increased energy consumption for snow production at winter recreational facilities (kWh), ↓ Decreased need for snow/ice removal services (events/year)
	Change in summer precipitation	1961-1979	n/a	↑ +2% (ave. prediction) -5% to +10% (very likely range)	↑ +1% to +2% (ave. prediction) -12% to +14% (very likely range)	-1% to +2% (ave. prediction) -24% to +23% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Change in winter precipitation	1961-1979	n/a	↑ +6% (ave. prediction) -2% to +15% (very likely range)	↑ +8% to +11% (ave. prediction) -4% to +26% (very likely range)	↑ 11% to 17% (ave. prediction) -4% to +36% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Intensity/duration of precipitation[1]	1961-1979	n/a	↑ 7% intensity ↑ 9% to 12% duration	↑ 8% intensity ↑ 8% to 13% duration	↑ 12% to 13% intensity ↑ 18% to 22% duration	↑ Increased flooding of low-lying areas (yearly days flooded). ↑ Increased overload and backup of stormwater drainage systems and combined sewer systems (# of days flooded; gal of overflow per year). ↑ Increased risk of water contamination (reported illnesses per year). ↑ Higher flood insurance rates (yearly premium).
COASTAL	Sea-level rise[2]	1981-2000	n/a	↑	↑	↑ 36 to 51 cm for New York, ↑ 37 to 52 cm for Boston, ↑ 33 to 44 cm for Washington D.C.	↑ Increased inundation of low-lying areas (yearly days flooded); ↓ loss of coastal lands (yearly sq. feet lost); ↑ Increased potential for substantial flooding in city cores (sq miles inundated)
	Storm surge frequency[3]	2005	n/a	↑ (Broad variability by geography)	↑ 100-year flood event occurs every 3 to 72 years (Broad variability by geography)	↑ 100-year flood event occurs every 2 to 49 years (Broad variability by geography)	↑ Increased risk of damage to buildings and infrastructure near coasts (cost of repair / reconstruction); ↑ Increased risk of flooding from storm surges (frequency of inundation)
	Storm surge elevation[3]	1961-2003	n/a	↑ (Broad variability by geography)	↑ 12 to 73 cm (Broad variability by geography)	↑ 18 to 189 cm (Broad variability by geography)	↑ Increased danger of inundation during storms (flood events/yr), ↑ Increased erosion in coastal areas (area lost / yr)
AIR QUALITY	Ground-level ozone[1]	2007	n/a	↑	↑	↑ 50% to 300% increase in days exceeding EPA 8hr ozone standard, ↑ 0% to 25% increase in average ground-level ozone concentration	↑ Increased air filtration needs, ↓ Decreased ability to use outside air for venting (ozone events/yr)
PESTS	Insect infestation	n/a	n/a	↑	↑	↑	↑ Increased risk of damage to buildings due to insect infestation; ↑ Increased vulnerability of landscape trees to infestation (number of trees replaced per year)
FIRE	Frequency and severity of drought periods	1958-2007	Hemlock wooly adelgid infestation	↑	↑	↑	↑ Increased vulnerability to wildfires near forested areas where trees have died (# of structures damaged; # of structures destroyed)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009.

Additional Sources:

[1] (NECIA 2007)

[2] (Yin et al. 2009)

[3] (Kirshen et al. 2008)

†Historical base periods used to establish reference points that predate significant climate change impacts

‡ Temperature ranges based on IPCC "very likely" range

Southeast Region Climate Change Impacts

The Southeast should expect increased warming, with the greatest seasonal increase in temperature occurring during the winter months. The impacts of increased warming will be greater temperature increases during the summer, declining rainfall in Southern Florida and in the Gulf Coast States during winter and spring, increased intensity of Atlantic hurricanes, and accelerated sea-level rise. The changing regional climate is expected to have the following impacts (USGCRP 2009):

- Increased heat-related stresses for people, plants, and animals
- Decreased water availability
- Increased damage from higher-intensity hurricanes and associated storm surge
- Sea-level rise

Over the next 50 to 100 years, severe heat extremes, water scarcity, and extreme weather events will have a dramatic effect on local urban areas and natural systems throughout the southeast region.

Predicted Climate Change Impacts: Southeast Region

	Climate Change Impacts	Relative To[†]	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 1.2 degrees F	↑ Increase of 1.2 to 3.2 degrees F‡	↑ Increase of 1.6 to 5.5 degrees F‡	↑ Increase of 2.4 to 10.9 degrees F‡	↑ Increased summertime HVAC energy usage (kWh); ↓ Decreased wintertime HVAC energy usage (kWh)
	Average Summer air temperature	1961-1979	n/a	↑ Increase of 0.7 to 3.8 degrees F‡	↑ Increase of 1.6 to 6.7 degrees F‡	↑ Increase of 2.3 to13.5 degrees F‡	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)	1961-1979	n/a	↑	↑	↑ Increase of 100% or more	↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of extreme heat events (yearly likelihood of event occurring)[1]	5% yearly chance (20-year event recurrence)	n/a	↑	↑	50% - 100% yearly chance of (1-2 year event recurrence)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Average Winter air temperature	1961-1979	n/a	↑ Increase of 0.3 to 3.6 degrees F‡	↑ Increase of 0.5 to 5.4 degrees F‡	↑ Increase of 1.7 to 9.4 degrees F‡	↓ Decreased wintertime HVAC energy demand (kW); ↑ Increased number of cooling degree days (cooling degree days);
WATER/PRECIPITATION	Availability of fresh water[2]	2010	n/a	↓	↓	↓	↑ Increased # of days with irrigation restrictions (days per year); ↑ Increased # of days with service interruption (days per year); ↓ Decreased available water pressure (low-pressure days);
	Change in summer precipitation	1961-1979	n/a	0% (ave. prediction) -16% to +16% (very likely range)	↓ 0% to -2% (ave. prediction) -26% to +23% (very likely range)	↓ 0% to -8% (ave. prediction) -50% to +35% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
	Change in winter precipitation	1961-1979	n/a	-1% to 0% (ave. prediction) -11% to +9% (very likely range)	-2% to +1% (ave. prediction) -15% to +16% (very likely range)	↓ -3% to 0% (ave. prediction) -28% to +22% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Intensity of precipitation (seasonal polarity)	1961-1979	n/a	0% change in summer ↑ 1 to 2% in fall	↓ 0% to 2% in summer ↑ 1% to 2% in fall	↓ 0 to 8% in summer ↑ 2% to 3% in fall	↑ Increased seasonal flooding of low-lying areas (yearly days flooded).
	Duration and severity of droughts	Mid 1970s	↑ 12% to14% in spring and summer; 9% in fall	↑	↑	↑	↑ Increased dependence on irrigation systems (frequency of use, volume of water consumed); ↑ increased possibility of wildfires (fire events/year)
COASTAL	Sea-level rise	1980-1999	n/a	n/a	↑ 2.5ft to 3ft for LA/TX Chenier Plane; 3.5ft to 4ft for LA Deltaic Plain; 1.5ft to 2ft for MS-AL Sound	↑ 4ft to 5ft for LA/TX Chenier Plane; 5.5ft to 6ft for LA Deltaic Plain; 1ft to 3ft for MS-AL Sound	↑ Increased inundation of low-lying areas (yearly days flooded); ↓ loss of coastal lands (yearly sq. feet lost);
	Storm intensity and frequency	1975	↑	↑	↑	↑ 5% for category 1 storms; 20% for category 4 storms; 1 to 4 additional storms per year	↑ Increased building and infrastructural damage (cost of repair / reconstruction); ↑ Increased risk of flooding from storm surges (frequency of inundation); ↑ Increased hurricane insurance rates (yearly premium)
	Land subsidence and loss of coastal landforms	2010	Broad variability by geography	Broad variability by geography	Broad variability by geography	Broad variability by geography	↓ Yearly decline in elevation relative to current sea level (ft.); ↑ Loss of coastal landforms (number or sq. miles lost)
AIR QUALITY	Ground-level ozone	1996-2000	n/a	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	Under higher emissions scenario: ↑Increased need to filter indoor air to maintain IEQ (# of symptom complaints per season); ↓Decreased ability to use outdoor air ventilation (# of action days per year)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009.

Additional Sources:

[1] EPA, Excessive Heat Events Guidebook, 2006

[2] USDA Forest Service, E. Cohen et al., 2008

†Historical base periods used to establish reference points that predate significant climate change impacts

‡ Temperature ranges based on IPCC "very likely" range

Midwest Region Climate Change Impacts

The Midwest region is characterized by the vast agricultural lands that comprise a majority of its landmass. The warming of the climate will have mixed impacts on both the natural systems and the human populations of the Midwest. The two primary climatic changes will be an increase in the temperature throughout the year, and increasing variability in precipitation patterns. These climatic changes will produce the following impacts (USGCRP 2009):

- Increasingly frequent and sever heat waves
- Less severe cold during winter
- Increased precipitation during winter and spring, with heavier downpours resulting in more floods
- Reduced Great Lakes water levels
- Increased number of insects due to milder winters
- Decreased air quality

Predicted Climate Change Impacts: Midwest Region

	Climate Change Impacts	Relative To†	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 2.0 degrees F	↑ Increase of 1.3 to 3.9 degrees F‡	↑ Increase of 1.9 to 7.0 degrees F‡	↑ Increase of 3.0 to 13.8 degrees F‡	↑ Increased summertime HVAC energy usage (kWh), ↓ Decreased wintertime HVAC energy usage (kWh)
	Average summer air temperature	1961-1979	n/a	↑ Increase of 1.0 to 4.7 degrees F‡	↑ Increase of 1.5 to 8.3 degrees F‡	↑ Increase of 2.7 to 17.5 degrees F‡	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)	1960-1990	n/a	↑	↑	↑ Increase up to 100%	↑ Increased number of cooling degree days (cooling degree days); ↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of heat waves (yearly likelihood of event occurring)[1]	1995 Chicago / Milwaukee Heat Wave	n/a	Once every 10 years (lower emissions) Once every 6 years (higher emissions)	Once every 4 years (lower emissions) Once per year (higher emissions)	Once every 2 years (lower emissions) 3 times per year (higher emissions)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Average winter air temperature	1961-1979	↑ Increase of 5 to 6 degrees F	↑ Increase of 0.6 to 4.9 degrees F‡	↑ Increase of 1.7 to 7.9 degrees F‡	↑ Increase of 3.3 to 13.5 degrees F‡	↓ Decreased wintertime HVAC energy demand (kW); ↓ Decreased usage of outdoor wintertime amenities, like ice rinks (average weekly users).
	Number of days below freezing	1961-1979	n/a	n/a	↓ Decrease of 20 days per year	↓ Decrease of 40 days per year	Shift in tree species to the North (less maple, beech, and birch; more oak, hickory, and complete loss of spruce-fir)
WATER/PRECIPITATION	Winter precipitation	1961-1979	n/a	↑ +6% to +7% (ave. prediction) -3% to +16% (very likely range)	↑ +8% to +9% (ave. prediction) -6% to + 21% (very likely range)	↑ +10% to +14% (ave. prediction) -3% to + 30% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Summer precipitation	1961-1979	n/a	↓ -1% (ave. prediction) -14% to +13% (very likely range)	↓ -1% to -4% (ave. prediction) -26% to + 19% (very likely range)	↓ -2% to -9% (ave. prediction) -53 to + 36% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
	Frequency and intensity of extreme precipitation events[2,3]	2009	↑ Increased frequency of 27% ↑ Increased intensity of 31% (1958 to 2007)	↑ up to 15% increase in frequency ↑ 20% to 66% increase in intensity (variable by geography)	↑	↑ 50% to 100% increase in frequency	↑ Increased flooding of low-lying areas (yearly days flooded). ↑ Increased overload and backup of stormwater drainage systems and combined sewer systems (# of days flooded; gal of overflow per year). ↑ Increased risk of water contamination (reported illnesses per year). ↑ Higher flood insurance rates (yearly premium).
COASTAL	Great Lakes average level	2010	n/a	↓ 0.2 to 0.3 ft drop (variable by lake)	↓ 0.7 to 1.7 ft drop (variable by lake)	↓ 0.6 to 1.9 ft drop (variable by lake)	↑ Increased distance to lakeshore (feet). ↑ Increased dredging costs (average cost per year). ↑ Increased electricity costs due to loss of hydroelectric generation capacity (cost per kWh)
AIR QUALITY	Ground-level ozone	1996-2000	n/a	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	Under higher emissions scenario: ↑Increased need to filter indoor air to maintain IEQ (# of symptom complaints per season); ↓Decreased ability to use outdoor air ventilation (# of action days per year)
PESTS	Insect infestation	n/a	n/a	↑	↑	↑	↑Increased risk of damage to buildings due to insect infestation; ↑Increased vulnerability of landscape trees to infestation (number of trees replaced per year)
FIRE	Frequency and severity of drought periods	1958-2007	Increasing in most areas	↑	↑	↑	↑Increased vulnerability to wildfires near forested areas (# of structures damaged; # of structures destroyed)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009

Additional Sources:

[1] Ebi and Meehl, 2007

[2] Union of Concerned Scientists, 2009

[3] Groisman et al., 2005

†Historical base periods used to establish reference points that predate significant climate change impacts

‡ Temperature ranges based on IPCC "very likely" range

Great Plains Region Climate Change Impacts

While the Great Plains region is primarily categorized as having semi-arid conditions (USGCRP 2009), there are substantial climatic differences between different areas within the region, particularly from north to south. Projected increases in temperature are expected to have the greatest impacts in the summer, while precipitation changes are expected to have the greatest impacts during winter and spring. Precipitation is expected to increase in the north and decrease in the south. According to the 2009 USGCRP Report, the primary impacts of the climatic changes will be:

- Increased drought frequency due to increased temperature and evaporation rates leading to increased water scarcity
- Declining air quality due to increased pollen and ozone levels
- Shifting habitat zones affecting the distribution of native plant and animal species and increasing risk of insect infestation

Predicted Climate Change Impacts: Great Plains Region

	Climate Change Impacts	Relative To†	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 1.3 degrees F	↑ Increase of 1.1 to 3.8 degrees F‡	↑ Increase of 1.6 to 6.9 degrees F‡	↑ Increase of 2.5 to 13.2 degrees F‡	↑ Increased summertime HVAC energy usage (kWh), ↓ Decreased wintertime HVAC energy usage (kWh)
	Average Summer air temperature	1961-1979	n/a	↑ Increase of 0.8 to 4.6 degrees F‡	↑ Increase of 1.7 to 8.7 degrees F‡	↑ Increase of 2.4 to 16.6 degrees F‡	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)	1961-1979	n/a	↑	↑	↑ Increase up to 100%	↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of extreme heat waves (yearly likelihood of event occurring)	5% yearly chance (20-year event recurrence)	n/a	↑	↑	↑ 50% to 100% yearly chance (1 or 2 year event recurrence)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Average Winter air temperature	1961-1979	n/a	↑ Increase of 0.6 to 4.2 degrees F‡	↑ Increase of 1.2 to 6.9 degrees F‡	↑ Increase of 2.2 to 12.5 degrees F‡	↓ Decreased wintertime HVAC energy demand (kW), ↑ Increased risk of freeze/thaw damage (freezing rainfall events).
WATER/PRECIPITATION	Availability of water resources	1950	↓ 9% decrease in aquifer storage	↓	↓	↓	↑ Increased # of days with irrigation restrictions (days per year); ↑ Increased # of days with service interruption (days per year); ↓ Decreased available water pressure (low-pressure days).
	Change in summer precipitation	1961-1979	n/a	↓ -2% to -3% (ave. prediction) -15% to +11% (very likely range)	↓ -3% to -5% (ave. prediction) -30% to +19% (very likely range)	↓ -3% to -9% (ave. prediction) -49% to +31% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
	Change in winter precipitation	1961-1979	n/a	↑ +3% (ave. prediction) -5% to +10% (very likely range)	↑ +4% to +5% (ave. prediction) -6% to +14% (very likely range)	↑ +5% to +8% (ave. prediction) -9% to +25% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Intensity/duration of precipitation	1961-1979 (1958)	n/a, ↑ 13% increase in number of days with very heavy precipitation since 1958	↑ 7% intensity ↑ 9% to 12% duration	↑ 8% intensity ↑ 8% to 13% duration	↑ 12% - 13% intensity ↑ 18% - 22% duration	↑ Increased flooding of low-lying areas (yearly days flooded). ↑ Increased overload and backup of stormwater drainage systems and combined sewer systems (# of days flooded; gal of overflow per year). ↑ Higher flood insurance rates (yearly premium).
AIR QUALITY	Pollen levels	n/a	n/a	↑	↑	↑	↑ Increased need to filter indoor air to maintain IEQ (# of symptom complaints per season)
	Ground-level ozone	2007	n/a	↑	↑	↑ 50% to 300% increase in days exceeding EPA 8hr ozone standard ↑ 0% to 25% increase in average ground-level ozone concentration	↑ Increased need to filter indoor air to maintain IEQ (# of symptom complaints per season), ↓ Decreased ability to use outdoor air ventilation (# of action days per year)
PESTS	Greater numbers, earlier emergence, and northward migration of insects	n/a	n/a	↑	↑	↑	↑ Increased need for pest control services (# of pest complaints per season); ↑ Increased damage to landscaping and green roofs (% of greenery damaged; yearly plant replacement costs)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009

†Historical base periods used to establish reference points that predate significant climate change impacts
‡ Temperature ranges based on IPCC "very likely" range

Southwest Region Climate Change Impacts

The Southwest region covers the land area from the Rocky Mountains to the Pacific Coast. While it is primarily arid or semi-arid, there is substantial variety in the geology, topography, and precipitation patterns throughout the region (USGCRP 2009). The general global warming trend is projected to have a significant impact on the regional climate of the Southwest. The region is likely to experience a significant increase in summer temperatures and in the variability of water cycles. Climate change is expected to have the following impacts:

- Scarcity of water supplies due to reduced snowpack, longer periods of low precipitation, shorter winters, longer summers, and increased evaporation
- Higher frequency and altered timing of flooding (shifting more to winter and early spring)
- Transformation of the landscape due to increasing temperature, drought, wildfires, and invasive species
- Increased water conflicts between agricultural and urban needs

Predicted Climate Change Impacts: Southwest Region

	Climate Change Impacts	Relative To[†]	Observed by 2010	Near-Term Projections (2010-2040)[‡]	Mid-Term Projections (2040-2070)[‡]	Long-Term Projections (2070-2100)[‡]	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 1.6 degrees F	↑ Increase of 1.0 to 3.7 degrees F[‡]	↑ Increase of 1.6 to 6.4 degrees F[‡]	↑Increase of 2.5 to 11.8 degrees F[‡]	↑ Increased summertime HVAC energy usage (kWh), ↓ Decreased wintertime HVAC energy usage (kWh)
	Average Summer air temperature	1961-1979	↑ Increase of 1.6 degrees F	↑ Increase of 1.1 to 4.2 degrees F[‡]	↑ Increase of 2.1 to 7.7 degrees F[‡]	↑ Increase of 2.8 to 13.5 degrees F[‡]	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)[1]	1961-1979	n/a	↑	↑	↑ Increase up to 100%	↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of extreme heat events (yearly likelihood of event occurring)[1]	5% yearly chance (20-year event recurrence)	n/a	↑	↑	50% to 100% yearly chance of (1-2 year event recurrence)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Average Winter air temperature	1961-1979	n/a	↑ Increase of 0.6 to 3.8 degrees F[‡]	↑ Increase of 0.8 to 6.2 degrees F[‡]	↑ Increase of 1.8 to 11.3 degrees F[‡]	↓ Decreased wintertime HVAC energy demand (kW); ↑ Increased number of cooling degree days (cooling degree days)
WATER/PRECIPITATION	Availability of fresh water supplies	2010	n/a	↓	↓	↓	↑ Increased # of days with irrigation restrictions (days per year); ↑ Increased # of days with service interruption (days per year); ↓ Decreased available water pressure (low-pressure days).
	Winter precipitation	1961-1979	n/a	↑ +2% to +4% (ave. prediction) -16% to +24% (very likely range)	↑ +1% to +5% (ave. prediction) -17% to + 27% (very likely range)	↑ +2% to +5% (ave. prediction) -30% to + 40% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Summer precipitation	1961-1979	n/a	↓ -4% to -5% (ave. prediction) -23% to +13% (very likely range)	↓ -5% to -8% (ave. prediction) -36% to + 21% (very likely range)	↓ -3% to -5% (ave. prediction) -43 to + 32% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season); ↑ Increased # of days with irrigation restrictions (days per year);
	Frequency and intensity of extreme precipitation	1958-2007	↑ Increased frequency of 16% ↑Increased intensity of 9%	↑	↑	↑	↑ Increased flooding of low-lying areas (yearly days flooded). ↑ Increased overload and backup of stormwater drainage systems and combined sewer systems (# of days flooded; gal of overflow per year). ↑ Higher flood insurance rates (yearly premium).
	Volume of runoff and stream flows	1901-1970	n/a	↓	↓ Decrease of 10% to 40% with driest areas experiencing largest declines.	↓	↓ Decreased volume of stormwater available for capture and use on-site (Gallons per year)
	Risk of flooding in river delta areas	2010	n/a	↑	↑ 2x today's risk	↑ 8x today's risk	Difficult to measure because impacts will likely manifest rapidly, not gradually. Source of impact will often be separated by great distances from building/neighborhood site.
COASTAL	Extreme sea-level rise events[2]	1958-2008	n/a	↑ increase by as much as 30%	↑ increase by as much as 700%	↑ Predicted 2 - 4 ft. overall rise	↑ Increased inundation of low-lying areas (yearly days flooded); ↓ loss of coastal lands (yearly sq. feet lost); ↑ increased vulnerability during El Nino years (days flooded during El Nino years).
	Land subsidence	2010	Broad variability by geography	Broad variability by geography	Broad variability by geography	Broad variability by geography	↓ Increased risk of flooding due to sea level rise and storm surge (yearly decline in elevation relative to current sea level).
PESTS	Insect infestation	n/a	Piňon Pine infestation	↑	↑	↑	↑ Increased risk of damage to buildings from insects; ↑ Increased vulnerability of landscape trees to infestation (number of trees replaced per year); ↑ Increased risk of damage from forest fires
STORMS	Intensity of strongest hurricanes	1980s	↑ Increased intensity of strongest 5%	↑	↑	↑ Increased incidence of category 4 and 5 hurricanes	↑ Increased risk of damage from strong storms near coast (yearly damage from strong storms); ↑ Increased insurance costs in coastal areas (yearly hurricane insurance premiums)
AIR QUALITY	Ground-level ozone	1996-2000	n/a	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	Under higher emissions scenario: ↑ Increased need to filter indoor air to maintain IEQ; ↓Decreased ability to use outdoor air ventilation (# of action days per year)
FIRE	Frequency and severity of drought periods[3]	1958-2007	Broad variability by geography	↑	↑	↑	↑ Increased vulnerability to wildfires near forested areas (# of structures damaged; # of structures destroyed)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009

Additional Sources:

[1] Diffenbaugh et. al., 2005

[2] Cayan et al., 2009

[3] Westerling et al. 2006

†Historical base periods used to establish reference points that predate significant climate change impacts

‡ Temperature ranges based on IPCC "very likely" range

Northwest Region Climate Change Impacts

Observations show that average annual temperature has increased by 1.5 degrees F in the Northwest region during the past century. This trend is very likely to continue and accelerate. Associated climate impacts include increased winter and decreased summer precipitation, declining snow packs, and rising sea level. Some specific effects of climate change in the region include (USGCRP 2009):

- Reduced summer stream flows resulting in strained water supplies
- Increased flooding associated with severe weather
- Increased frequency of wildfires
- Sea-level rise that will increase vulnerability and erosion along coastlines
- Increased insect outbreaks

Predicted Climate Change Impacts: Northwest Region

	Climate Change Impacts	Relative To[†]	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Mean annual air temperature	1961-1979	↑ Increase of 1.5 to 4.0 degrees F	↑ Increase of 0.7 to 3.7 degrees F[‡]	↑ Increase of 1.6 to 6.4 degrees F[‡]	↑Increase of 2.3 to 11.8 degrees F[‡]	↑ Increased summertime HVAC energy usage (kWh), ↓ Decreased wintertime HVAC energy usage (kWh)
	Mean Summer air temperature	1961-1979	n/a	↑ Increase of 0.7 to 4.6 degrees F[‡]	↑ Increase of 1.8 to 8.4 degrees F[‡]	↑ Increase of 2.5 to 15.7 degrees F[‡]	↑ Increased summertime HVAC energy demand (kW)
	Frequency of extremely hot days (high temperatures at or above 90 degrees F)	1961-1979	n/a	↑	↑	↑ Increase of up to 100%	↑ Increased number of cooling degree days (cooling degree days); ↑ Increased HVAC tonnage needed to achieve comfort levels (total installed tonnage); ↑ Increased symptom complaints during Summer months (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly outages).
	Frequency of heat waves [1]	1970 -1999	n/a	↑	↑ Increase of up to 3 additional heat waves per year. Particularly in central NW areas.	↑	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages); ↓ Decreased summertime usage of outdoor areas (average weekly users).
	Number of warm nights[1]	20th Century 90th percentile min. temperature	n/a	↑	↑	↑	↑ Increased summertime night-hours HVAC energy usage (kWh).
	Mean Winter air temperature	1961-1979	n/a	↑ Increase of 0.6 to 3.8 degrees F[‡]	↑ Increase of 1.1 to 6.5 degrees F[‡]	↑ Increase of 1.8 to 11.4 degrees F[‡]	↓ Decreased wintertime HVAC energy demand (kW),; ↑ Increased risk of freeze/thaw damage (freezing rainfall events).
WATER/PRECIPITATION	Summer streamflows and peak spring runoff timing	1950-2002	Average streamflow decline of 25% (up to 60%)	↓	↓	Peak runoff timing shifting 20-40 days earlier.	↑ Increased # of days with irrigation restrictions (days per year); ↑ Increased # of days with service interruption (days per year); ↓ Decreased available water pressure (low-pressure days). ↑ Increased Summer electricity rates.
	Change in summer precipitation	1961-1979	n/a	↓ -6% to -7% (ave. prediction) -27% to +12% (very likely range)	↓ -8% to -17% (ave. prediction) -40% to +10% (very likely range)	↓ -11% to -22% (ave. prediction) -62% to +18% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
	Change in winter precipitation	1961-1979	n/a	↑ +3% to +5% (average) -11% to +20% (very likely range)	↑ +5% to +7% (average) -12% to +27% (very likely range)	↑ 8% to 15% (ave. prediction) -14% to +43% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Frequency and intensity of extreme precipitation events	1958-2007	↑ Increased frequency of 12% ↑ Increased intensity of 16%	↑	↑	↑	↑ Increased flooding of low-lying areas (yearly days flooded). ↑ Increased overload and backup of stormwater drainage systems and combined sewer systems (# of days flooded; gal of overflow per year). ↑ Increased risk of water contamination (reported illnesses per year). ↑ Higher flood insurance rates (yearly premium).
	Winter precipitation mix	2010	n/a	↑ Increased Rain ↓ Decreased Snow	↑ Increased Rain ↓ Decreased Snow	↑ Increased Rain ↓ Decreased Snow	↑ Increased Winter flooding in watersheds West of the Cascades (days flooded per winter). ↑ Increased frequency and severity of landslides in coastal areas.
COASTAL	Coastal Erosion	2010	n/a	↑	↑	↑	↓ Loss of beaches and coastal land (sq feet lost per year)
	Net sea-level rise (after land subsidence or uplift)[2]	1958-2008	Broad variability by geography	Broad variability by geography	Broad variability by geography	↑ Predicted 1 - 4 ft. overall rise	↑ Increased inundation of low-lying areas, particularly around Puget Sound (yearly days flooded); ↓ loss of coastal lands (yearly sq. feet lost); ↑ increased vulnerability during El Nino years (days flooded during El Nino years). ↑ Increased vulnerability during winter months due to seasonal variations in sea level.
PESTS	Insect infestation[3]	n/a	Mountain Pine Beetle Infestation of up to 40% of mature pine forest in some areas.	↑	↑	↑	↑ Increased risk of damage to buildings due to insect infestation; ↑ Increased vulnerability of landscape trees to infestation; ↑ Increased risk of forest fires
STORMS	Intensity of strongest hurricanes	1980s	↑ Increased intensity of strongest 5%	↑	↑	↑	Although overall incidence of pacific hurricanes will decrease, the intensity of the strongest storms is likely to increase. (# of category 4 and 5 storms per decade)
	Risk of Pacific hurricane landfalls	2010	n/a	↑	↑	↑	↑ increased risk of hurricane landfalls along Pacific coast, particularly during El Nino years. (# of pacific hurricane landfalls per decade)
AIR QUALITY	Ground-level ozone	1996-2000	n/a	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	↑ under higher emissions scenario ↓under lower emissions scenario	Under higher emissions scenario: ↑ Increased need to filter indoor air to maintain IEQ; ↓Decreased ability to use outdoor air ventilation (# of action days per year)
FIRE	Frequency and severity of drought periods	1958-2007	Increasing in most areas	↑	↑	↑	↑ Increased vulnerability to wildfires near forested areas (# of structures damaged; # of structures destroyed)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009

Additional Sources:

[1] Salathe et. al., 2009

[2] Mote et al., 2008

[3] Ryan et al., 2008

[†] Historical base periods used to establish reference points that predate significant climate change impacts

[‡] Temperature ranges based on IPCC "very likely" range

Alaska Region Climate Change Impacts

On average Alaska has warmed twice as much as the rest of the United States, and its average temperature could increase by as much as 13 degrees F by 2100. The increase in average temperature is projected to result in increased frequency and intensity of precipitation, longer summers, shorter winters, and sea-level rise. The effects of the anticipated climate changes include the following (USGCRP 2009):

- Longer, warmer summers resulting in drier conditions (despite increased precipitation)
- Increased intensity and frequency of coastal storms
- Land subsidence/settling due to thawing permafrost damaging runways, water and sewer systems, and other infrastructure
- Increased coastal erosion
- More frequent wildfires
- Increased outbreaks of insects

Predicted Climate Change Impacts: Alaska

	Climate Change Impacts	Relative To†	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 3.4 degrees F	↑ Increase of 0.4 to 4.7 degrees F‡	↑ Increase of 2.9 to 5.7 degrees F‡	↑ Increase of 2.4 to 13.5 degrees F‡	↑ Increased summertime HVAC energy usage (kWh); ↓ Decreased wintertime HVAC energy usage (kWh)
	Average Summer air temperature	1961-1979	n/a	-0.1 to 2.8 degrees F‡	-0.8 to 5 degrees F‡	-1 to13.9 degrees F‡	↑ Increased summertime HVAC energy demand (kW)
	Thawing permafrost	1970s	↑	↑ Increased thawing; ↑ 10% to 20% higher infrastructure maintenance costs	↑	↑	↑ Increased land subsidence (area/year), ↑ Increased damage to infrastructure from sinking land ($ economic loss per year)
	Reduced access and mobility due to loss of ice	n/a	↓	↓	↓	↓	↓ Decreased mobility and accessibility (# of days inaccessible; average travel time)
	Frequency of extreme heat events (yearly likelihood of event occurring)	5% yearly chance (20-year event recurrence)	n/a	↑	↑	10% yearly chance (10-year event recurrence)	↑ Increased summertime night-hours HVAC energy usage (kWh); ↑ Increased summertime symptom complaints (Summer complaints); ↑ Increased frequency of brownouts and blackouts (yearly service outages);
	Average Winter air temperature	1961-1979	n/a	-1 to +8 degrees F‡	↑ Increase of 4 to 9 degrees F‡	↑ Increase of 5 to 20 degrees F‡	↓ Decreased wintertime HVAC energy demand (kW), ↑ Increased winter rainfall (inches as rain), ↑ Increased risk of freeze/thaw damage (seasonal maintenance costs)
WATER/PRECIPITATION	Water resource stores	1970	↓ Approximately 10 day reduction in snow season	↓ Decreased natural snowpack storage	↓ Decreased natural snowpack storage	↓ Decreased natural snowpack storage	↑ Increased dependence on reservoir storage (ft^3 storage capacity); ↑ Increased well depth necessary to reach aquifer (feet)
	Change in summer precipitation	1961-1979	n/a	↑ +6% (ave. prediction) -1% to +13% (very likely range)	↑ +11% to +13% (ave. prediction) +3% to +20% (very likely range)	+17% to +23% (ave. prediction) +11% to +36% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Change in winter precipitation	1961-1979	n/a	↑ +6% to +9% (ave. prediction) -5% to +23% (very likely range)	↑ +15% to +17% (ave. prediction) +4% to +25% (very likely range)	↑ 23% to 37% (ave. prediction) 13% to 59% (very likely range)	↑ Increased risk of water damage (yearly maintenance costs).
	Intensity of precipitation	1958	↑ Increase 23% precipitation intensity; ↑ Increase 13% days with heavy precipitation	↑	↑	↑	↑ Increased seasonal flooding of low-lying areas (yearly days flooded).
COASTAL	Storm frequency and intensity	1950-1980	↑	↑	↑	↑	↑ Increased building and infrastructural damage and maintenance (cost of repair / reconstruction); ↑ Increased risk of flooding from storm surges (frequency of inundation)
	Sea ice extent	1980	↓ Overall decrease in September extent	↓ Decrease overall with year-to-year variability	↓ Decrease overall with year-to-year variability	↓ Decrease overall with year-to-year variability	↑ Increased danger of inundation during storms (flood events/yr), ↑ Increased erosion in coastal areas (area lost / yr),↑ Increased vulnerability to storm damage ($ cost of repair)
	Coastal erosion	1960	↑ 100% increase in rate of erosion	↑	↑	↑	↑ Increased loss of coastal land (sq. miles / year), ↑ Increased risk of damage from inundation to coastal development (frequency of inundation)
PESTS	Insect outbreaks	1990	Spruce Beetle Infestation	↑	↑	↑	↑ Increased need for pesticides for landscaping (frequency of treatment), ↑ Increased likelihood of wildfires due to wood-boring insects (events/year or area burned/year); ↑ Increase risk of damage to buildings from insects.
FIRE	Fires due to deteriorating forests	1960	↑ Area burned increased 300% in 1990	↑	↑ additional 200% increase in area burned	↑ additional 300% to 400% increase in area burned	↑ Increased danger of fire damage to structures ($ economic loss), ↑ Increased insurance costs (annual insurance premium)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009

†Historical base periods used to establish reference points that predate significant climate change impacts
‡ Temperature ranges based on IPCC "very likely" range

Islands Region Climate Change Impacts

Due to their relative isolation, proximity to the ocean, and dependence on local ecosystems for economic stability, island communities are extremely vulnerable to climate change impacts. The U.S.- affiliated Pacific and Caribbean Islands are faced with unique and difficult climate change-related challenges. With populations located primarily along coastal regions, island communities are intensely vulnerable. Projections of climate change in the Pacific and Caribbean Island regions anticipate increased temperatures, sea-level rise, decreased year-round precipitation (despite more frequent heavy rain events and increased rainfall during summer months), and a likely increase in hurricane wind speeds and rainfall. These climate changes will have the following effects (USGCRP 2009):

- Reduced access to freshwater
- Increasing vulnerability of communities, infrastructure, and ecosystems due to sea-level rise and coastal storms
- Changing coastal and marine ecosystems

Predicted Climate Change Impacts: Islands

	Climate Change Impacts	Relative To†	Observed by 2010	Near-Term Projections (2010-2040)	Mid-Term Projections (2040-2070)	Long-Term Projections (2070-2100)	Effects on the Built Environment
TEMPERATURE	Average annual air temperature	1961-1979	↑ Increase of 3.4 degrees F	↑ Increase of 0 to 3 degrees F in Hawaii; 1 to 3 degrees F in Caribbean.‡	↑ Increase of 1 to 5 degrees F in Hawaii; 1 to 4 degrees F in Caribbean.‡	↑ Increase of 2 to 9 degrees F in Hawaii; 2 to 8 degrees F in Caribbean.‡	↑ Increased annual HVAC energy usage (kWh)
	Average Summer air temperature	1961-1979	n/a	↑ Increase of 0 to 3 degrees F in Hawaii; 1 to 3 degrees F in Caribbean.‡	↑ Increase of 1 to 5 degrees F in Hawaii; 2 to 4 degrees F in Caribbean.‡	↑ Increase of 2 to 9 degrees F in Hawaii; 2 to 8 degrees F in Caribbean.‡	↑ Increased summertime HVAC energy demand (kW)
	Average Winter air temperature	1961-1979	n/a	↑ Increase of 0 to 3 degrees F in Hawaii; 1 to 5 degrees F in Caribbean.‡	↑ Increase of 1.1 - 4.6 degrees F in Hawaii; ↑ Increase 1.3 - 3.9 degrees F in Caribbean.‡	↑ Increase of 2 to 9 degrees F in Hawaii; 2 to 8 degrees F in Caribbean.‡	↑ Increased wintertime HVAC energy demand (kW)
WATER/PRECIPITATION	Availability of fresh water (Caribbean Islands only; predictions for Pacific islands are highly uncertain)	1900-2000	n/a	↓	↓	↓	↑ Increased dependence on rainwater storage; ↑ Increased dependence on desalination techniques (gal/day desalination), ↓ Decreased ability to use water resources for irrigation (days/year without service); ↑ Increased incidence of water shortage (days with usage restrictions per year)
	Change in summer precipitation (Caribbean Islands only; predictions for Pacific islands are highly uncertain)	1961-1979	n/a	↓ -7% to -10% (ave. prediction) -23% to +8% (very likely range)	↓ -12% to -18% (ave. prediction) -44% to +11% (very likely range)	↓ -14% to -36% (ave. prediction) -68% to +14% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
	Change in winter precipitation (Caribbean Islands only; predictions for Pacific islands are highly uncertain)	1961-1979	n/a	↓ -1% to -3% (ave. prediction) -15% to +11% (very likely range)	↓ -3% to -5% (ave. prediction) -14% to +5% (very likely range)	↓ -3% to 0% (ave. prediction) -35% to +19% (very likely range)	↑ Increased dependence on irrigation to maintain landscaping (gallons of water used per season)
COASTAL	Storm frequency and intensity	n/a	n/a	↑	↑	↑	↑ Increased potential for building and infrastructural damage and maintenance (cost of repair / reconstruction); ↑ Increased risk of flooding from storm surges (frequency of inundation); ↑ Higher storm insurance rates (annual insurance premium)
	Sea level rise	1961-1979	↑ Increased frequency of extreme sea level event from <5% annual probability to 20%	↑	↑	↑	↑ Increased danger of inundation during storms (flood events/yr); ↑ Increased vulnerability to storm damage (annual cost of repairs), ↑ Increased saltwater contamination of freshwater reserves (average saline concentration)
	Coastal erosion	n/a	n/a	↑	↑	↑	↑ Increased loss of coastal land (sq. miles / year), ↑ Increased risk of damage from inundation to coastal development (frequency of inundation), ↑ Increased costs and frequency of infrastructure maintenance (annual maintenance costs)

Primary Sources: United States Global Change Research Program (USGCRP), 2009; Federal Highway Administration (FHWA), 2009.

†Historical base periods used to establish reference points that predate significant climate change impacts

‡ Temperature ranges based on IPCC "very likely" range

References

IPCC. *IPCC Publications and Data*. Available from http://www.ipcc.ch/publications_and_data/publications_and_data.shtml.

Northeast Climate Impacts Assessment (NECIA). *Northeast Climate Impacts Assessment*. Available from http://www.northeastclimateimpacts.org/.

U.S. Census Bureau. *2009 Population Estimates*. Available from http://www.census.gov/popest/estimates.html.

USCCSP. 2008. Effects of Climate Change on Energy Production and Use in the United States. *U.S. Climate Change Science Program*.

USGCRP. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. In *Environmental Conservation*. Cambridge, UK.

———. 2009. Global Climate Change Impacts in the United States. In *Society*. New York.

APPENDIX C: Adaptation Strategies

This appendix provides a set of basic strategies to help a design, construction, and/or operations and maintenance team to incorporate adaptation principles into its project. Less detailed in scope than the Best Management Practices (BMPs) issued by many Federal and State agencies, each of the 81 strategies is provided to encourage a broad discussion of how specific climate impacts should be addressed by a project team. Because of the limited scope and lack of explicit detail for each strategy, teams should to do additional research to implement each strategy into their project. It is best to incorporate these strategies at the beginning of a project, in pre- or schematic design. As a project progresses, teams can utilize the additional information listed at the end of each strategy to follow through on the design, detailing, and construction.

Strategy Format

Each of the strategies includes the following information:

1. Objective: The purpose of each strategy.
2. Description: A two- to three- sentence description of the strategy and how it responds to climate impacts.
3. Regional Priority: A map of the United States divided into the regions used by the USGCRP in its most recent climate change assessment. Each strategy is designated as a "high" or "low" priority for that region. If the strategy is not applicable, it is listed as "N/A".
4. Primary/Secondary Impact: The primary and secondary impact categories the strategy address such factors as temperature, water/precipitation, pests, fire, storms, etc. For more detailed information on each climate impact category, refer to Appendix B.
5. Measured Effect of Strategy: How each strategy responds to a changing climate, such as a reduction of interior air temperature, reduction in peak electrical demand (kW), etc.
6. Level: Whether the strategy is a "no regrets" strategy or a "resilience" strategy. A no-regrets strategy is defined as a climate adaptation strategy that will generate social and/or economic benefits whether or not climate change occurs. A

resilience strategy is a climate adaptation strategy that allows a system to absorb disturbances while maintaining its structure and function.

7. Duration: The expected effective useful life of the strategy, measured in years.
8. Control: Who has control over the operation of the strategy, such as the Owner, Occupant, or Operations and Maintenance staff (O&M). A strategy may also be passively controlled. Passive control are strategies that require no intervention or activation once they are implemented, such as building orientation.
9. Associated LEED Credits: Which credits in the LEED-ND, LEED-NC, LEED-H, and LEED-EB rating systems are associated with each strategy.
10. Related Strategies: Which of the other strategies in Appendix C are related to this strategy. Up to three strategies are listed, though many more may be applicable.
11. Additional Information: Additional Internet or common design resources to assist with the development of each strategy.

Envelope Category

The no-regrets envelope strategies focus on improving the thermal properties of the building shell to respond to temperature-driven impacts. The resilient strategies in this category help the shell respond to other climate impacts such as termite damage (pests) or wind-driven rain (storms).

Type	Strategy Name	Page #
No Regrets	Interior Shading Devices	C-7
	Exterior Shading Devices	C-9
	High Performance Glazing	C-11
	Beyond Code Insulation: Wall	C-13
	Beyond Code Insulation: Roof	C-15
	High Albedo Roofing	C-17
	Green Roofs	C-19
Resilient	Enhanced Roof Access	C-21
	Ice Dam Resistant Construction	C-23
	Class "A" Roofing System	C-25
	Design for Increased Wind	C-27
	"Steeper" Low Slope Roofing	C-29
	Oversized Roof Drainage	C-31
	Pitched Roof	C-33
	Prevent Flame/Ember Entry	C-35
	No Eaves/No Gutters	C-37
	Pressure Neutral Rain Screens	C-39
	Flood Resistive Materials	C-41
	Noncombustible Siding	C-43
	Tempered Glazing	C-45
	Plan for Pest Expansion	C-47
	Hardened Foundations	C-49
	Miami-Dade County Opening Protection	C-51
	Noncombustible Decking	C-53

Siting and Landscape Category

The no-regrets siting and landscape strategies focus on improving the performance of a site or landscape to respond to temperature and water/precipitation impacts. The resilient strategies in this category help a project or landscape respond to other climate impacts such as wildfire or storm surge (coastal).

Type	Strategy Name	Page #
No Regrets	Compact and Mixed-Use Development	C-55
	Climate-Appropriate Landscaping	C-57
	Woody Trees and Shrubs	C-59
	Minimize Impervious Surfaces	C-61
	Building Orientation	C-63
	Retention Ponds	C-65
	Infiltration Galleries/French Drains	C-67
	Bioswales	C-69
	Natural or Constructed Wetlands	C-71
	Solar Zoning/Solar Envelope	C-73
	High Albedo Paving	C-75
	Covered or Shaded Parking	C-77
Resilient	Redundant Transportation Options	C-79
	Fire-Safe Landscaping	C-81
	Fire Breaks	C-83
	Avoidance of Flood Plains	C-85
	Avoidance of Storm Surge Zones	C-87
	Elevated First Floor	C-89
	Elevated Essential Infrastructure	C-91
	Scour-Resistant Foundations	C-93

Heading, Cooling, Lighting Category

The no-regrets heating, cooling, and lighting strategies focus on improving the performance of building mechanical and electrical systems to respond to temperature impacts. The only resilient strategy in this category adds resilience to egress lighting systems.

Type	Strategy Name	Page #
No Regrets	Cross Ventilation	C-95
	Thermal Zoning	C-97
	Stack Ventilation	C-99
	Mixed-Mode Ventilation	C-101
	Ceiling Fans	C-103
	Thermal Energy Storage	C-105
	Passive Solar Design	C-107
	Increased Thermal Mass	C-109
	Evaporative Cooling Towers	C-111
	Earth Cooling/Sheltering	C-113
	Daylighting	C-115
Resilient	High Efficacy Egress Lighting	C-117

Water and Waste Category

The no-regrets water and waste strategies focus on improving the efficiency of building plumbing systems to respond to decreases in water supply or interruption of electrical power to a building. The resilient strategies in this category aim to treat water on site to replace potable water use, prevent sewage backup into a building, or catch water for use on site.

Type	Strategy Name	Page #
No Regrets	Graywater System Rough Out	C-119
	High Efficiency Fixtures	C-121
	HVAC Condensate Capture	C-123
	Solar Domestic Water Heating	C-125
	Insulated Water System	C-127
	Graywater System	C-129
Resilient	Reclaimed Water Use	C-131
	Sewage Backflow Preventer	C-133
	Water Catchment Systems/Cistern	C-135

Equipment Category

The no-regrets equipment strategies focus on improving the efficiency of building mechanical systems to allow for increases in capacity without reducing total performance. The resilient strategies in this category aim to prevent damage to building equipment in the event of a flood or storm surge, or to provide backup and redundancy for critical systems.

Type	Strategy Name	Page #
No Regrets	Variable Frequency Drives	C-137
	Energy Management System	C-139
	Reduced Friction Losses	C-141
Resilient	Residential Sprinkler System	C-143
	Elevator System Design	C-145
	Critical System Backup	C-147
	System Redundancy	C-149
	M.E.P. Equipment Pads/Rooms	C-151
	Insulated Refrigeration Equipment	C-153

Process and Operations Category

The no-regrets process and operations strategies focus on improving design processes or improving energy performance in the building. The resilient strategies in this category help to prepare the operations and maintenance staff for climate events by designating a staff member as the point of contact, providing areas of refuge in the building, and creating an emergency management plan.

Type	Strategy Name	Page #
No Regrets	Energy/Environmental Modeling	C-155
	Building Operations Manual	C-157
	Flexible Dress Codes/Scheduling	C-159
	Retrocommissioning	C-161
Resilient	Climate Change Champion	C-163
	Areas of Refuge	C-165
	Emergency Management Plan	C-167

Envelope

Interior Shading Devices

Objective: To provide occupants with a method to control solar heat gain, indoor air temperature, and daylight levels in response to changing exterior climatic conditions.

Description: Well-designed interior sun control and shading devices allow occupants to reduce solar heat gain while improving daylighting quality. This can reduce interior air temperature, peak electrical demand, and annual cooling requirements. By controlling daylighting and glare, occupants can also rely less on electric lighting, further reducing cooling requirements and electrical demand.

Typical interior shading device systems installed in a building include Venetian blinds, adjustable louvers, or shade cloth. Fixed systems, such as light shelves, can help to redistribute daylight throughout a space without requiring occupant adjustments.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of solar heat gain (W/square meter)

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Reduction of interior glare (footlamberts)

Level: No Regrets

Duration: 4-10 Years

Control: Occupant

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 8.1 - Daylight and Views

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 4 - Windows

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2.4 - Daylight and Views

Related Strategies:

1. High Performance Glazing
2. Daylighting
3. Exterior Shading Devices

Objective: To prevent overheating in buildings by limiting excess solar heat gain in response to a seasonal change in solar altitude.

Description: Well-designed exterior sun control and shading devices reduce solar heat gain in the summer and permit solar energy to enter the building in the winter. This can help to prevent interior overheating, thereby reducing peak electrical demand and annual cooling requirements.

Typical exterior shading device systems installed on a building include horizontal overhangs, adjustable louvers, or "egg crate" style systems. Operable systems, such as exterior Venetian blinds, can respond to daily changes in daylight availability and are often controlled by a building management system.

Regional Priority:

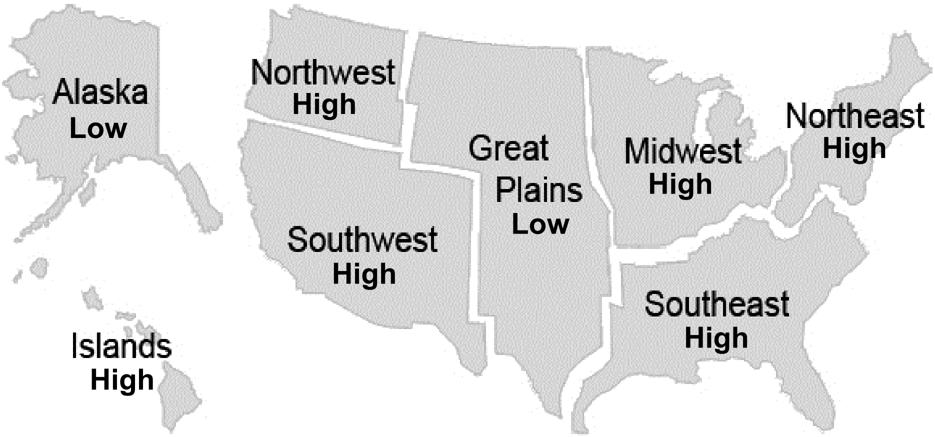


Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of solar heat gain (W/square meter)

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	11-30 Years
Control:	Passive
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance
	IEQ Credit 8.1 - Daylight and Views
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance
	EA Credit 4 - Windows
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance
	IEQ Credit 2.4 - Daylight and Views

Related Strategies:

1. High Performance Glazing
2. Daylighting
3. Interior Shading Devices

High Performance Glazing

Objective: To prevent overheating in buildings by limiting excess solar heat gain and conductive gains in response to a seasonal change in solar altitude and temperature.

Description: Well-specified glazing reflects unwanted solar heat gain and permits adequate visible light for daylighting. This can help to prevent interior overheating, thereby reducing peak electrical demand and annual cooling requirements.

Typical glazing systems consist of a frame material, a spacer material, panes of glass, inert gas between panes, and a selective coating on one or more surfaces of the glass. Careful analysis and specification of all of these components is necessary to reduce energy use and prevent building overheating while limiting first cost.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of solar heat gain (W/square meter)

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Reduction of interior glare (footlamberts)

Envelope — High Performance Glazing

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 8.1 - Daylight and Views

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 4 - Windows

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2.4 - Daylight and Views

Related Strategies:

1. Interior Shading Devices
2. Exterior Shading Devices
3. Daylighting

Objective: To prevent overheating in buildings by reducing conductive gains through the envelope.

Description: Well-designed insulation systems reduce conduction through the thermal envelope. During the summer, this can reduce interior air temperature, peak electrical demand, and annual cooling requirements. By controlling conductive gains and losses, the building also relies less on heating and cooling systems, further reducing cooling requirements and electrical demand.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction of heat gain (W/square meter)

Reduction of heat loss (W/square meter)

Reduction of peak electrical demand (kW)

Reduction of annual energy usage (kWh)

Beyond Code Insulation: Wall

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 2 - Insulation
EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Beyond Code Insulation: Roof
2. High Performance Glazing
3. Thermal Zoning

Objective: To prevent overheating in buildings by limiting conductive gains through the roof.

Description: Well-designed insulation systems reduce conduction through the roof system. During the summer, this can reduce interior air temperature, peak electrical demand, and--in warm climate zones--the annual cooling requirements. By controlling conductive gains and losses, the building also relies less on heating and cooling systems, further reducing cooling requirements and electrical demand.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of interior air temperature (degrees)

Reduction of peak electrical demand (kW)

Reduction of annual energy usage (kWh)

Reduction of heat gain (W/square meter)

Envelope Beyond Code Insulation: Roof

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 2 - Insulation
EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Beyond Code Insulation: Wall
2. High Albedo Roofing
3. Green Roofs

Envelope

High Albedo Roofing

Objective: To prevent overheating in buildings by reducing radiative gains and the sol-air temperature of the roof.

Description: High albedo roofing, also known as light-colored or cool roofing, reduces solar gain through a roof assembly. During the summer, this can reduce interior air temperature, peak electrical demand, and--in warm climate zones--the annual energy use. (High albedo roofing may slightly increase heating requirements in cool or cold climates.) High albedo roofing also reduces the urban heat island effect.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of solar heat gain (W/square meter)

Reduction of interior air temperature (degrees)

Reduction of peak electrical demand (kW)

High Albedo Roofing

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 9 - Heat Island Reduction
GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): SS Credit 7 - Heat Island Effect: Roof
EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): SS Credit 3 - Local Heat Island Effects

LEED-EB Credit(s): SS Credit 7 - Heat Island Reduction: Roof

Related Strategies:

1. Beyond Code Insulation: Roof
2. Green Roofs
3. High Albedo Paving

Objective: To reduce the rate and quantity of stormwater from the roof surface and help prevent overheating in buildings by adding thermal mass and insulation to the roof.

Description: Green roofs reduce solar gain through a roof system. During the summer, this can reduce interior air temperature, peak electrical demand, and--in warm climate zones--the annual cooling requirements. (It may slightly increase heating requirements in cool or cold climates.) High albedo roofing also reduces the urban heat island effect.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Temperature

Measured Effect of Strategy: Reduction of solar heat gain (W/square meter)

Reduction of interior air temperature (degrees)

Envelope

Green Roofs

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 9 - Heat Island Reduction
GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): SS Credit 7 - Heat Island Effect: Roof
EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): SS Credit 3 - Local Heat Island Effects

LEED-EB Credit(s): SS Credit 7 - Heat Island Reduction: Roof

Related Strategies:

1. Beyond Code Insulation: Roof
2. High Albedo Roofing
3. Climate Appropriate Landscaping

Objective: To allow for regular inspection of the roof membrane to prevent rain, wind, and/or moisture damage.

Description: Many buildings have only limited access to the roof through a hatch. This may discourage maintenance staff from regularly inspecting the roof membrane, flashing, and drainage system. A full man door to the roof will allow easy access to the roof for inspections, and in the event of a wildfire, may allow firefighting equipment to access the roof to prevent ignition from embers.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Fire

Measured Effect of Strategy: Reduced risk of damage from membrane or flashing failure

Reduced risk of ignition from embers from a vegetation fire

Level:	Resilient
Duration:	30+ Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	N/A
LEED-H Credit(s):	N/A
LEED-EB Credit(s):	N/A

Related Strategies:

1. "Steeper" Low Slope Roofing
2. Design for Increased Wind
3. Building Operations Manual

Envelope

Ice Dam Resistant Construction

Objective: To prevent backup of meltwater on a roof due to a ridge of ice forming on an exposed eave.

Description: Meltwater from ice dams can cause significant damage to roof sheathing and structure. As warmer temperatures may cause increased freeze/thaw cycles, detailing the roof-eave assembly and insulation to prevent ice dams will become more important.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduced risk of moisture damage or roof failure

Envelope

Ice Dam Resistant Construction

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EA Credit 2 - Insulation

LEED-EB Credit(s): N/A

Related Strategies:

1. Beyond Code Insulation: Roof
2. Beyond Code Insulation: Wall
3. Pitched Roof

Objective: To resist the intrusion of flames or burning embers from a vegetation fire into the building envelope.

Description: Class "A" roofing systems have the highest fire-resistance rating for roofing per ASTM E-108. Class "A" roofing systems are already required in many wildland-urban interface locations, or in high-density urban developments. Adding Class "A" roofing to locations where it is not required by code may help to protect a building from unexpected wildfires caused by changing temperature and precipitation patterns.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. High Albedo Roofing
2. Green Roofs
3. Beyond Code Insulation: Roof

Design for Increased Wind

Objective: To reduce the risk of roof tear-off or damage to the primary water resistive membrane during a wind storm or hurricane.

Description: Building codes often require that roof deck constructions and coverings be designed to resist a wind uplift pressure based on historical climate data. Increasing the standard to which a roof is designed may anticipate an increase in wind speed or storm severity and better protect a building from roof tear off or moisture damage.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Coastal

Measured Effect of Strategy: Reduced risk of moisture damage or roof failure

Envelope — Design for Increased Wind

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Pressure Neutral Rain Screens
2. High Albedo Roofing
3. "Steeper" Low Slope Roofing

Objective: To shed water from a roof surface more quickly than a code minimum roof slope and to reduce the risk of roof ponding.

Description: Most jurisdictions require a minimum roof rise of 0.25" per foot of run. While this rise is sufficient to shed rain during normal storm events, roofs with this shallow of a slope may pond during extreme precipitation events. Increasing roof slope to 0.5 to 1" of rise per foot of run may help to clear rain more quickly from a roof, especially if the roof drains to a gutter at the roof edge rather than an internal drain.

Regional Priority:

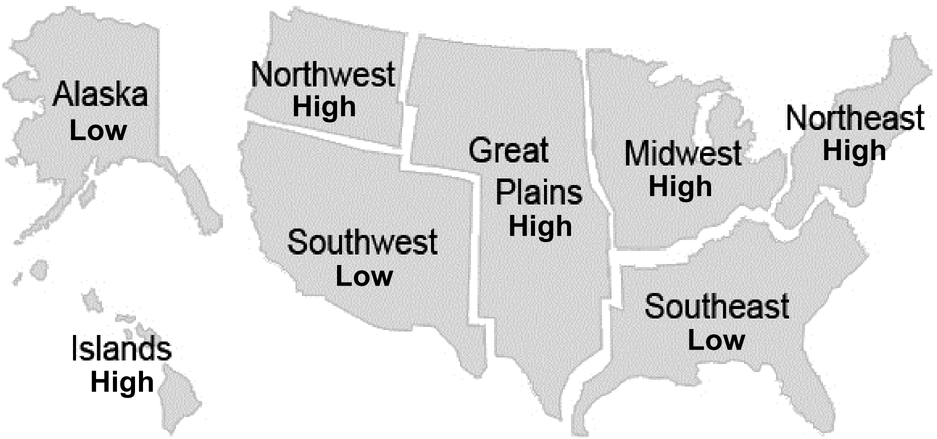


Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of moisture damage or roof failure

Envelope

"Steeper" Low Slope Roofing

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EQ Credit 3: Moisture Control

LEED-EB Credit(s): N/A

Related Strategies:

1. High Albedo Roofing
2. Class "A" Roofing
3. Oversized Roof Drainage

Objective: To allow a roof system to shed larger volumes of rainwater than required by code.

Description: Roof leaders, gutters, downspouts, and drains are all sized to the maximum rain rate as recorded in historical data. Increasing the diameter of piping or the size of gutters can help prevent ponding, sheeting, and roof damage in the event of severe precipitation.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of moisture damage or roof failure

Oversized Roof Drainage

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EQ Credit 3: Moisture Control

LEED-EB Credit(s): N/A

Related Strategies:

1. "Steeper" Low Slope Roofing
2. High Albedo Roofing
3. No Gutters

Objective: To allow a roof system to shed large volumes of snow, thereby protecting the roof structure from premature failure during heavy snow.

Description: Most jurisdictions require a minimum roof rise of 0.25" per foot of run. While this is usually sufficient to shed rain during normal storm events, and to stay stable during normal snowfalls, roofs with this shallow of a slope may collect excessive snow in the event of a severe snowfall. A pitched roof may help to clear the snow from the roof in the event of a severe snow; however care needs to be taken to avoid property damage from falling snow.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of roof failure from snow load

Pitched Roof

Level: Resilient

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EQ Credit 3: Moisture Control

LEED-EB Credit(s): N/A

Related Strategies:

1. "Steeper" Low Slope Roofing
2. Class "A" Roofing
3. Noncombustible Decking

Objective: To resist the intrusion of flames or burning embers from a vegetation fire into the building envelope.

Description: Roof and HVAC vents in buildings can pull embers or hot gases into the buildings, leading to the ignition of materials on the building interior. Eliminating exposed vents, installing oversized vents with mesh screens, and placing vents in locations away from other buildings or vegetation may help to prevent ignition or damage to the house during a wildfire.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Level:	Resilient
Duration:	11-30 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	N/A
LEED-H Credit(s):	N/A
LEED-EB Credit(s):	N/A

Related Strategies:

1. Noncombustible Siding
2. No Gutters
3. Class "A" Roofing

Objective: To prevent burning embers from a vegetation fire from accumulating in rain gutter.

Description: Embers and hot gases from a fire can be trapped underneath an eave during a fire. Embers can also collect in gutters and ignite debris collected in the gutter. Omitting eaves and gutters can help to eliminate the risk of ignition from embers and hot gases during a wildfire.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Envelope

No Eaves/No Gutters

Level: Resilient

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Class "A" Roofing
2. Noncombustible Siding
3. Ice Dam Resistant Construction

Objective: To prevent wind-driven rain from penetrating the vertical enclosure, damaging building structure and/or causing moisture damage.

Description: Rain enters a wall assembly when three conditions occur: rain strikes the assembly, openings allow a path inward, and there is a force (such as wind) to drive the water into the openings. To prevent wind-driven rain from entering a building envelope, a pressure neutral rain screen system includes a gap between the exterior cladding and an interior water-resistant membrane that limits the effect of air pressure, capillary action, and rain drop momentum.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of moisture damage from wind-driven rain

Envelope

Pressure Neutral Rain Screens

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Design for Increased Wind
2. Beyond Code Insulation: Wall
3. Noncombustible Siding

Objective: To install building materials that can survive getting wet and dry without damage or mold growth.

Description: Newer building materials such as fiber cement products and certain types of metals and plastics resist water damage. To prevent mold and/or mildew growth on these materials after being submerged they need to be detailed to allow water to drain completely and the assembly to dry thoroughly.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduced risk of moisture damage from flood water

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EQ Credit 3: Moisture Control

LEED-EB Credit(s): N/A

Related Strategies:

1. Avoidance of Flood Plains
2. Avoidance of Storm Surge Zones
3. Building Operations Manual

Objective: To resist the intrusion of flames or burning embers from a vegetation fire into the building envelope.

Description: Exterior walls are susceptible to flames, conductive heat, and radiant heat from wildfires. These can, in combination, ignite combustible wall coverings. Increasing the fire resistance of exterior walls may prevent fire damage or the loss of the structure in the event of a wildfire.

Regional Priority:

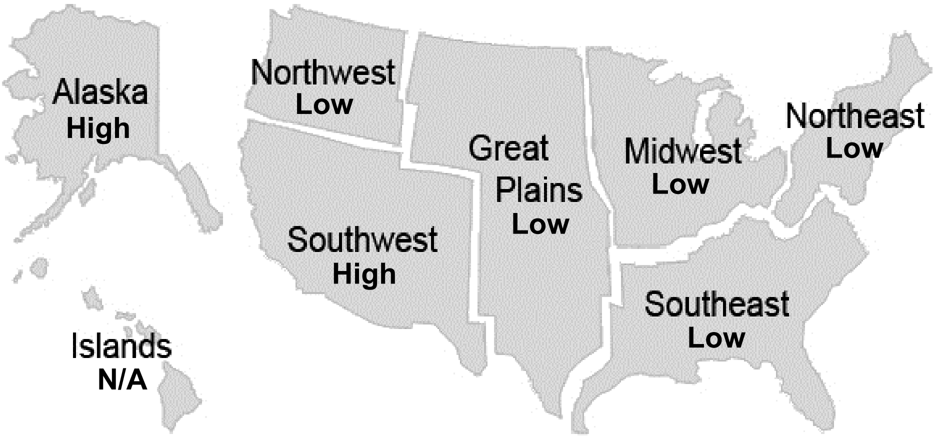


Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Envelope

Noncombustible Siding

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Pressure Neutral Rain Screens
2. Beyond Code Insulation: Wall
3. Noncombustible Decking

Tempered Glazing

Objective: To resist the intrusion of flames or burning embers from a vegetation fire into the building envelope.

Description: Exterior walls are susceptible to flames, conductive heat, and radiant heat from wildfires. These can, in combination, ignite combustible wall coverings. Tempered windows may prevent fire damage or the loss of the structure because they do not shatter when subjected to flames or heat, protecting the building interior.

Regional Priority:

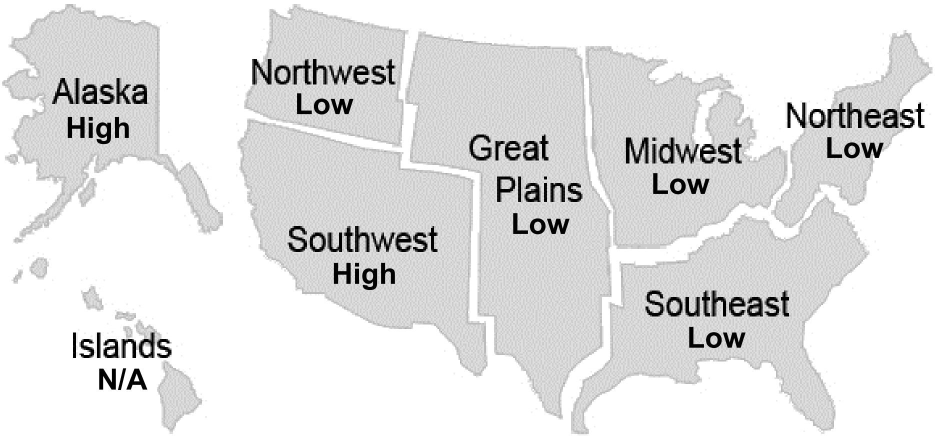


Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Envelope

Tempered Glazing

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. High Performance Glazing
2. Noncombustible Decking
3. Daylighting

Objective: To resist the intrusion of termites and other pests into the building envelope and structure.

Description: Many different types of pests, especially termites, do damage to buildings and wooden structures. Because of warmer winters, the ranges of these pests may expand and cause increased damage to buildings. Designing in termite resistance, performing integrated pest management, or avoiding wood construction all can prevent damage to buildings from pests such as termites.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Pests

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of structural damage from termites

Plan for Pest Expansion

Level: Resilient

Duration: 30+ Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): SS Credit 5 - Nontoxic Pest Control

LEED-EB Credit(s): IEQ Credit 3.6 - Green Cleaning: Indoor Integrated Pest Management

Related Strategies:

1. Integrated Pest Management
2. Woody Trees and Shrubs
3. Climate Appropriate Landscaping

Envelope

Hardened Foundations

Objective: To prevent damage to a building's foundation due to changing temperatures and/or soil moisture.

Description: Changes in soil moisture or winter freeze/thaw cycles may cause damage to existing building foundations. Building frost-resistant foundations in locations where they are not currently required (e.g., permafrost) and/or anticipating changes in soil moisture may help to prevent damage over the long term to a building's structure.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Coastal

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of structural damage from foundation failure

Envelope — Hardened Foundations

Level: Resilient

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Scour Resistant Foundations
2. Beyond Code Insulation: Wall
3. Increased Thermal Mass

Objective: To prevent storm damage to a building's interior due to a failure of window or door systems.

Description: The Miami-Dade County Building Code requires every exterior opening to be protected or be hardened against wind-borne debris caused by hurricanes. Protection can be either shutters, screens, or impact-resistant products such as laminated glazing. Miami-Dade County maintains a list of building materials and assemblies that meet the requirements of the code, and these materials can be used in locations that currently have lesser hurricane code requirements, as the severity of coastal storms is expected to increase with warmer temperatures.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Coastal

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of storm damage due to the failure of door or window systems

Envelope — Miami-Dade County Opening Protection

Level: Resilient

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): EA Credit 4 - Windows

LEED-EB Credit(s): N/A

Related Strategies:

1. Tempered Glazing
2. Exterior Shading Devices
3. Design for Increased Wind

Objective: To resist the intrusion of flames or burning embers from a vegetation fire.

Description: Exterior decking is susceptible to burning embers, flames, conductive heat, and radiant heat from wildfires. These can, in combination, ignite combustible decking. Increasing the fire resistance of exterior decking may prevent fire damage or the loss of the structure in the event of a wildfire.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of ignition from embers from a vegetation fire

Envelope Noncombustible Decking

Level: Resilient

Duration: 4-10 Years

Control: Owner

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): N/A

LEED-EB Credit(s): N/A

Related Strategies:

1. Noncombustible Siding
2. Class "A" Roofing
3. Fire Breaks

Objective: To create neighborhoods that foster walking, biking, and the use of public transportation in order to reduce vehicle greenhouse gas emissions and air pollution.

Description: Compact mixed-use development focuses on infill development rather than suburban or greenfield development. Land uses are mixed, and streets have greater connectivity to promote walking, biking, and public transit systems instead of vehicle traffic.

Reducing air pollution is an important strategy to reduce the negative effect of increased temperature on air quality. Mixed-use development also provides access to multiple transportation options in the event that one system is affected by a climatic event.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Air Quality

Measured Effect of Strategy:

Reduction of vehicle miles traveled (VMT)

Reduction of air pollution

Increased number of transportation options

Increased floor area ratio (FAR)

Level:	No Regrets
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	NPD Prerequisite 2 – Compact Development NPD Credit 3 – Mixed-Use Neighborhood Centers
LEED-NC Credit(s):	SS Credit 2 – Development Density and Community Connectivity
LEED-H Credit(s):	LL Credit 1 – LEED for Neighborhood Development
LEED-EB Credit(s):	N/A

Related Strategies:

1. Building Orientation
2. Solar Envelope
3. Redundant Transportation Options and Access

Objective: To create landscapes that will maintain their design and function in response to changes in precipitation, temperature, and pest types.

Description: Landscapes designed to accommodate future climate change will include herbaceous (single growing season) and wood plants (trees and shrubs) that are drought resistant and can survive increased temperatures. Landscapes should include diverse plant types, and designers should consider the expanding ranges of some pests due to warmer temperatures. Designers can protect the landscape's function and design by selecting plants that can survive a range of climate conditions. Native plants are preferable.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Pests

Measured Effect of Strategy: Reduction or elimination of water use for irrigation (gal)

Reduction in or elimination of fertilizer use (gal)

Level:	No Regrets
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 4 - Water Efficient Landscaping
LEED-NC Credit(s):	WE Credit 1 - Water Efficient Landscaping
LEED-H Credit(s):	SS Credit 2 - Landscaping WE Credit 2 - Irrigation System
LEED-EB Credit(s):	WE Credit 3 - Water Efficient Landscaping SS Credit 3 - Integrated Pest Management, Erosion Control, and Landscape Management Plan
Related Strategies:	1. Woody Trees and Shrubs 2. Vegetative Cover 3. Fire-Safe Landscaping

Objective: To limit the effect of the urban heat island in the case of warmer temperatures, including increased energy demand and air conditioning costs, reduced air quality, and increased heat-related illness and mortality.

Description: While all types of vegetative cover lessen urban heat island effects through evapotranspiration, woody trees and shrubs have the added benefit of providing shade. Both evapotranspiration and shading have cooling effects. Increasing vegetative cover also provides soil stability, allows groundwater recharge, and can maintain humidity in the air in dryer regions.

Regional Priority:

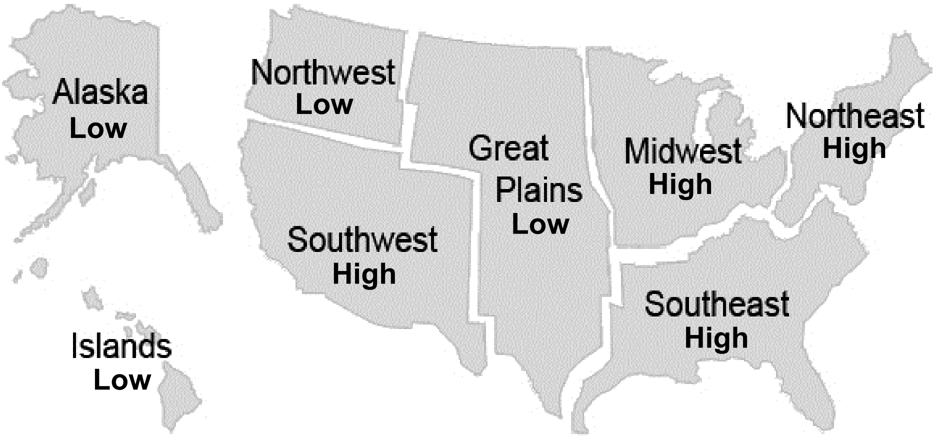


Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Water/Precipitation

Measured Effect of Strategy:

Reduced ground surface temperature (degrees)

Reduced amount of stormwater runoff (gal)

Reduced air temperature (degrees)

Siting and Landscape — Woody Trees and Shrubs

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): NPD Credit 14 - Tree Lined and Shaded Streets
GIB Credit 9 - Heat Island Reduction

LEED-NC Credit(s): SS Credit 5 - Site Development
SS Credit 7 - Heat Island Effect

LEED-H Credit(s): SS Credit 3 - Local Heat Island Effects

LEED-EB Credit(s): SS Credit 7 - Heat Island Reduction

Related Strategies:

1. Vegetative Cover
2. High Albedo Paving
3. Climate Appropriate Landscaping

Objective: To reduce erosion and stormwater runoff from sites and to limit increased surface temperature. To reduce the risk of combined sewer overflow and flooding in response to increased precipitation or severe storm events.

Description: Sites that minimize impervious surface area and use permeable surface strategies allow stormwater to infiltrate the groundwater instead of flowing from the site directly to streams or storm drains, protecting the water system from pollutants and flooding. Reducing the amount of impervious surface on sites also reduces erosion by slowing down the flow of surface water.

Impervious surface area can be replaced with pervious pavement or natural landscapes. Pervious surface allows for evapotranspiration, which has a cooling effect on surface temperature.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Temperature

Measured Effect of Strategy:

Reduced amount of runoff (gal)

Reduced non-point source pollution (gal)

Reduced surface temperature (degrees)

Siting and Landscape — Minimize Impervious Surfaces

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 8 - Stormwater Management

LEED-NC Credit(s): SS Credit 6 - Stormwater Design

LEED-H Credit(s): SS Credit 4 - Surface Water Management

LEED-EB Credit(s): SS Credit 6 - Stormwater Quantity Control

Related Strategies:

1. Bioswales/Retention Ponds
2. Infiltration Galleries
3. Climate Appropriate Landscaping

Objective: To limit an increase in energy use as a building responds to changing climate conditions. To allow for the optimal use of passive heating and cooling strategies.

Description: Buildings oriented to take advantage of passive and active solar strategies and natural ventilation and wind patterns can prevent an increase in energy and electricity demand in response to warmer temperatures. Buildings should be oriented to take advantage of the sun, wind, and daylight. Building orientation should be combined with tree planting or exterior shading to moderate solar heat gain. These strategies can help to maintain interior temperatures under changing climatic conditions.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction in annual electrical usage (kWh)

Reduction in summertime peak electrical demand (kW)

Reduction of solar heat gain (W/ square meter)

Reduction of interior air temperature (degrees)

Siting and Landscape — Building Orientation

Level: No Regrets

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): GIB Credit 10 - Solar Orientation
GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): IEQ Credit 8 - Daylight and Views
EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): N/A

Related Strategies:

1. Solar Envelope
2. Cross Ventilation
3. Passive Solar Apertures

Objective: To collect and hold stormwater, even in the case of severe storm events.

Description: Retention ponds are designed to collect stormwater from a site or defined area in order to prevent flooding and combined sewer overflow. Retention ponds capture and hold the first flush of contaminants from an impervious surface area following precipitation.

Retention ponds should be designed to consider future climate change, including an increase in quantity and frequency of precipitation.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy:

Reduced runoff from the site (gal)

Increased capture of solids from runoff (cu ft/gal)

Increased aquifer recharge (gal)

Retention Ponds

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 8 - Stormwater Management

LEED-NC Credit(s): SS Credit 6 - Stormwater Design

LEED-H Credit(s): SS Credit 4 - Surface Water Management

LEED-EB Credit(s): SS Credit 6 - Stormwater Quantity Control

Related Strategies:

1. Natural or Constructed Wetlands
2. Reduced Quantity of Impervious Surfaces
3. Infiltration Galleries/French Drains

Objective: To manage increased precipitation and support groundwater recharge on site.

Description: An infiltration gallery or french drain is a pit or trench that is filled with rubble or gravel. It is design to capture stormwater, filter contaminants, and then allow for groundwater infiltration. This strategy should be part of a comprehensive approach to landscaping that also minimized the area of impervious surface.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy:

Reduced runoff from the site (gal)

Increased capture of solids from runoff (cu. ft./ gal)

Increased aquifer recharge (gal)

Level:	No Regrets
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 8 - Stormwater Management
LEED-NC Credit(s):	SS Credit 6 - Stormwater Design
LEED-H Credit(s):	SS Credit 4 - Surface Water Management
LEED-EB Credit(s):	SS Credit 6 - Stormwater Quantity Control

Related Strategies:

1. Natural or Constructed Wetlands
2. Retention Ponds
3. Bioswales

Objective: To limit the effects of increased precipitation by reducing impervious cover, increasing on-site infiltration, reducing pollution from stormwater runoff, and eliminating contaminants.

Description: Bioswales prevent erosion with vegetation by slowing the flow of stormwater. They also filter pollutants, especially the first flush of pollutants from impervious surfaces, and infiltrate stormwater back into the ground. Bioswales help to mitigate the effects of increased precipitation, including flooding and combined sewer overflow events.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Volume of water captured from the site (gal)

Volume of pollutants and solids captured from the site (cu. ft./ gal)

Level:	No Regrets
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 8 - Stormwater Management
LEED-NC Credit(s):	SS Credit 6 - Stormwater Design
LEED-H Credit(s):	SS Credit 4 - Surface Water Management
LEED-EB Credit(s):	SS Credit 6 - Stormwater Quantity Control

Related Strategies:

1. Climate Appropriate Landscapes
2. Reduced Quantity of Impervious Surface
3. Vegetative Cover

Objective: To manage increased precipitation through captured stormwater and pollutant loads. To manage increased temperatures with cooling from evapotranspiration.

Description: Both natural and constructed wetlands collect stormwater and prevent erosion during severe storm events. Wetland vegetation also provides cooling effects through evapotranspiration.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Temperature

Measured Effect of Strategy:

Volume of stormwater collected (gal)

Volume of pollutants and solids captured from the site (cu. ft./ gal)

Reduction in air temperature (degrees)

Level:	No Regrets
Duration:	11-30 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	SLL Credit 7 - Site Design for Habitat or Wetland and Water Body Conservation SLL Credit 8 - Restoration of Habitat or Wetlands and Water Bodies
LEED-NC Credit(s):	SS Credit 1 - Site Selection SS Credit 6 - Stormwater Design
LEED-H Credit(s):	LL Credit 2 - Site Selection SS Credit 4 - Surface Water Management
LEED-EB Credit(s):	SS Credit 6 - Stormwater Quantity Control SS Credit 7 - Heat Island Reduction
Related Strategies:	1. Bioswales 2. Retention Ponds 3. Reduced Quantity of Impervious Surfaces

Objective: To increase energy efficiency by maximizing the ability of a building to utilize solar energy for space heating, water heating, and daylighting.

Description: Solar zoning prioritizes a building's access to solar exposure through street layout, building orientation, and setbacks. Solar zoning considers the layout of the entire neighborhood or site and attempts to preserve solar access for all buildings. Designers should consider solar access to allow for photovoltaics (especially on the roof of a building). They should also consider passive heating and cooling strategies.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in energy use (kWh)

Increase in renewable energy production (kWh)

Level: No Regrets

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 8.1 - Daylight and Views

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 4 - Windows

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2.4 - Daylight and Views

Related Strategies:

1. Building Orientation
2. Compact and Mixed-Use Development
3. Passive Solar Design

High Albedo Paving

Objective: To adapt to increased temperatures by reducing the heat absorption potential of paving.

Description: Albedo, or solar reflectance, refers to a material's ability to reflect solar wavelengths. Lighter-colored materials are associated with greater reflectivity, or high albedo. Materials with greater reflectivity will reduce the effect of increased temperatures associated with the urban heat island. The urban heat island effect is associated with increased energy use for air conditioning and heat-related morbidity and mortality.

Regional Priority:

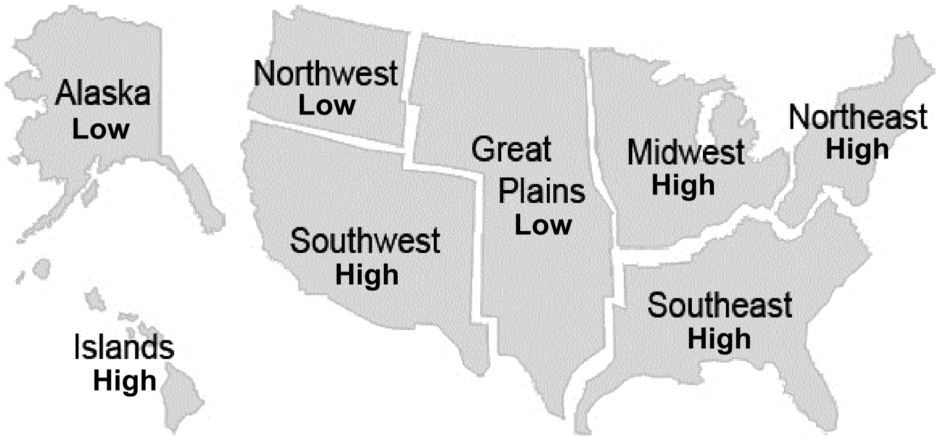


Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction in ground surface temperature (degrees)

Reduction in air temperature (degrees)

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 9 - Heat Island Reduction
NPD Credit 5 - Reduced Parking Footprint

LEED-NC Credit(s): SS Credit 7 - Heat Island Effect

LEED-H Credit(s): SS Credit 3 - Local Heat Island Effects

LEED-EB Credit(s): SS Credit 7 - Urban Heat Island Reduction

Related Strategies:

1. High Albedo Roofing
2. Woody Trees and Shrubs
3. Covered Parking

Objective: To reduce the effect of increased temperatures on urban heat island by covering or shading the parking lot.

Description: A covered or shaded parking area will absorb less heat than the conventional asphalt used in parking lots, reducing the effect of increased temperatures on urban heat island, which can result in increased cooling demands. Regions that currently experience high temperatures and regions where temperature increase is projected cshould prioritize this strategy.

Regional Priority:

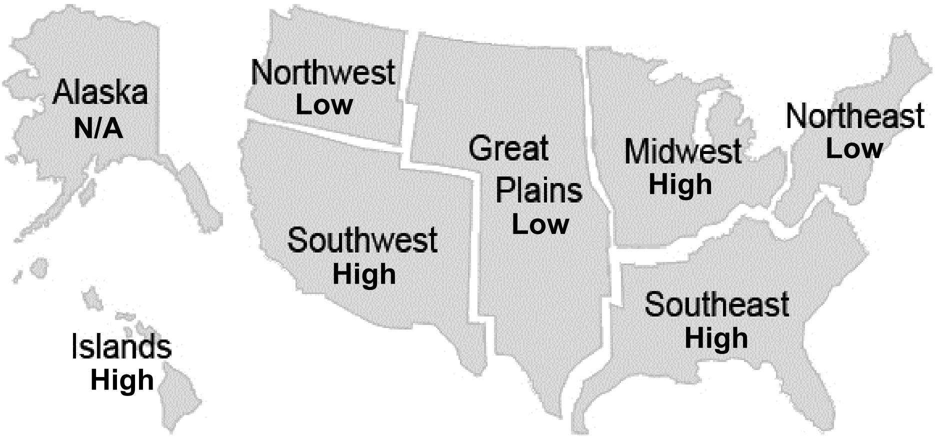


Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in ground surface temperature (degrees)

Reduction in air temperature (degrees)

Level: No Regrets

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): GIB Credit 9 - Heat Island Reduction
NPD Credit 5 - Reduced Parking Footprint

LEED-NC Credit(s): SS Credit 7 - Heat Island Effect

LEED-H Credit(s): SS Credit 3 - Local Heat Island Effects

LEED-EB Credit(s): SS Credit 7 - Urban Heat Island Reductions

Related Strategies:

1. High Albedo Paving
2. High Albedo Roofing
3. Green Roofs

Objective: To provide alternative modes of transportation in the event that one system is compromised due to a flood, storm, or other severe weather event.

Description: Neighborhoods that provide multiple transportation options, including access to public transportation, a well-connected street grid, and sidewalks, will allow residents to maintain transportation access in the event of a flood, storm, or severe weather event. Redundancy in the transportation system will also encourage non-vehicle trips, which will result in fewer greenhouse gas emissions.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Increased transportation access following a severe weather event

Redundant Transportation Options

Level:	Resilient
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	SLL Credit 3 - Locations with Reduced Automobile Dependence NPD Credit 7 - Transit Facilities
LEED-NC Credit(s):	SS Credit 1 - Site Selection SS Credit 4 - Alternative Transportation
LEED-H Credit(s):	LL Credit 3 - Preferred Locations LL Credit 5 - Community Resources/Transit
LEED-EB Credit(s):	SS Credit 4 - Alternative Commuting Options
Related Strategies:	1. Avoidance of Flood Plains 2. Avoidance of Storm Surge Zones 3. Compact/Mixed-Use Development

Objective: To protect a home or building from wildfire by incorporating fire-resistant plants in the landscape design.

Description: A site that is resilient to wildfire should include fire-safe landscaping. Fire-resistant plant species include plants that are low growing, open structured, and less resinous. Plants that have a high moisture content in their leaves, such as succulents, are also more fire resistant. Plants with strong root structures will regenerate after a fire and help to prevent erosion. Plant selection should be specific to the climate and location and plants need maintenance to resist fire, including irrigation and trimming.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of fire damage from a wildfire

Level: Resilient

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): N/A

Related Strategies:

1. Fire Breaks
2. Climate Appropriate Landscaping
3. Woody Trees and Shrubs

Objective: To minimize the spread of wildfire by including fire-resistant material or space to provide a break in the landscape.

Description: Fire breaks control the spread of wildfire by isolating vegetative cover and decreasing the fuel density on site. Fire breaks also allow access for fire fighting equipment to the site. Fire breaks can include walkways, rocks, or open space.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact:

Measured Effect of Strategy: Reduced risk of fire damage from a wildfire

Siting and Landscape — Fire Breaks

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): N/A

Related Strategies:

1. Fire-Safe Landscaping
2. Climate Appropriate Landscaping
3. Woody Trees and Shrubs

Objective: To limit the risk of flooding to a building or site by not developing on flood plains or flood-prone areas.

Description: Avoiding sites with an elevation that is lower than 5 feet above the 100-year flood plain, or base flood elevation, as defined by the Federal Emergency Management Agency (FEMA) will reduce the risk of flooding to the site. This is particularly important in regions where the quantity and intensity of precipitation is projected to increase. Increases in precipitation could result in more frequent floods or an expansion of flood plains.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Elimination or reduction of risk from floods

Avoidance of Flood Plains

Level: Resilient

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): SLL Credit 1 - Preferred Locations

LEED-NC Credit(s): SS Credit 1 - Site Selection

LEED-H Credit(s): LL Credit 2 - Site Selection

LEED-EB Credit(s): N/A

Related Strategies:

1. Elevated Essential Infrastructure
2. Elevated First Floor
3. Avoidance of Storm Surge Zones

Objective: To reduce the impact of sea level rise and the associated increase in storm surge heights by avoiding storm surge zones.

Description: Avoiding storm surge zones will protect buildings from increased frequency and intensity of storms. Climate change is projected to bring a rise in sea level, so the storm surge area will also increase. Building professionals should avoid building in current storm surge areas and consider potential sea level rise and the associate shift in storm surge area when selecting a site.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Coastal

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk from storm surge and/or sea level rise

Level:	Resilient
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	SLL Credit 1 - Preferred Locations
LEED-NC Credit(s):	SS Credit 1 - Site Selection
LEED-H Credit(s):	LL Credit 2 - Site Selection
LEED-EB Credit(s):	N/A

Related Strategies:

1. Avoidance of Flood Plains
2. Scour Resistant Foundations
3. Elevated First Floor

Objective: To limit the impacts of flooding and storm surge on a building by elevating the first floor above a potential water elevation.

Description: If it is not possible to build outside of a flood plain or a storm surge zone, the first floor of the building should be elevated well above the projected base flood elevation or storm surge height. Elevating the structure will help to prevent damage during a flood from inundation, high velocity water, erosion, sedimentation, and flood-borne debris.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Coastal

Measured Effect of Strategy: Reduced risk of flood or storm damage

Level:	Resilient
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	SLL Credit 1 - Preferred Locations SLL Credit 7 - Site Design for Habitat or Wetland and Water Body Conservation
LEED-NC Credit(s):	SS Credit 1 - Site Selection
LEED-H Credit(s):	LL Credit 2 - Site Selection SS Credit 4 - Surface Water Management
LEED-EB Credit(s):	N/A
Related Strategies:	1. Avoidance of Flood Plains 2. Avoidance of Storm Surge Zones 3. Elevated Essential Infrastructure

Objective: To limit the effects of flooding and storm surge on building support systems, including HVAC, fuel supply, electrical systems, and sewerage by elevating essential infrastructure above the projected water elevation.

Description: Essential infrastructure systems should be protected from floodwater and storm surge because it often contains dissolved chemicals, silt, suspended solids, and floating debris. Moving floodwater and storm surge also exerts pressure and can damage building infrastructure. Building systems should be located above the base flood elevation or projected storm surge height to prevent damage during a flood.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Coastal

Measured Effect of Strategy: Reduced risk of flood or storm damage

Level:	Resilient
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	SLL Credit 1 - Preferred Location
LEED-NC Credit(s):	SS Credit 1 - Site Selection
LEED-H Credit(s):	LL Credit 2 - Site Selection
LEED-EB Credit(s):	N/A

Related Strategies:

1. Avoidance of Flood Plains
2. Avoidance of Storm Surge Zones
3. Elevated First Floor

Objective: To limit damage to the building foundation from flooding or storm surges.

Description: When it is not possible to build on a site outside of the storm surge area or flood plain, the building foundation should be designed to prevent scour. Scour occurs as water passes around obstructions in the water column, changes direction, and accelerates. As a result, soil is loosened and carried away. Scour can affect pilings, pile caps, columns, walls, footings, slabs, and other objects under a building. Scour resistant foundations include open pile and column foundations that are deeply embedded into the soil. The degree of scour will depend on the conditions of the soil.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Coastal

Measured Effect of Strategy: Reduced risk of flood or storm damage

Level:	Resilient
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	SLL Credit 1 - Preferred Locations SLL Credit 7 - Site Design for Habitat or Wetland and Water Body Conservation
LEED-NC Credit(s):	SS Credit 1 - Site Selection
LEED-H Credit(s):	LL Credit 2 - Site Selection SS Credit 4 - Surface Water Management
LEED-EB Credit(s):	N/A
Related Strategies:	1. Avoidance of Flood Plains 2. Avoidance of Storm Surge Zones 3. Elevated First Floor

Objective: To provide occupants with a method to control indoor air temperature in response to changing exterior climatic conditions.

Description: Cross ventilation relies on the air pressure from the wind to remove heat from a space. Designing spaces to allow for cross ventilation provides a passive method of cooling the building on warm days. In the event of a power failure, cross ventilation may allow the building to continue to be occupied even if there is no mechanical cooling present.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	30+ Years
Control:	Occupant
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 2 - Increased Ventilation
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance EQ Credit 4 - Outdoor Air Ventilation
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Thermal Zoning
2. Stack Ventilation
3. Daylighting

Objective: To zone the building so that spaces that can tolerate temperature swings are located between protected rooms and the undesired heat or cold.

Description: Many rooms in a building have less rigid temperature requirements because of their use (e.g., storage), their schedule (e.g., breakfast room) or the duration one spends in the space (e.g., vestibules). These rooms can be placed between regularly occupied spaces and sources of heat to limit overheating of a space.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 7 - Thermal Comfort
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance EA Credit 5 - Heating and Cooling Distribution System
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance IEQ Credit 2 - Occupant Comfort
Related Strategies:	1. Cross Ventilation 2. Stack Ventilation 3. Passive Solar Apertures

Objective: To provide occupants with a method to control indoor air temperature in response to changing exterior climatic conditions.

Description: Stack ventilation relies on the buoyancy of warm air to remove heat from a space. Designing spaces to allow hot air to rise up and out of the space provides a passive method to cool the building on warm days. In the event of a power failure, stack ventilation may allow the building to continue to be occupied even if there is no mechanical cooling present.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level: No Regrets

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 2 - Increased Ventilation

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EQ Credit 4 - Outdoor Air Ventilation

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Cross Ventilation
3. Evaporative Cooling Towers

Objective: To provide occupants with a method of controlling indoor air temperature in response to changing exterior climatic conditions.

Description: Mixed-mode ventilation systems rely on cross ventilation, stack ventilation, and mechanical cooling to remove heat from a space. In a mixed-mode system, the control of the mechanical cooling system is integrated with sensors that detect if windows are opened or closed. This prevents unnecessary cooling of spaces when conditions for natural ventilation are present. In the event of a power failure, the passive environmental systems associated with the mixed-mode system may allow occupants to remain in the building even if there is no mechanical cooling present.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level: No Regrets

Duration: 11-30 Years

Control: Occupant

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 2 - Increased Ventilation

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EQ Credit 4 - Outdoor Air Ventilation

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Cross Ventilation
3. Stack Ventilation

Objective: To provide occupants with a method of controlling air movement in response to changing exterior climatic conditions.

Description: Electric fans increase indoor air speeds, helping to provide thermal comfort. When used in conjunction with air conditioning, they can help to reduce energy use if the thermostat set point temperature is raised. This can reduce electrical energy demand and usage through the cooling season.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	4-10 Years
Control:	Occupant
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 7 - Thermal Comfort
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance EA Credit 6 - Space Heating and Cooling Equipment
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance IEQ Credit 2 - Occupant Comfort
Related Strategies:	1. Thermal Zoning 2. Cross Ventilation 3. Stack Ventilation

Objective: To store thermal energy in the form of heat or coolth to reduce peak heating or cooling loads.

Description: Thermal energy storage can reduce energy demand during the daytime by producing chilled water at night to reduce the load on mechanical systems and the electrical grid. This can help a building to respond to increased temperatures by reducing peak daytime demand, allowing existing systems to respond to greater demand for cooling without reconfiguration.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in peak electrical demand (kW)

Reduction in annual electrical cost ($)

Thermal Energy Storage

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 7 - Thermal Comfort

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 6 - Space Heating and Cooling Equipment

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Increased Thermal Mass
3. Earth Sheltering

Objective: To provide an alternate, passive form of space heating in the event of a power outage.

Description: Passive solar design reduces a building's reliance on the electrical and natural gas grid, and may temper interior temperatures in the event of a grid failure. During normal operation, passive solar design will also reduce wintertime heating demand and total electric or natural gas usage.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in peak heating demand (kW)

Reduction in annual electrical energy (kWh)

Heating, Cooling, Lighting

Passive Solar Design

Level: No Regrets

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 8 - Daylight and Views

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 4 - Windows

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Direct/Indirect Systems
3. Daylighting

Objective: To store thermal energy in the form of heat or coolth to reduce peak heating or cooling loads.

Description: Like thermal energy storage, increased thermal mass stores excess heat or cooling in the building's structure to reduce peak cooling or heating demand. Increased thermal mass can help a building to "ride" through periods of high heating or cooling demand, reducing dependence on HVAC systems.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction in peak electrical demand (kW)

Reduction in peak heating demand (kW)

Reduction in annual electrical cost ($)

Level: No Regrets

Duration: 30+ Years

Control: Passive

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 7 - Thermal Comfort

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 6 - Space Heating and Cooling Equipment

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Thermal Energy Storage
3. Earth Sheltering

Objective: To provide an alternate, passive form of space cooling in the event of a power outage.

Description: Evaporative cooling towers consist of a tower with pads of cool water at the top that induce a down draft current of cool air. This can reduce a building's reliance on air conditioning and the electrical grid, and may help to temper interior temperatures in the event of a grid failure.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
IEQ Credit 7 - Thermal Comfort

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 6 - Space Heating and Cooling Equipment

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
IEQ Credit 2 - Occupant Comfort

Related Strategies:

1. Thermal Zoning
2. Stack Ventilation
3. Cross Ventilation

Objective: To use the high heat capacity of the earth to reduce peak heating or cooling loads.

Description: Earth sheltering, similar in concept to increased thermal mass and thermal energy storage, uses the heat capacity of the ground to reduce peak cooling or heating demand. This increased thermal mass can help a building to "ride" through periods of high heating or cooling demand, reducing dependence on HVAC systems. In earth cooling tube systems, direct contact of ductwork with the earth transfers heat energy from incoming air into the ground, precooling the air for the air conditioning system, and thereby reducing electrical demand.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	30+ Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 2 - Increased Ventilation
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance EQ Credit 9 - Radon Protection
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance IEQ Credit 2 - Occupant Comfort
Related Strategies:	1. Thermal Zoning 2. Earth Sheltering 3. Increased Thermal Mass

Objective: To limit the effects of increased temperature and power outages by relying primarily on daylight rather than electrical lighting systems.

Description: Daylighting addresses increased temperatures by reducing the use of electrical lighting and the associated heat gain indoors. In addition, daylighting limits the effect of a power outage during the daytime by providing an alternative source of light. Daylighting is a recognized strategy for increasing the energy efficiency of a building and should be incorporated at the initial design stages to maximize the benefit and savings.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Storms

Measured Effect of Strategy:

Reduction of heat gain (W/ square meter)

Reduction of interior air temperature (degrees)

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Level:	No Regrets
Duration:	30+ Years
Control:	Passive
LEED-ND Credit(s):	GIB Credit 10 - Solar Orientation
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 8 - Daylight and Views
LEED-H Credit(s):	EA Credit 8 - Lighting
LEED-EB Credit(s):	IEQ Credit 2 - Daylight and Views
Related Strategies:	1. Solar Zoning/Solar Envelope 2. Building Orientation 3. Interior Shading Devices

Objective: To allow egress lighting to last for a longer period of time in the event of a power failure.

Description: Energy efficient lighting, including fluorescent lighting and LED lighting, lasts longer in exit signage and requires less amp-hours to run from a battery in the event of a power outage.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: N/A

Measured Effect of Strategy:

Reduction in peak electrical demand (kW)

Reduction in annual electrical energy (kWh)

Reduced egress time during a power failure (minutes)

Reduction of heat gain (W/ square meter)

Reduction of interior air temperature (degrees)

High Efficacy Egress Lighting

Level:	Resilient
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance EA Credit 5 - Measurement and Verification
LEED-H Credit(s):	N/A
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance EA Credit 3 - Building Automation System
Related Strategies:	1. Daylighting 2. Emergency Management Plan 3. Critical System Backup

Objective: To allow for future use of graywater on site in the event of decreased precipitation and water availability.

Description: Graywater refers to reclaimed water from clothes washers, showers, bathtubs, and restroom faucets. It excludes water from toilets, kitchen sinks, and dishwashers. Graywater is collected by a separate drainage system. This requires two plumbing systems for a building, one for graywater reuse and one for wastewater drainage. Some states do not permit the use of graywater, but as it becomes a more common practice, restrictions on its use are beginning to be eased. It is easier to incorporate a graywater system during construction than it is to add piping after the building is complete.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of potable water use (gal)

Water and Waste

Graywater System Rough Out

Level:	No Regrets
Duration:	11-30 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 4 - Water Efficient Landscaping GIB Credit 14 - Wastewater Management
LEED-NC Credit(s):	WE Credit 1 - Water Efficient Landscaping WE Credit 2 - Innovative Wastewater Technologies
LEED-H Credit(s):	WE Credit 1 - Water Reuse
LEED-EB Credit(s):	N/A
Related Strategies:	1. Reclaimed Water Use 2. Water Catchment Systems/Cistern 3. HVAC Condensate Capture

Objective: To allow for an efficient use of water in the event of decreased precipitation.

Description: Water efficient fixtures, including faucets, showerheads and toilets, reduce the flow rate of water through the fixture. The EPA product labeling program, WaterSense, helps building professionals identify products that do not exceed a maximum flow rate. This strategy is important for regions where the quantity of precipitation is projected to decrease, leading to drought.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduced flow rate (gal/ min)

Reduced annual water usage (gal)

Level: No Regrets

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 3 - Building Water Efficiency

LEED-NC Credit(s): WE Credit 3 - Water Use Reduction

LEED-H Credit(s): WE Credit 3 - Indoor Water Use

LEED-EB Credit(s): WE Credit 1 - Water Performance Measurement
WE Credit 2 - Additional Indoor Plumbing Fixture and Fitting Efficiency

Related Strategies:

1. Reclaimed Water Use
2. Water Catchment Systems/Cistern
3. Graywater System

Objective: To allow for the use of HVAC condensate in the event of decreased precipitation.

Description: Condensate from home air conditioner systems can be used for irrigation. At non-residential sites, the condensate water can be used for the cooling tower, for cooling building equipment, in water features, in evaporative coolers, or for irrigation. In areas where water scarcity is projected, HVAC condensate capture and reuse may be a valuable option for reducing potable water demand.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of potable water use (gal)

Level: No Regrets

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 4 - Water Efficient Landscaping
GIB Credit 14 - Wastewater Management

LEED-NC Credit(s): WE Credit 1 - Water Efficient Landscaping
WE Credit 2 - Innovative Wastewater Technologies

LEED-H Credit(s): WE Credit 1 - Water Reuse

LEED-EB Credit(s): WE Credit 4 - Cooling Tower Water Management

Related Strategies:

1. High Efficiency Water Fixtures
2. Graywater System Roughout
3. Water Catchment Systems/Cistern

Objective: To limit the reliance on the grid for hot water in the event of power failure.

Description: Solar water heaters increase the energy security of a building by providing an on-site energy supply for water heating. Solar water heaters use solar energy to heat water rather than relying on electricity or natural gas.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in energy demand (kW)

Reduction in energy usage (kWh)

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Critical Systems Backup
2. Highly Insulated Refrigeration Equipment
3. System Redundancy

Objective: To prevent pipes from freezing or bursting in the event of a power outage or heating system failure.

Description: Insulating pipes helps to minimize heat loss and to protect cold water lines from freezing. Pipes can be insulated with sleeves, batt insulation, or other insulating materials. Installing insulation around hot water pipes will increase the efficiency of the hot water system.

Regional Priority:

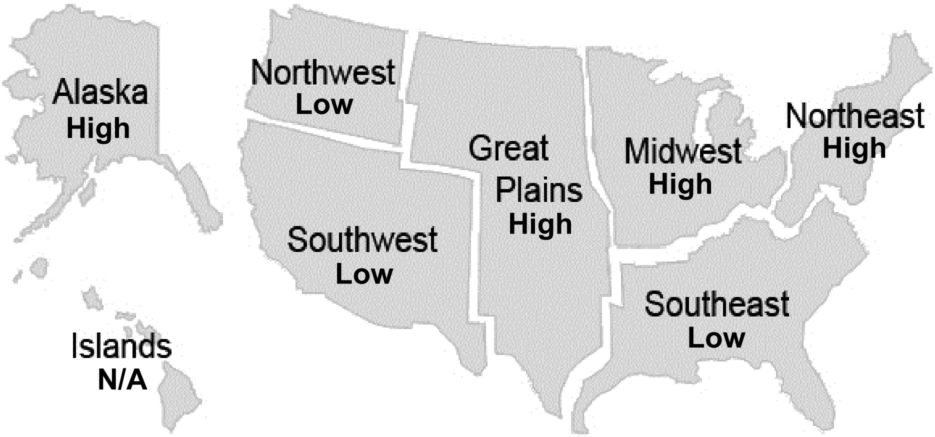


Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in heat loss from piping (W/ square meter)

Reduced risk of freezing damage

Insulated Water System

Level: No Regrets

Duration: 30+ Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Solar Domestic Hot Water Heating
2. Passive Solar Design
3. Graywater System

Objective: To reduce the use of potable water during of extended periods of drought.

Description: Graywater refers to reclaimed water from clothes washers, showers, bathtubs, and restroom faucets. It excludes water from toilets, kitchen sinks, and dishwashers. Graywater is collected by a separate drainage system. This requires two plumbing systems for a building, one for graywater reuse and one for wastewater drainage. Graywater use reduces the amount of wastewater that needs to be treated and preserves potable water for other uses. A graywater system includes storage tanks, color-coded piping, filters, pumps, valves, and controls.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of potable water use (gal)

Graywater System

Level:	No Regrets
Duration:	11-30 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	GIB Credit 4 - Water Efficient Landscaping GIB Credit 14 - Wastewater Management
LEED-NC Credit(s):	WE Credit 1 - Water Efficient Landscaping WE Credit 2 - Innovative Wastewater Technologies
LEED-H Credit(s):	WE Credit 1 - Water Reuse
LEED-EB Credit(s):	WE Credit 3 - Water Efficient Landscaping
Related Strategies:	1. Graywater System Roughout 2. Water Catchment Systems/Cistern 3. High Efficiency Fixtures

Objective: To increase water reliability and reduce the impact on the local water utility during extended periods of drought or decreased precipitation.

Description: Reclaimed water reduces the amount of water discharged to the sewer system by reusing water on site. Reclaimed water is different from graywater in that it requires treatment before use. Reclaimed water can be used for landscape irrigation, golf course irrigation, vehicle washing, groundwater recharge, water cooled HVAC, and industrial cooling processes.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of potable water use (gal)

Level: Resilient

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 4 - Water Efficient Landscaping
GIB Credit 14 - Wastewater Management

LEED-NC Credit(s): WE Credit 1 - Water Efficient Landscaping
WE Credit 2 - Innovative Wastewater Technologies

LEED-H Credit(s): WE Credit 1 - Water Reuse

LEED-EB Credit(s): WE Credit 3 - Water Efficient Landscaping

Related Strategies:

1. Water Catchment Systems/Cistern
2. Graywater System
3. High Efficiency Fixtures

Objective: To prevent sewage backup into a building from increased precipitation and/or floods.

Description: A sewage backflow preventer allows wastewater to flow out in one direction by restricts the flow from reversing back into a building. Sewage backflow preventers can be of several types from simple check valves to more complex spring-loaded relief valves. In addition, access to the sewer pipe should be incorporated outside of the building to allow easier access for cleanout in the event of a backup.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduced risk of sewage backup into a building

Level:	Resilient
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	EA Credit 3 - Advanced Commissioning
LEED-H Credit(s):	ID 1 - Integrated Project Planning
LEED-EB Credit(s):	EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. Avoidance of Flood Plains
2. Elevated First Floor
3. Elevated Essential Infrastructure

Objective: To collect water for future use in the event of decreased precipitation, extended periods of drought, or extreme variation in water availability.

Description: Water catchment systems include cisterns, storage tanks, and ponds. Tanks can be located above or below ground to store water. Storage should be sized based on projected precipitation volumes in order to maximize the volume of water that can be captured during a storm event.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: N/A

Measured Effect of Strategy: Reduction of potable water use (gal)

Water Catchment Systems/Cistern

Level: Resilient

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 4 - Water Efficient Landscaping
GIB Credit 14 - Wastewater Management

LEED-NC Credit(s): WE Credit 1 - Water Efficient Landscaping
WE Credit 2 - Innovative Wastewater Technologies

LEED-H Credit(s): WE Credit 1 - Water Reuse

LEED-EB Credit(s): WE Credit 3 - Water Efficient Landscaping

Related Strategies:

1. Graywater System
2. High Efficiency Fixtures
3. HVAC Condensate Capture

Objective: To maintain energy efficiency under part load conditions.

Description: Variable frequency drives control the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supply to the motor. Variable frequency drives increase energy efficiency under part load conditions because they have more flexibility to respond to smaller steps in load. If systems are oversized to deal with expected changes in demand, using variable frequency drives may help to prevent unnecessary energy waste.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Air Quality

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Equipment Variable Frequency Drives

Level: No Regrets

Duration: 4-10 Years

Control: Owner

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance

Related Strategies:

1. Energy Management System
2. Energy/Environmental Modeling
3. System Redundancy

Equipment

Energy Management System

Objective: To maintain the efficiency of building systems in the event of increased temperatures.

Description: Energy management and control systems can reduce the energy use of building systems by monitoring and controlling their operation. By comparing data from these systems against weather data, building managers may be able to anticipate when changes in mechanical system design or operation are necessary. Priority should be given to the equipment with the largest electrical demand. Energy management can include start/stop functions, temperature setback/setup, and economizer controls.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Equipment

Energy Management System

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 5 - Measurement and Verification

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
EA Credit 3 - Building Automation System

Related Strategies:

1. Energy/Environmental Modeling
2. Variable Frequency Drives
3. Building Operations Manual

Reduced Friction Losses

Objective: To respond to increased heating or cooling needs while maintaining energy efficiency goals.

Description: The number of bends and the aspect ratio of ductwork affects how efficiently air is distributed through a building. Ductwork that is sized to the minimum cross section may not be able to accommodate increased heating or cooling needs. Oversized ductwork not only reduces friction loss because of lower air speeds but also allows the system to add additional air flow if heating or cooling needs increase.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Equipment Reduced Friction Losses

Level: No Regrets

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance
EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
ID 1 - Integrated Project Planning

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. M/E/P Equipment Rooms
2. HVAC Air Intake Location
3. Variable Frequency Drives

Objective: To resist damage from burning embers or firebrands if they penetrate the building envelope during a wildfire.

Description: During wildfires, burning embers and hot gases can penetrate the building's envelope and ignite interior materials. Fire sprinklers are not common in residential construction, but they can be effective in preventing damage from a wildfire. Several states are considering adding residential fire sprinkler requirements for homes constructed at the wildland-urban interface.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Fire

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of fire damage during a wildfire

Equipment

Residential Sprinkler System

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): N/A

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): N/A

Related Strategies:

1. Class "A" Roofing
2. Noncombustible Siding
3. Tempered Windows

Objective: To prevent damage to or failure of the elevator system in the event of a flood or power outage.

Description: Elevator systems should be designed with a back-up power source or automatic return so that they return to the first floor in the event of a power outage. Elevator system design should also consider the potential for flooding; elevator machinery should be located above flood level in order to prevent permanent damage to the system. The elevator tower should also be sealed to prevent water contamination to the hydraulic fluid.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of persons trapped in the elevator

Reduced risk of damage to the elevator system

Level: Resilient

Duration: 11-30 Years

Control: Passive

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): N/A

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. Elevated First Floor
2. Elevated Essential Infrastructure
3. Avoidance of Flood Plains

Objective: To maintain critical building functions in the event of a power outage.

Description: The maintenance and operation of critical systems in the event of a power outage should be prioritized in the design of the building as well as in the operations and maintenance plans. Critical systems should be backed up with renewable power generation, a generator, or a battery backup system.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of critical system loss or damage

Equipment — Critical System Backup

Level: Resilient

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. Enhanced Signal Systems
2. Elevator System Design
3. System Redundancy

Objective: To increase a building's resilience to severe weather events, including extreme heat events and storms.

Description: Redundancy of key systems, including heating and cooling systems, would allow the building to continue to function until a compromised system can be replaced or repaired. Redundant systems may reduce efficiency, but may be necessary to increase resilience. Examples include dividing cooling load across several compressors, or heating load across several boilers.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Temperature

Measured Effect of Strategy: Reduced risk to building occupants in the event of equipment failure

Equipment System Redundancy

Level: Resilient

Duration: 11-30 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. Enhanced Signal Systems
2. Elevated Essential Infrastructure
3. Critical System Backup

Objective: To allow for improvements or upgrades to HVAC, electrical, or mechanical systems in response to increased cooling demands.

Description: Equipment pads and mechanical/electrical closets should allow for flexibility in size and type of equipment. As the demands on the building system change or equipment technology advances, it may be necessary to replace or upgrade the size or type of the equipment. Building professionals should be careful not to oversize the equipment at the cost of reducing efficiency. Instead, the equipment rooms or areas should be sized to allow for future changes.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduced future cost of installation

Level:	Resilient
Duration:	30+ Years
Control:	Owner
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	EA Credit 3 - Advanced Commissioning
LEED-H Credit(s):	ID Credit 1 - Integrated Project Planning
LEED-EB Credit(s):	EA Credit 2 - Existing Building Commissioning

Related Strategies:

1. Reduced Friction Losses
2. Elevated First Floor
3. Elevated Essential Infrastructure

Objective: To maintain critical temperatures in refrigeration equipment for a longer period of time during a power outage.

Description: Perished food in refrigerators and freezers results in a high cost for insurers following storms that disrupt power. Refrigeration systems that have higher insulation levels will preserve food and other goods at critical temperatures for longer periods of time.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: N/A

Measured Effect of Strategy: Reduced risk of food perishing due to high temperatures

Equipment Insulated Refrigeration Equipment

Level: No Regrets

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning

Related Strategies:
1. Critical System Backup
2. System Redundancy
3. Emergency Management Plan

Objective: To model changes in temperature and precipitation to better understand the effect of climate change on building systems.

Description: Advances in climate models, building energy models, and other environmental modeling tools (e.g., precipitation) can help a team with sizing building equipment for projected changes in temperature and precipitation levels. This can be useful for a team to prioritize strategies or to understand how to size systems for future climates. Great care must be taken in using the climate data, however, as downscaling of data introduces significant uncertainty.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Level: No Regrets

Duration: 1-3 Years

Control: Operations & Maintenance

LEED-ND Credit(s): GIB Credit 2 - Building Energy Efficiency

LEED-NC Credit(s): EA Credit 1 - Optimize Energy Performance

LEED-H Credit(s): EA Credit 1 - Optimize Energy Performance
ID Credit 1 - Integrated Project Planning

LEED-EB Credit(s): EA Credit 1 - Optimize Energy Efficiency Performance
EA Credit 3 - Building Automation System

Related Strategies:

1. Mixed-Mode Ventilation
2. Increased Thermal Mass
3. Energy Management System

Objective: To develop a detailed, facility-specific operations and maintenance manual to assist staff with the proper operation of building equipment.

Description: The utility of building operations manuals is well documented. To allow a building to respond to changes in climate, proper operation and maintenance of equipment must be documented and accessible to building managers. Without such information, signals that a building or project is not responding to climate change may be missed or inadvertently ignored.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Level: No Regrets

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Advanced Commissioning

LEED-H Credit(s): AE Credit 1 - Education of the Homeowner or Tenant
AE Credit 2 - Education of the Building Manager

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning
EA Credit 3 - Building Automation System

Related Strategies:

1. Energy Management System
2. Energy/Environmental Modeling
3. Retrocommissioning

Objective: To give occupants the opportunity to adapt to increased temperatures either by modifying their clothing or avoiding the warmest part of a day.

Description: Flexible dress codes and schedules allow building occupants to adapt to warmer temperatures by either dressing lighter or avoiding working during the hottest part of the day. While both strategies seem to be commonsense, many companies have strict dress codes that require heavier amounts of clothing to be worn, even in summer. Other companies may have a culture that requires additional clothing, such as long shirts and ties. Developing a building- or project- wide policy will allow staff to adapt to changing climatic conditions and potentially reduce energy use and demand in a building.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: N/A

Measured Effect of Strategy:

Increased staff comfort

Increase in air temperature (degrees)

Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Level:	No Regrets
Duration:	1-3 Years
Control:	Occupant
LEED-ND Credit(s):	GIB Credit 2 - Building Energy Efficiency
LEED-NC Credit(s):	EA Credit 1 - Optimize Energy Performance IEQ Credit 7 - Thermal Comfort
LEED-H Credit(s):	EA Credit 1 - Optimize Energy Performance EA Credit 5 - Heating and Cooling Distribution System
LEED-EB Credit(s):	EA Credit 1 - Optimize Energy Efficiency Performance IEQ Credit 2 - Occupant Comfort
Related Strategies:	1. Energy Management System 2. Mixed-Mode Ventilation 3. Electric Fans

Objective: To establish an ongoing process to evaluate and recalibrate building systems to achieve peak energy efficiency and performance.

Description: Retrocommissioning, or the recommissioning of building equipment, is a common practice to ensure that building equipment is operating as designed. Retrocommissioning as an adaptation measure is a process by which data is gathered on outdoor weather conditions and compared to the operations of equipment. If it is expected that temperature will increase over time, equipment can be tuned to perform better as temperatures increase, or replaced if no longer operating efficiently.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Water/Precipitation

Measured Effect of Strategy: Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Level: No Regrets

Duration: 4-10 Years

Control: Operations & Maintenance

LEED-ND Credit(s): N/A

LEED-NC Credit(s): EA Credit 3 - Enhanced Commissioning

LEED-H Credit(s): AE Credit 1 - Education of the Homeowner or Tenant
AE Credit 2 - Education of the Building Manager

LEED-EB Credit(s): EA Credit 2 - Existing Building Commissioning
EA Credit 3 - Building Automation System

Related Strategies:

1. Energy Management System
2. Energy/Environmental Modeling
3. Building Operations Manual

Objective: To establish a "point person" in each organization to manage the adaptation process and to coordinate efforts between departments.

Description: To address climate risks, building owners, managers, and occupants should organize resources, assess risks, develop a plan, and implement the plan. To monitor the progress on the plan, many agencies recommend designating a person to champion the process and ensure that all personnel are prepared for future events. Similar to a LEED-AP, this person would continually update progress and be sure that changes to facility operations reflect the current risk profile.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Temperature

Secondary Impact: Water/Precipitation

Measured Effect of Strategy:

Reduced risk of property damage

Reduced risk of loss of life

Reduction in electrical demand (kW)

Reduction in electrical usage (kWh)

Level:	Resilient
Duration:	4-10 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	IDP Credit 2 - LEED Accredited Professional
LEED-NC Credit(s):	ID Credit 2 - LEED Accredited Professional
LEED-H Credit(s):	AE Credit 1 - Education of the Homeowner or Tenant AE Credit 2 - Education of the Building Manager
LEED-EB Credit(s):	IO Credit 2 - LEED Accredited Professional

Related Strategies:

1. Energy Management System
2. Energy/Environmental Modeling
3. Building Operations Manual

Objective: To provide occupants with a hardened area inside a building to survive unexpected climate events such as a storm or flash flood.

Description: Areas of refuge are typically provided in buildings for persons with disabilities. These spaces have enhanced signal systems to communicate with first responders, and are hardened to protect the person from multiple hazards (e.g., fire, smoke) until a responder is able to assist them out of the building. Areas of refuge are typically designed to respond only to fires, but as the risk of severe precipitation events and flooding increases, areas on the upper floors of buildings may need to be designated as hardened areas to protect occupants until help arrives.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Water/Precipitation

Secondary Impact: Storms

Measured Effect of Strategy: Reduced risk of loss of life

Process and Operations — Areas of Refuge

Level:	Resilient
Duration:	30+ Years
Control:	Occupant
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	N/A
LEED-H Credit(s):	N/A
LEED-EB Credit(s):	N/A
Related Strategies:	1. Elevator System Design 2. Critical System Backup 3. Emergency Management Plan

Objective: To develop a facility-wide plan to respond to the impacts of climate change.

Description: Emergency management plans are the first step in reducing risk from natural disasters. To address climate risks, building owners, managers, and occupants should organize resources, assess risks, develop a plan, and implement the plan. Few organizations provide guidance on climate-specific risks; however, preparation for other possible events (e.g., wildfire, flood, tsunami) will help a facility and occupants to be more resilient to the effects of climate change.

Regional Priority:

Image source: http://www.globalchange.gov

Primary Impact: Storms

Secondary Impact: Fire

Measured Effect of Strategy: Reduced risk of property damage

Reduced risk of loss of life

Level:	Resilient
Duration:	1-3 Years
Control:	Operations & Maintenance
LEED-ND Credit(s):	N/A
LEED-NC Credit(s):	N/A
LEED-H Credit(s):	AE Credit 1 - Education of the Homeowner or Tenant AE Credit 2 - Education of the Building Manager
LEED-EB Credit(s):	N/A

Related Strategies:

1. Areas of Refuge
2. Climate Change Champion
3. Critical System Backup

APPENDIX C: References

Envelope Category

Building Science Corporation. *High R-Value Wall Assemblies*. Available from http://www.buildingscience.com/resources/high-r-value.

———. *High R-Value Foundations*. Available from http://www.buildingscience.com/resources/high-r-value-foundation-assemblies.

———. *High R-Value Roofs*. Available from http://www.buildingscience.com/resources/high-r-value-roof-assemblies.

California Department of Forestry and Fire Protection. *California's Wildland-Urban Interface Code Information*. Available from http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland.php.

———. *Building Materials Listing Program*. Available from http://osfm.fire.ca.gov/licensinglistings/licenselisting_bml_searchcotest.php.

Federal Emergency Management Agency. 1994. Mitigation of Flood and Erosion Damage to Residential Buildings in Coastal Areas. In *FEMA 257*. http://www.fema.gov/library/viewRecord.do?id=1643.

———. 2007. Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings. In *FEMA 543*. http://www.fema.gov/library/viewRecord.do?id=2441.

———. 2007. Design Guidelines for Flood Damage Reduction. In *FEMA 15*. http://www.fema.gov/library/viewRecord.do?id=1628.

———. 2008. Home Builder's Guide to Construction in Wildfire Zones. In *FEMA 737*. http://www.fema.gov/library/viewRecord.do?id=3646.

———. 2009. Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations. In *FEMA P550*. http://www.fema.gov/library/viewRecord.do?id=1853.

———. 2009. Local Officials Guide for Coastal Construction. In *P-762*. http://www.fema.gov/library/viewRecord.do?id=3647.

———. 2010. Wind Retrofit Guide for Residential Buildings. In *FEMA P-804*. http://www.fema.gov/library/viewRecord.do?id=4569.

———. 2011. Catalog of FEMA Flood and Wind Publications, Training Courses, and Workshops. In *FEMA 787*. http://www.fema.gov/library/viewRecord.do?id=3184.

———. 2011. Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas. In *FEMA 55*. http://www.fema.gov/library/viewRecord.do?id=1671.

Kwok, Alison G., and Walter T. Grondzik. 2011. *The Green Studio Handbook: Environmental Strategies for Schematic Design*. 2nd ed. Burlington, MA: Architectural Press.

Larson, Timothy, Lewis Hendricks, Patrick Huelman, and Richard Stone. *Ice Dams*. Available from http://www.extension.umn.edu/distribution/housingandclothing/dk1068.html.

Lawrence Berkeley National Laboratory. *Cool Roofing Materials Database*. Available from http://eetd.lbl.gov/CoolRoofs.

———. 1997. Shading Strategy. In *Tips for Daylighting with Windows*. Berkeley, CA. http://windows.lbl.gov/pub/designguide/download.html.

———. 1997. Glazing Selection. In *Tips for Daylighting with Windows*. Berkeley, CA. http://windows.lbl.gov/pub/designguide/download.html.

Lstiburek, Joseph, and Building Science Corporation. Understanding Drainage Planes. http://www.buildingscience.com/documents/digests/bsd-105-understanding-drainage-planes/.

———. Flood and Hurricane Resistant Buildings. http://www.buildingscience.com/documents/digests/bsd-111-flood-and-hurricane-resistant-buildings/.

Miami-Dade County. *Product Control Search*. Available from http://www.miamidade.gov/building/pc-search_app.asp.

Mills, Evan. 2003. Climate change, insurance and the buildings sector: technological synergisms between adaptation and mitigation. *Building Research & Information* 31 (3-4):257-277.

National Center for Healthy Housing. *Integrated Pest Management in Affordable Housing*. Available from http://www.healthyhomestraining.org/ipm.

National Institute of Building Sciences. *Building Envelope Design Guide*. Available from http://www,wbdg.org/design/envelope.php.

———. *Daylighting Principles and Strategies for Sustainable Design*. Available from http://www.wbdg.org/education/daylight.php.

———. *Sustainable Roofing Design Considerations and Applications*. Available from http://www.wbdg.org/education/roofing.php.

National Roofing Contractors Association. 2011. *The NRCA Roofing Manual: Steep-Slope Roof Systems*. Rosemont, IL.

Potter, Mike. *Protecting Your Home Against Termites*. Available from http://www.ca.uky.edu/entomology/entfacts/ef605.asp.

Rousseau, M.Z., G.F. Poirier, and W.C. Brown. *Pressure Equalization in Rainscreen Wall Systems*. Available from http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ctus/ctus-n17.html.

Straube, John, and Building Science Corporation. *Ice Dams*. Available from http://www.buildingscience.com/documents/digests/bsd-135-ice-dams.

U.S. Environmental Protection Agency. *Technical Guidance to the Indoor airPLUS Construction Specifications*. Available from http://www.epa.gov/indoorairplus/technical/moisture/1_5.html.

Siting and Landscape Category

Brown, G. Z., and Mark DeKay. 2001. *Sun, Wind & Light: Architectural Design Strategies*. 2nd ed. New York: John Wiley & Sons, Inc.

Federal Emergency Management Agency. *Map Service Center*. Available from http://msc.fema.gov.

———. 2008. Home Builder's Guide to Construction in Wildfire Zones. In *FEMA 737*. http://www.fema.gov/library/viewRecord.do?id=3646.

———. 2009. Hurricane Ike Recovery Advisories. http://www.fema.gov/library/viewRecord.do?id=3539.

———. 2010. Highlights of ASCE 24-05 Flood Resistant Design and Construction. http://www.fema.gov/library/viewRecord.do?id=3515.

———. 2011. Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas. In *FEMA 55*. http://www.fema.gov/library/viewRecord.do?id=1671.

Grondzik, Walter T., Alison G. Kwok, Benjamin Stein, and John S. Reynolds. 2010. *Mechanical and Electrical Equipment for Buildings*. Hoboken, NJ: John Wiley & Sons, Inc.

H. John Heinz III Center for Science, Economics and the Environment, and Ceres. 2009. Resilient Coasts: A Blueprint for Action. http://www.ceres.org/resources/reports/resilient-coasts-blueprint-for-action-2009/at_download/file.

Hunter, Mary Carol R. 2008. Mitigation, Adaptation, Uncertainty -- Managing Sense of Place in Transition: Coping with Climate Change. *Places* 20 (2):20-25.

Institute for Business & Home Safety. 2009. Hurricane Ike: Nature's Force vs. Structural Strength. http://www.disastersafety.org/content/data/file/hurricane_ike.pdf.

Lawrence Berkeley National Laboratory. *Heat Island Group*. Available from http://eetd.lbl.gov/HeatIsland.

National Association of Home Builders. *Smarter Growth*. Available from http://www.nahb.org/page.aspx/category/sectionID=221.

National Fire Protection Association. *Firewise Communities Program*. Available from http://www.firewise.org.

———. *Firewise Communities Program Plant List by State*. Available from http://www.firewise.org/Information/Research-and-Guidance/Firewise-Landscaping-and-Plant-Lists.aspx.

National Institute of Building Sciences. *Optimize Site / Existing Structure Potential*. Available from http://www.wbdg.org/design/site_potential.php.

———. *Achieving Sustainable Site Design Through Low Impact Development*

Practices. Available from http://www.wbdg.org/resources/lidsitedesign.php.

———. *Passive Solar Heating*. Available from http://www.wbdg.org/resources/psheating.php.

Prince George's County, Maryland Department of Environmental Resources Programs and Planning Division. 1999. Low Impact Development Design Strategies: An Integrated Design Approach. http://www.epa.gov/owow/NPS/lidnatl.pdf.

Thompson, J. William. 2008. *Sustainable Landscape Construction: A Guide to Green Building Outdoors*. 2nd ed. Washington, D.C.: Island Press.

U.S. Department of Energy. *Community Solar Access*. Available from http://www.energysavers.gov/renewable_energy/solar/index.cfm.

U.S. Department of Transportation. *Climate Change Impacts & Adaptation*. Available from http://climate.dot.gov/impacts-adaptations/index.html.

U.S. Environmental Protection Agency. *Environmental Benefits of Smart Growth*. Available from http://www.epa.gov/smartgrowth/topics/eb.htm.

———. *A Source Book on Natural Landscaping for Public Officials*. Available from http://www.epa.gov/greenacres/toolkit/index.html.

———. *Heat Island Effect*. Available from http://www.epa.gov/hiri.

———. *Reducing Urban Heat Islands: Compendium of Strategies*. Available from http://www.epa.gov/hiri/resources/compendium.htm.

———. *Low Impact Design*. Available from http://www.epa.gov/owow/NPS/lid.

———. *Stormwater Best Management Practices*. Available from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

———. *Heat Island Reduction Initiative*. Available from http://www.epa.gov/heatisland.

U.S. Fire Administration. *Fire-Safe Landscaping Can Save Your Home*. Available from http://www.usfa.dhs.gov/citizens/home_fire_prev/rural/landscape.shtm.

U.S. Geological Survey. *National Wetlands Research Center*. Available from http://www.nwrc.usgs.gov/.

Heating, Cooling, Lighting Category

Brown, G. Z., and Mark DeKay. 2001. *Sun, Wind & Light: Architectural Design Strategies*. 2nd ed. New York: John Wiley & Sons, Inc.

Grondzik, Walter T., Alison G. Kwok, Benjamin Stein, and John S. Reynolds. 2010. *Mechanical and Electrical Equipment for Buildings*. Hoboken, NJ: John Wiley & Sons, Inc.

Kwok, Alison G., and Walter T. Grondzik. 2011. *The Green Studio Handbook: Environmental Strategies for Schematic Design*. 2nd ed. Burlington, MA: Architectural Press.

Lawrence Berkeley National Laboratory. 1997. Tips for Daylighting with Windows. Berkeley, CA. http://windows.lbl.gov/pub/designguide/download.html.

Mills, Evan. 2003. Climate change, insurance and the buildings sector: technological synergisms between adaptation and mitigation. *Building Research & Information* 31 (3):257-277.

National Institute of Building Sciences. *Energy Efficient Lighting*. Available from http://www.wbdg.org/resources/efficientlighting.php.

———. *Balancing Security/Safety and Sustainability Objectives*. Available from http://www.wbdg.org/resources/balancing_objectives.php.

———. *Daylighting*. Available from http://www.wbdg.org/resources/daylighting.php.

Sonne, Jeff, and Danny Parker. 1998. Measured Ceiling Fan Performance and Usage Patterns: Implications for Efficiency and Comfort Improvement. www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1770-98.pdf.

Water and Waste Category

American Rainwater Catchment Systems Association. *American Rainwater Catchment Systems Association Website*. Available from http://www.arcsa.org.

Efficiency, Alliance for Water. *Condensate Water Introduction*. Available from http://www.allianceforwaterefficiency.org/Condensate_Water_Introduction.aspx.

Federal Emergency Management Agency. 2008. After The Flood Home Maintenance Series: (4) Install Sewer Backflow Valves. In *FEMA 737*. http://www.fema.gov/news/newsrelease.fema?id=3860.

Federal Energy Management Program (FEMP). *Federal Water Efficiency Best Management Practices*. Available from http://www1.eere.energy.gov/femp/program/waterefficiency_bmp.html.

Kwok, Alison G., and Walter T. Grondzik. 2011. *The Green Studio Handbook: Environmental Strategies for Schematic Design*. 2nd ed. Burlington, MA: Architectural Press.

National Institute of Building Sciences. *Protect and Conserve Water*. Available from http://www.wbdg.org/design/conserve_water.php.

———. *Solar Water Heating*. Available from http://www.wbdg.org/resources/swheating.php.

———. *Mechanical Insulation Design Guide*. Available from http://www.wbdg.org/design/midg.php.

Thompson, J. William. 2008. *Sustainable Landscape Construction: A Guide to Green Building Outdoors*. 2nd ed. Washington, D.C.: Island Press.

U.S. Department of Energy. Solar Water Heaters.

U.S. Environmental Protection Agency. *WaterSense*. Available from http://www.epa.gov/WaterSense.

Wilson, Alex. 2008. Alternative Water Sources: Supply-Side Solutions for Green Buildings. *Environmental Building News*.

Equipment Category

State of California. Electric Power Disruption Toolkit for Local Government. http://www.calema.ca.gov/PlanningandPreparedness/Documents/PowerDisruptionToolkit.pdf.

ResilientCity.org. *Resilient Design Principles*. Available from http://www.resilientcity.org/index.cfm?pagepath=Resilience/Resilient_Design_Principles&id=11900.

National Institute of Building Sciences. *About the Integrated Resilient Design Program*. Available from http://www.nibs.org/index.php/irdp/aboutirdp/.

———. *HVAC System Dynamic Integration*. Available from http://www.wbdg.org/resources/hvacdi.php.

———. *High-Performance HVAC*. Available from http://www.wbdg.org/resources/hvac.php.

Mills, Evan. 2003. Climate change, insurance and the buildings sector: technological synergisms between adaptation and mitigation. *Building Research & Information* 31 (3):257-277.

Federal Emergency Management Agency. 2010. Elevator Installation. In *TB 4*. http://www.fema.gov/library/viewRecord.do?id=1717.

———. 2008. Home Builder's Guide to Construction in Wildfire Zones. In *FEMA P-737*. http://www.fema.gov/library/viewRecord.do?id=3646.

California Department of Forestry and Fire Protection. *Building Materials Listing Program*. Available from http://osfm.fire.ca.gov/licensinglistings/licenselisting_bml_searchcotest.php.

———. *California's Wildland-Urban Interface Code Information*. Available from http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland.php.

Process and Operations Category

Crawley, Drury Browne. 2008. Building Performance: A Tool for Policymaking. http://www.strath.ac.uk/esru/research/projects.

de Dear, Richard, and Gail Brager. *The Adaptive Model of Thermal Comfort: University of Sydney's ASHRAE RP-884 Project* 1997. Available from http://sydney.edu.au/architecture/staff/homepage/richard_de_dear/index.shtml.

Federal Emergency Management Agency. *Protect Your Property or Business from Disaster*. Available from http://www.fema.gov/plan/prevent/howto/index.shtm.

———. *Safe Rooms*. Available from http://www.fema.gov/plan/prevent/saferoom/index.shtm.

———. *Plan for Emergencies*. Available from http://www.fema.gov/plan/prepare/plan.shtm.

———. 2001. Telling the Tale of Disaster Resistance: A Guide to Capturing and Communicating the Story. http://www.fema.gov/library/viewRecord.do?id=1762.

———. 2004. Developing and Promoting Mitigation Best Practices and Case Studies: Communication Strategy Toolkit. http://www.fema.gov/library/viewRecord.do?id=1774.

———. 2008. Taking Shelter From the Storm: Building a Safe Room For Your Home or Small Business. http://www.fema.gov/library/viewRecord.do?id=1536.

Kwok, Alison G., and Nicholas B. Rajkovich. 2010. Addressing climate change in comfort standards. *Building and Environment* 45 (1):18-22.

Middlebury College. *Middlebury College Thermal Comfort Policy*. Available from http://www.middlebury.edu/about/handbook/misc/thermal_comfort.

National Institute of Building Sciences. *Facilities Operations & Maintenance*. Available from http://www.wbdg.org/om/om.php.

———. *Comprehensive Facility Operation & Maintenance Manual*. Available from http://www.wbdg.org/om/om_manual.php.

———. *Computerized Maintenance Management Systems (CMMS)*. Available from http://www.wbdg.org/om/cmms.php.

State of California. *Commissioning and Retro-Commissioning Buildings*. Available from http://www.green.ca.gov/CommissioningGuidelines/default.htm.

University of Southampton. *Climate Change World Weather File Generator*. Available from http://www.energy.soton.ac.uk/ccworldweathergen/index.html.

Xu, Peng, Yu Joe Huang, Norman Miller, and Nicole Schlegel. 2009. Effects of Global Climate Changes on Building Energy Consumption and its Implications on Building Energy Codes and Policy in California. http://www.energy.ca.gov/.