Resilient Adaptation of Sustainable Buildings

Center for Sustainable Building Research

University of Minnesota

May 2018

Prepared By:
Richard Graves, AIA, Center for Sustainable Building Research
William Weber, Center for Sustainable Building Research
Liz Kutschke, Center for Sustainable Building Research

Principal Investigator: Richard Graves, CSBR
1425 University Ave SE
Minneapolis, MN 55414

Prepared For the Minnesota Pollution Control Agency:
Laura Millberg, Sustainable Development and Climate Resilience Planner

MPCA
520 Lafayette Road North
Saint Paul, MN 55155

Acknowledgments

This project was supported in part by a grant from the Minnesota Pollution Control Agency, through the Environmental Assistance (EA) Grant Program in the category *Communities Adapting to Climate Change and Extreme Weather.*

The authors would like to acknowledge all those who provided input, in particular Douglas Pierce of Perkins + Will, Elizabeth Tomlinson of TKDA, Molly Eagan of HGA, and Ariane Laxo of HGA.

Disclaimers

The buildings and systems modeled in this report are predictions of actual use and costs for proposed designs after construction. Actual experience will differ from these calculations due to variations such as occupancy, building operation and maintenance, weather, energy use not covered in this study, and the precision of the calculation tool. Building energy use was modeled with IES Virtual Environment 2015.

TABLE OF CONTENTS

SECTION **PAGE**

SECTION 1 - INTRODUCTION

Sustainable Development has been a focus of the international community for at least the last 25 years. However, the development community has failed to transform the fundamental performance of the built environment with regard to the most critical indicator: ecological footprint. National and regional sustainability certification programs have made progress, but they have not shifted the green building paradigm from efficiency and waste reduction.

Consideration of resilience in design is a more recent phenomena stemming from a need and interest in adaptation planning in both the private and public sectors. The Rockefeller Foundation states: “We live in a world of increasing dynamism and volatility, where technology and greater interconnectedness have accelerated change and altered the way people live. Resilience is the capacity of individuals, communities and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it. Building resilience is about making people, communities and systems better prepared to withstand catastrophic events—both natural and man made—and able to bounce back more quickly and emerge stronger from these shocks and stresses.” The building community is trying to reconcile the progress made in creating sustainable design over the last twenty years with the new goal of “resilience.” There is a danger that as strategies are developed for resilience, the design community will forget about sustainability. In addition, there is the potential that some strategies developed for “high-performance” and sustainability in the current paradigm may decrease the resilience. It is important to find a pathway forward that creates both “resilience” and “sustainability.”

Emerging focus on regenerative design presents the potential to create resilience and sustainability in the built environment to a regenerative systems model as defined by John Tillman Lyle in his book Regenerative Design for Sustainable Development. John Tillman Lyle created two diagrams to show the difference between a mechanistic approach (Figure 1) and an alternative model for a regenerative system based upon his understanding of the patterns of living systems (Figure 2). As defined, a regenerative system provides for continuous production of resources that support the functional processes of development. Energy, water and other materials are renewed through natural processes and fueled primarily by incoming solar radiation.

In Lyle’s view, regenerative systems have the following characteristics:

- Integration with natural processes and by extension with social processes
- Minimal use of fossil fuels and man-made chemicals except for back up applications
- Minimal use of non-renewable resources except for future reuse or recycling
- Use of renewable resources within their capacities for renewal
- Composition and volume of waste within the capacity of the environment to assimilate without damage (Lyle, 1994)

This report explores the following hypothesis: “A building adapted to replicate a regenerative system state, (Figure 3) will be both sustainable and resilient.” The investigation includes an examination of recent publications by Minnesota state agencies, a review and summary of peer U.S. city planning on resilience and disaster preparedness, the potential impact of future weather and climate on building loads and energy consumption, and scenario planning for two prototype buildings. The prototype buildings (a library and a multi-family housing project) were developed to comply with a 70% reduction in energy usage to comply with Minnesota’s Sustainable Buildings 2030 program (SB2030) and high performance criteria modified using the regenerative system thinking. The modified prototypical buildings were then tested with a series of service disruptions to probe their level of resilience.

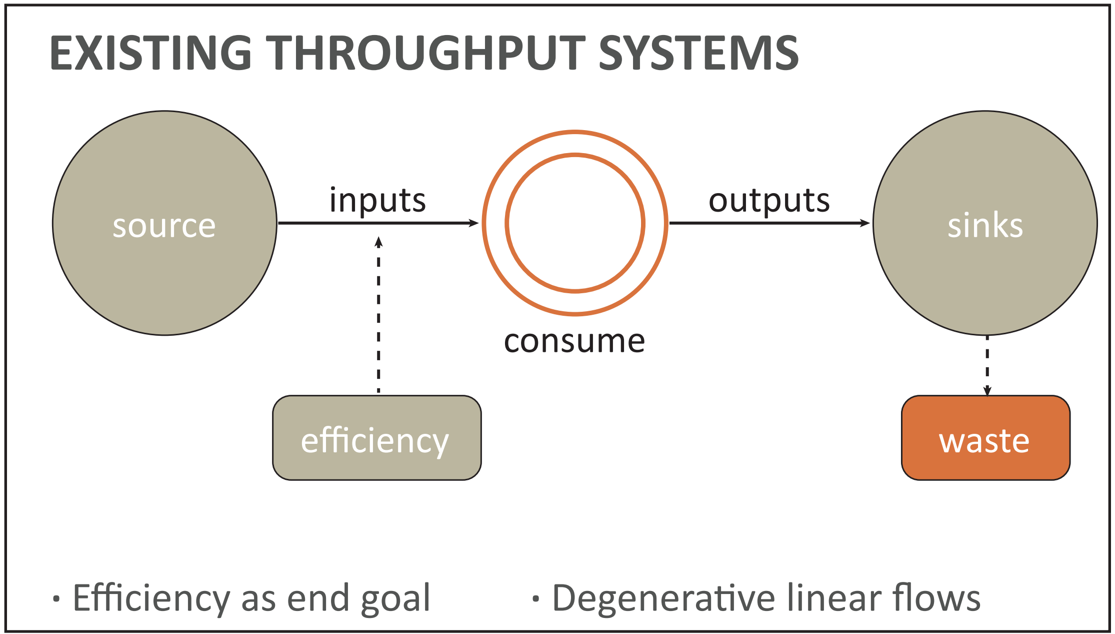


Figure 1: An existing throughput system based upon John Tillman Lyle, Regenerative Design for Sustainable Development, 1994

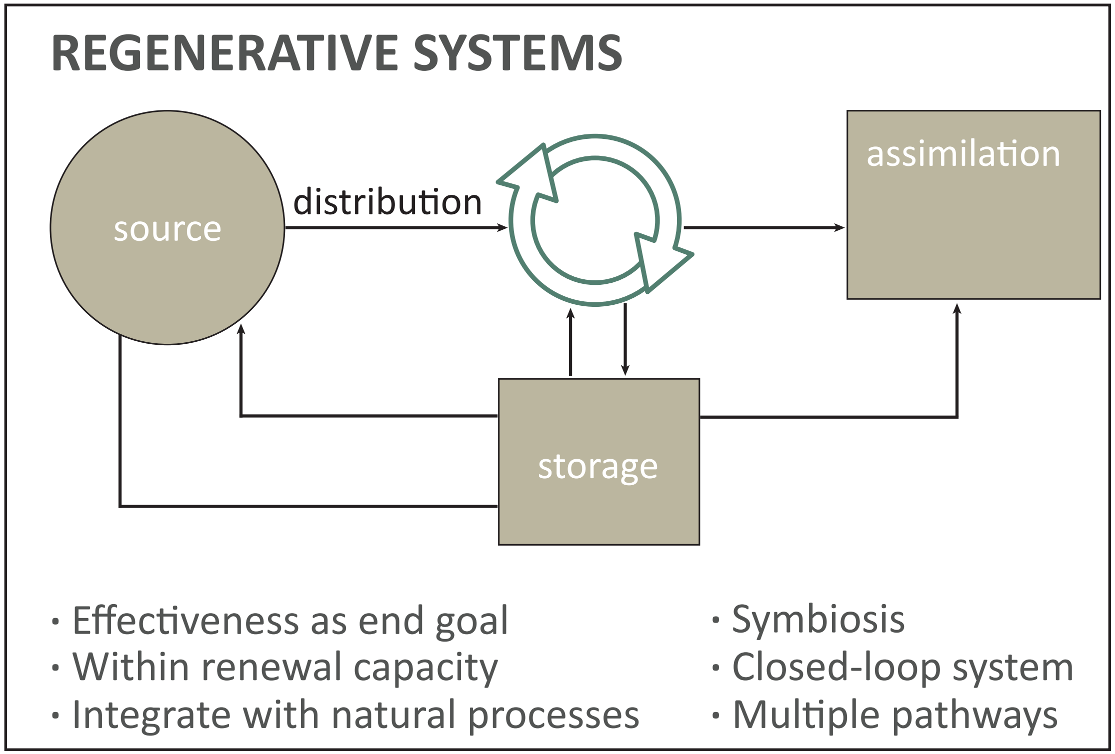


Figure 2: A regenerative system based up John Tillman Lyle, Regenerative Design for Sustainable Development, 1994

SECTION 2 - PRECEDENTS AND CONTEXT

A limited literature review was conducted of research and planning on disaster relief and preparedness, climate change and health by State of Minnesota agencies and peer U.S. cities. The intent of this review was to provide context for the exploration and to understand the common ground shared across the country. In addition to these reports, a study and literature review conducted by the University of Michigan and U.S. Green Building Council was examined.

STATE OF MINNESOTA AGENCIES

Reports from the Minnesota Department of Health, Minnesota Homeland Security and Emergency Management, and the Minnesota Pollution Control Agency are summarized below. These reports informed the research into vulnerable populations, risk assessment, and the most significant and common types of disaster events experienced in Minnesota.

Minnesota Climate Change Vulnerability Assessment 2014
Minnesota Department of Health

The Minnesota Climate Change Vulnerability Assessment 2014 (CCVA) from the Minnesota Department of Health (MDH) accessed, quantified and mapped climate change vulnerability on a county-by-county basis in Minnesota. The assessment was conducted between 2012 and 2014 utilizing existing datasets and historic weather data. Visualization of information was produced using geographic information systems (GIS). The climate hazards examined include extreme heat events, air pollution, vector-borne diseases, flooding and flash flooding, and drought. The report includes a literature review of existing reports on climate change indicators and vulnerable populations.

The Association of State and Territorial Health Officials (ASTHO) Climate Change Population Vulnerability Screening Tool was used to create a vulnerability index and vulnerability score for all counties in Minnesota for three climate hazards: extreme heat events, air pollution, and flooding. The maps were generated by combining demographic, socioeconomic and health vulnerability over a specific risk event, e.g. extreme heat. The mapping indicated that all but two counties in Minnesota have at least one climate hazard, 39 counties have five to six climate hazards, and 12 counties have seven to nine climate hazards. Similarly, all counties have at least two vulnerable populations greater than the 50th percentile of all counties. Twenty-one counties have six to seven vulnerable populations, and 11 counties have ten to twelve vulnerable populations within the top 50th percentile.

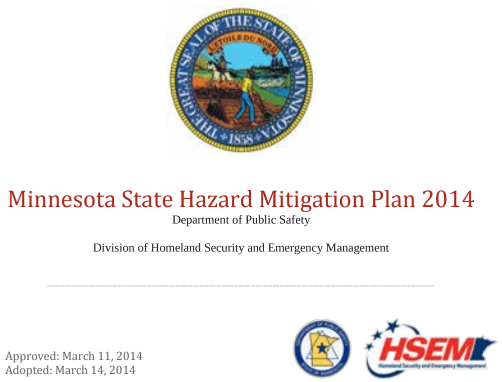
The MDH findings make it clear that further study is needed with a finer geographic scale, and this report will start a conversation and raise awareness of climate change vulnerability that will lead to adaptation planning at the local level.

MINNESOTA CLIMATE CHANGE VULNERABILITY ASSESSMENT **2014**

Minnesota
Department of Health
MINNESOTA CLIMATE & HEALTH PROGRAM, ENVIRONMENTAL IMPACTS ANALYSIS UNIT

Climate Hazards:
Number of extreme heat events
Number of days exceeding fine particle pollution air quality standard
Number of days exceeding ozone air quality standard
Lyme disease incidence
Human anaplasmosis incidence
West Nile Virus incidence
Number of flood events
Number of flash floods
Percentage of months of extreme drought
Longest run of months of extreme drought

Vulnerable Populations and Vulnerability Indicators:
65 years old and older
65 years old and older living alone
Less than 5 years old
Population in poverty
People of color
Workers employed in agriculture, forestry, hunting, and mining industries
Workers employed in construction industry
Asthma emergency department visits
Asthma hospitalizations
Chronic obstructive pulmonary disease hospitalizations
Older adults living below 150 percent of poverty line
Families with children in poverty
Housing units that are mobile homes
Households with no vehicles
Limited English proficiency



Minnesota State Hazard Mitigation Plan 2014
Department of Public Safety

Division of Homeland Security and Emergency Management

Approved: March 11, 2014
Adopted: March 14, 2014

State Mitigation Strategies:
Prevention
Property Protection
Public Education
Natural Resources
Emergency Services
Structural Improvements

Benefits of Hazard Mitigation:
Saving lives, protecting the health of the public, and reducing injuries.
Preventing or reducing property damage.
Reducing economic losses.
Minimizing social dislocation and stress.
Reducing agricultural losses.
Maintaining critical facilities in functioning order.
Protecting infrastructure from damage.
Protecting mental health.
Reducing legal liability of government and public officials.

Natural Hazards:
Flooding
Wildfire
Tornadoes
Windstorms
Hail
Coastal Erosion
Severe Winter Storms
Dam Failure
Landslide
Sinkholes and Land Subsidence
Earthquake
Drought
Extreme Temperatures
Lightning

Minnesota All-Hazard Mitigation Plan Update (2014)
Minnesota Division of Homeland Security and Emergency Management

The Minnesota All-Hazard Mitigation Plan Update is an update to a report from 2008. It identifies both natural and man-made hazards to which Minnesota is vulnerable, assesses the level of risk, and recommends steps to reduce vulnerability. The plan identifies goals, benefits of mitigation, recommended actions for the state government to reduce and/or prevent injury and damage, and provides guidance for coordination of mitigation and recovery efforts.

State Mitigation Goals:

Goal 1. Maintain and enhance the State's capacity to continuously make Minnesota less vulnerable to all hazards.
Goal 2. Build and support local capacity and commitment to continuously become less vulnerable to natural hazards.

The planning considered the probability of event and the mitigation potential for natural hazards in assessing risk and vulnerability state wide and on a county by county basis. The hazards of drought, extreme heat, and winter storms were identified as having a high probability, but a low potential for mitigation. The criteria for a 'low' rating in mitigation potential include lack of knowledge of methods of mitigation, lack of experience in implementing mitigation strategies, a limited range of mitigation methods, or the mitigation measures have not been proven cost effective. Flooding, tornadoes, high winds, and wildfires are identified as being highly probable with high mitigation potential. Hail and coastal erosion have high probability and medium mitigation potential. The categorization of potential hazards and mitigation potential was considered in the development of the approach taken to research mitigation and adaptation strategies in response to these natural disasters.

The Minnesota All-Hazard Mitigation Plan is most helpful in narrowing the research and planning scope to hazard events that have both high probability and high potential for mitigation, and make the primary focus on the health and safety of people. The planning also identifies key mitigation strategies that are appropriate at the building and neighborhood scale of intervention explored here. Chief among them is prevention, which includes adaptation of buildings, modification of building codes, and land use.

Adapting to Climate Change in Minnesota 2017
State of Minnesota Interagency Climate Adaptation Team (ICAT)

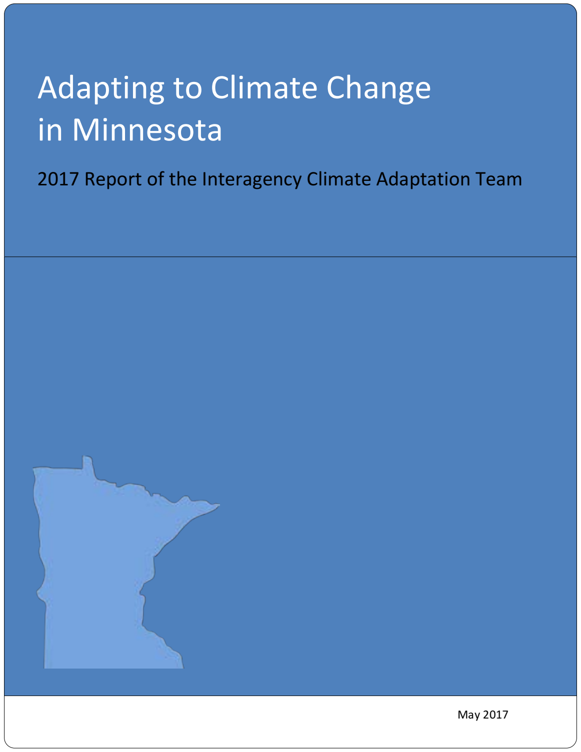
The State of Minnesota Interagency Climate Adaptation Team (ICAT) 2017 Report: Adapting to Climate Change in Minnesota highlights how state government is working to adapt to the changing climate, reduce risks and impacts, and increase the resilience of our communities.

ICAT's vision is a resilient, economically thriving, and healthy Minnesota that is prepared for both short- and long-term climate changes and weather extremes. The team recognizes that building a resilient Minnesota in the face of a changing climate is a complex challenge.

While Minnesota state agencies are carrying out a wide range of activities related to adaptation as described in this report, additional opportunities also exist for agencies to increase collaborative efforts on this issue. ICAT has identified the priority recommendations listed in the sidebar for needed action in climate adaptation by state government. ICAT will work in 2017 to further flesh out priority actions and work plans related to these recommendations.

In addition to the specific recommendations, ICAT also recommends that Minnesota state government accelerate the incorporation of climate adaptation into all aspects of state agency operations. This can be accomplished through a variety of methods, such as Governor's Executive Orders, Legislative directives, commissioner-led agency operational orders, agency strategic planning processes, program budgeting and development, and staff training.

ICAT also recognizes that state government will not be able to fully achieve the complex and evolving goal of climate adaptation on its own. It will be necessary and important to build and nurture partnerships on climate adaptation among state government and federal, tribal, and local governments, higher educational institutions, the private sector, nonprofit organizations, community members, and other collaborators. As a vehicle for focusing this collaboration, ICAT recommends that Minnesota state government engage in a comprehensive effort along with public and private partners to develop a multi-stakeholder statewide climate adaptation plan by 2020.


Adapting to Climate Change in Minnesota

2017 Report of the Interagency Climate Adaptation Team

May 2017

Recommendations for action include:

1. Build greater resilience to extreme precipitation.
2. Identify ways to support health of vulnerable populations through state and local government cooperation.
3. Increase focus on preserving terrestrial and aquatic habitat to increase resilience of wildlife and native plants.
4. Strengthen agricultural water management efforts to increase resilience to climate change impacts.
5. Increase focus on managing climate impacts in cities, towns, and other population centers.
6. Strengthen our climate information infrastructure to support climate adaptation practices.


MPCA Climate Adaptation Strategy and Proposed Near-Term Actions

MPCA Climate Adaptation Team (MCAT)

Minnesota Pollution Control Agency

July 2014

MPCA Climate Adaptation Strategy and Proposed Near-Term Actions – July 2014
MPCA Climate Adaptation Team (MCAT)

The MPCA Climate Adaptation Strategy and Proposed Near-Term Actions document is the summary of recommended strategies and near-term actions put forward by the Minnesota Pollution Control Agency's Climate Adaptation Team (MCAT). MCAT was formed in 2013, and is consists of 26 representatives from programs within each of the MPCA's seven divisions. The team reviewed the MPCA mission to consider how the agency's plan, vision, and goals relate to climate adaptation and resilience. They found it consistent with immediate implementation of climate adaptation actions throughout the agency.

MCAT found climate adaptation considerations and actions essential to the agencies preparedness and resilience to expected changes in climate. The team put forth ten broad climate adaptation recommendations without prioritization, and the recommendation that the next step is the development of a work plan for implementation.

Top Ten Climate Adaptation Recommendations
1. Increase outreach, education, and training to stakeholders and the public
2. Increase financial and technical assistance to local communities
3. Build new partnerships including vulnerable populations and the insurance industry
4. Increase staff training and capacity building
5. Prepare one-time report to the Legislature on barriers to climate adaptation
6. Hold and annual meeting between MPCA programs impacted by extreme weather to discuss and identify risks with high consequences, and to move from being reactive to proactive
7. Increase data collection related to climate trends and impacts to better assess risks
8. Implement hydrologic simulation and other modeling of climate scenarios with greater precipitation and/or temperature
9. Integrate best practices into grant programs
10. Integrate best practices into regulations and environmental review

This work has served as a jumping off point for the MPCA's efforts in climate change adaptation and has led to studies such as this one. The MPCA has recently adopted a new five-year strategic plan that includes a cross-agency goal: "Act on opportunities to increase resilience of communities and the environment to climate change impacts."[1]

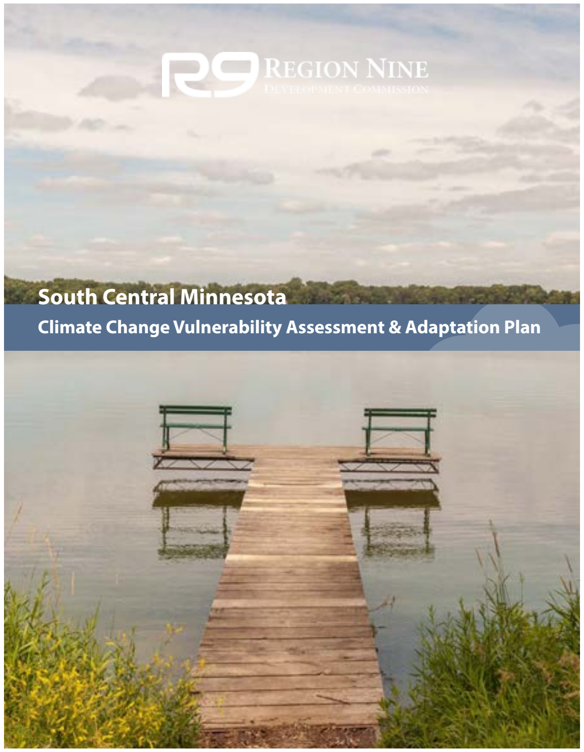
---

[1] L. Millberg, personal communication, April 8,2018

South Central Minnesota Climate Change Vulnerability Assessment and Adaptation Plan
Region Nine Development Commission, Climate Adaptation Task Force
Prepared For: Region Nine Development Commission
Funded By: Minnesota Pollution Control Agency, Minnesota Department of Health

The South Central Minnesota Climate Change Vulnerability Assessment and Adaptation Plan was prepared for the Region Nine Development Commission, in collaboration with a Climate Change Adaptation Task Force with funding and support from the Minnesota Pollution Control Agency and Minnesota Department of Health. It utilized the National Climate Assessment to identify top priority sectors, climate change impacts, and mitigation and adaptation strategies for the nine south central Minnesota counties that make up region 9 (Blue Earth, Brown, Faribault, Le Sueur, Martin, Nicollet, Sibley, Waseca and Watonwan). This report gives an overview of the assessment and planning process and provides action by sector. The top priority sectors identified are agriculture, water, human health, energy, transportation, forests, ecosystems, business and economy. The climate change impacts to be addressed with hazard mitigation include flooding, drought, extreme summer and winter storms, infectious diseases, fire, and land subsidence.

Assessment and Planning methodology:
1.Find a model that works
2. Create a project charter
3. Create a critical path worksheet
4.Assemble a well-rounded task force
5. Identify most important impact sectors
6. Identify impacts
7. Conduct research
8.Review hazard mitigation plans
9. Gather insights from subject matter experts
10. Gather insight from local government
11. Create actionable solutions
12. Review and Adoption
13. Implementation



Adaptation Plan:

Objective 1: Maximize soil and water conservation
Objective 2: Expand alternative genetics and crop choices
Objective 3: Infrastructure management
Objective 4: Increase adaptive capacity for livestock and human health
Objective 5: Expand risk management and management planning across planning platforms
Objective 6: Special focus on resilience sector strategies
Objective 7: Strengthen local food production

CITY RESILIENCE PLANNING SUMMARIES

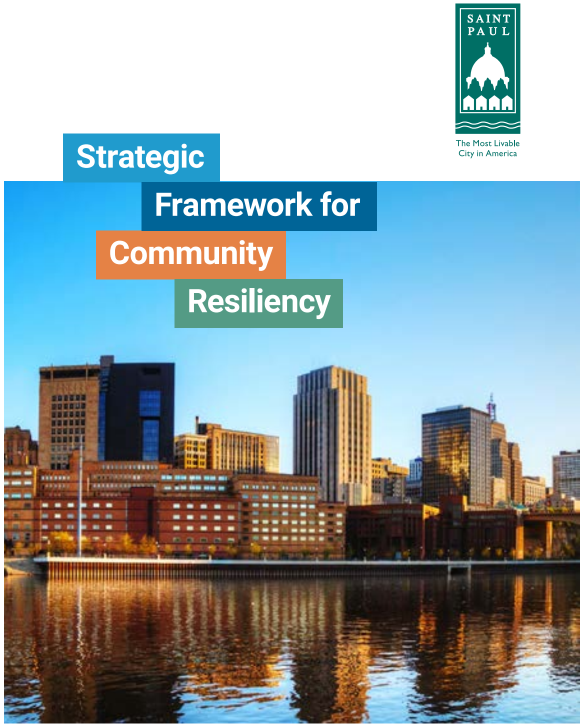
In addition to reviewing work done within the state of Minnesota, it was necessary to review studies and reports from other cities that have made progress in building resiliency. The reports reviewed here come from cities with robust resiliency efforts underway, and represent a diverse set of conditions and responses. All of these cities face climate-related hazards and have vulnerable populations within them. The findings and recommendations from these reports informed our research directions and recommendations for resiliency.

City of Saint Paul Strategic Framework for Community Resiliency (2016)

The Saint Paul Strategic Framework for Community Resiliency was developed by the office of Saint Paul Mayor Chris Coleman with funding from the Environmental Assistance grant program at the Minnesota Pollution Control Agency. With a goal of maintaining its status as “Most Livable City in America” the City of St. Paul has worked to understand the range of plausible shocks and stresses it could experience in the next 30-50 years. In the spring of 2015, Saint Paul began a strategic climate resiliency framework initiative based on the following principles for stakeholders to engage in community resiliency:

- Incorporate climate change adaptation into relevant local and regional plans and projects
- Establish a climate change adaptation public outreach and education program
- Build collaborative relationships between regional entities and neighboring communities to promote complementary adaptation strategy development and regional approaches
- Establish an ongoing monitoring program to track local and regional climate impacts and adaptation strategy effectiveness
- Review and update heat response plan in light of climate change projections
- Partner with existing public health community outreach and engagement efforts.

Using provided definitions of shocks (sudden, sharp events) and stresses (ongoing conditions), stakeholders identified top shocks as flooding, severe thunderstorms, infrastructure failure, and winter storms. Top stresses identified were aging/overwhelmed infrastructure, insufficient funding, and lack of trained professionals.

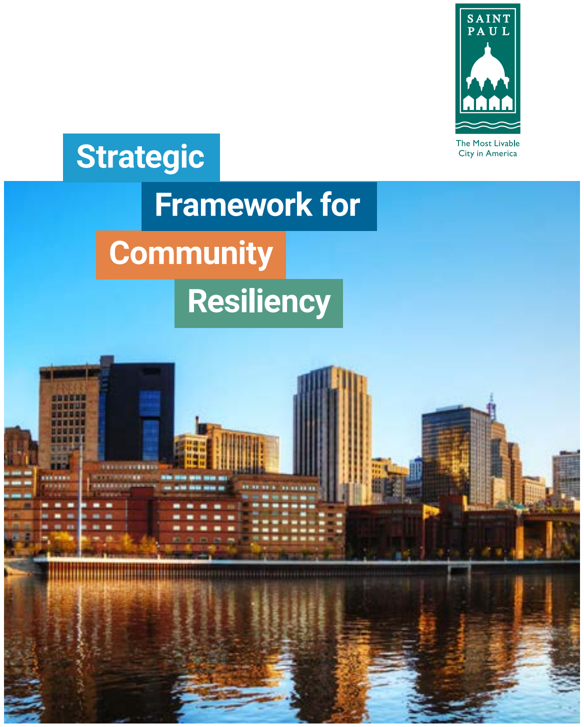


SAINT PAUL
The Most Livable City in America

Strategic
Framework for
Community
Resiliency

Framework Process Steps:

1. Research
2. Assess
3. Organize
4. Plan
5. Document



City of Saint Paul Strategic Framework for Community Resiliency (2016) (Continued)

Economic and Social Well-Being Strategies:

- Raise awareness about vulnerabilities and solutions

  Public service announcements, identify communication networks
- Ensure financial and social access to energy

  Enhance reliability and durability of electrical grid throughout city
- Communicate about and help prevent urban flooding

  Identify vulnerabilities in structures, create and maintain green infrastructure

Emergency Response and Health Systems Strategies:

- Enhance health and wellness of staff supporting the city

  Stress management, staffing and workload updates
- Expand current green infrastructure

  Water management, pollinator habitat, soil stabilization, and changes to property values
- Continue community outreach

  Partner with community-based organizations to develop education and outreach campaigns

Infrastructure Strategies:

- Enhance coordination planning and resources

  Ensure all stakeholders have a seat at the table, maintain open dialog, pursue joint funding, encourage resource sharing
- Protect and maintain critical assets

  Assess existing infrastructure and define critical assets. Analyze system effects of proposed new infrastructure. Research efforts by peers and other best practices
- Ensure financial and social access to energy

  Emphasize energy efficiency to reduce strain on power system, have back up power available at critical facilities and key locations

Natural Resources Strategies:

- Conduct landscape management

  Emphasize green infrastructure, low-impact land uses, and utilize natural resources.
- Develop and align organizational capacity

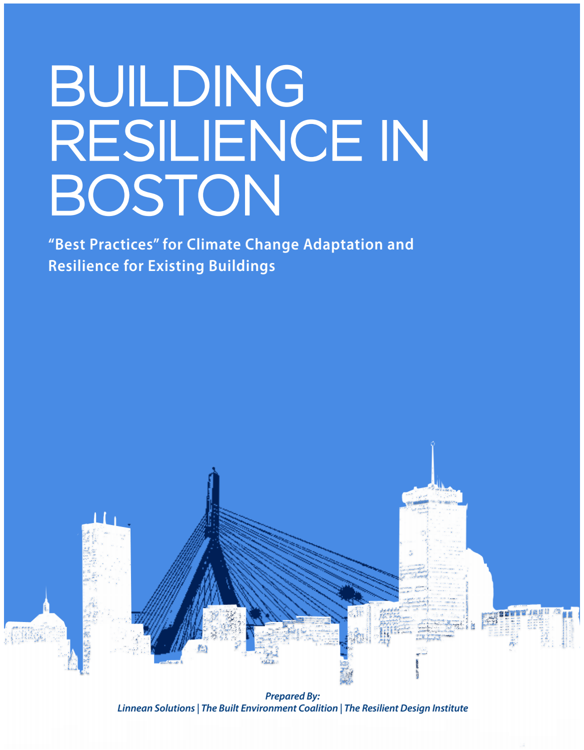
  Consider policy changes, incentives, regulations, staffing, team structure, revenue streams, and long-term goal alignment
- Increase awareness

  Educate and utilize the public, create recognizable ‘branding’, implement youth outreach

Building Resilience in Boston (July 2013)

Commissioned by The Boston Society of Architects
Prepared for the Boston Green Ribbon Commission Climate Preparedness Working Group
Prepared By: Linnean Solutions, The Built Environment Coalition, and The Resilient Design Institute
Funding Provided by the Barr Foundation

The report aims to provide a better understanding of strategies and specific measures that property owners can use to reduce vulnerability to climate change. It is focused on the City of Boston and its specific and unique context and susceptibility to extreme temperatures, rain, coastal flooding, high wind, sea level rise, and storm surge. Vulnerable population distribution, existing building stock, known environmental hazards, and future weather projects were analyzed to create resilience strategies across scales. The report includes 30 resiliency strategies across the following categories: General Actions, Site, Building Structure, Building Enclosure, Building Systems, Building Operations, People.



BUILDING RESILIENCE IN BOSTON

"Best Practices" for Climate Change Adaptation and Resilience for Existing Buildings

Prepared By:
Linnean Solutions | The Built Environment Coalition | The Resilient Design Institute

Chicago Climate Action Plan (2008)

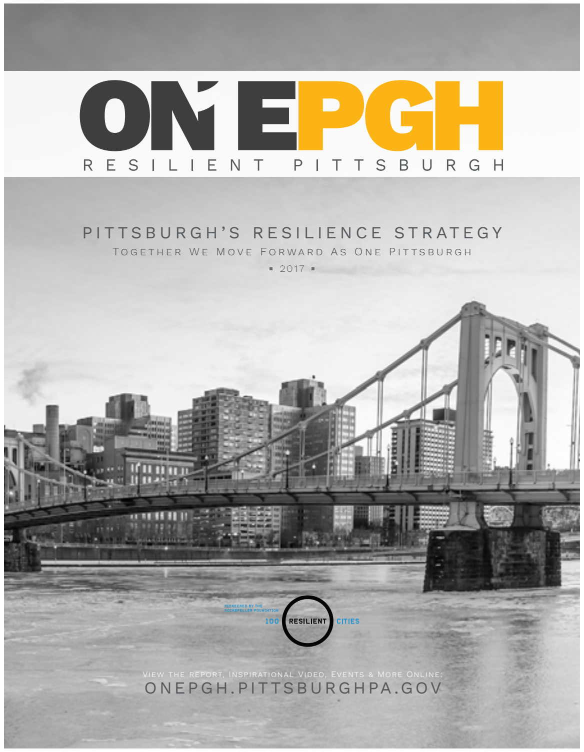
Commissioned by Former Chicago Mayor Richard M. Daley
Prepared by Chicago Climate Task Force

The Chicago Climate Action Plan attempts to:
Determine the challenges Chicago faces as climate changes
Describe the sources of greenhouse gas emissions in Chicago
Set goals to reduce emissions and adapt to changes already affecting Chicago
Find ways to leverage knowledge to improve Chicago's economy and quality of life
Outline concrete, achievable goals for the city and its residents

The task force for this report set the emissions reduction target at an 80 percent reduction from 1990 greenhouse gas emissions by the year 2050, with an intermediate goal of a 25 percent reduction from 1990 levels by 2020.

CHICAGO CLIMATE ACTION PLAN

OUR CITY. OUR FUTURE.



One PGH – Resilient Pittsburgh (2017)
Commissioned by the Rockefeller Foundation's 100 Resilient Cities Initiative
Funding provided by The RAND Corporation

Pittsburgh is a city in transition. Between 1970 and 2006, the city lost 40% of its population. Today, the city is growing again, due in part to the 8% increase in millennials and college graduates moving to Pittsburgh in the last ten years. This promising growth stands in contrast to the industrial legacy, crumbling infrastructure, persistent socioeconomic inequities, and a history of fragmented governance. This report comes at "…an important crossroads for the city. Pittsburgh seeks to capitalize on its recovery with sustainable growth, but needs to avoid repeating the mistakes of the past."
Although Pittsburgh is inland and protected from many natural hazards that occur in coastal regions, the city faces significant challenges with social, racial, and economic inequalities that have led to unequal access to housing, transportation, and other services for the most vulnerable populations. This resilience strategy works to relieve these chronic stresses, while also preparing for acute shocks that may come at the hands of a changing climate.

Pittsburgh's resiliency strategy consists of four parts:

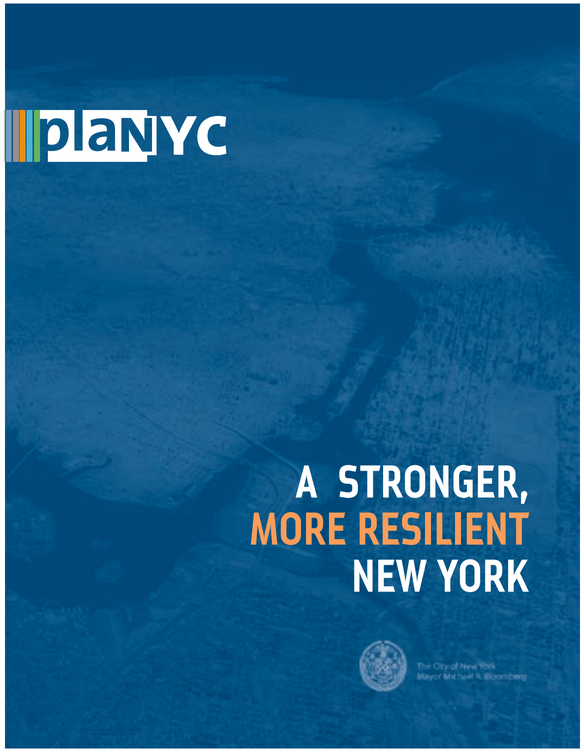
People: Pittsburgh will empower all residents to contribute to thriving and supportive communities by ensuring that basic needs are met. We will be an inclusive city of innovation that celebrates our diversity, and all residents will have equal access to resources and opportunity.

Place: Pittsburgh will use land to benefit all residents; to increase social cohesion, connectivity, public and ecological health; and to protect against current and future risks. We will design, scale, and maintain our infrastructure for current and future needs, providing benefits and services to our neighborhoods during times of calm and crisis.

Planet: Pittsburgh will achieve long-term environmental health through wise stewardship, improved use of our resources, and a reduced carbon footprint.

Performance: Pittsburgh will work closely with neighbors and partners for improved planning and decision-making.

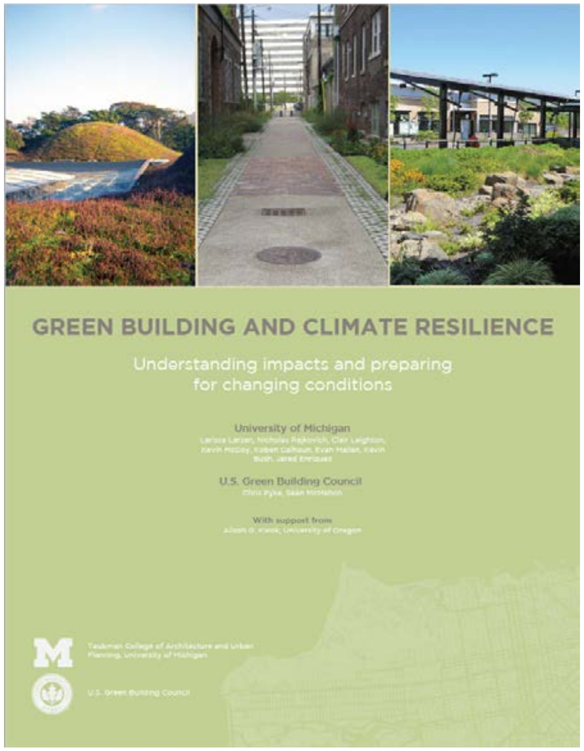
A Stronger, More Resilient New York (2013)
Commissioned by Former Mayor Bloomberg
Prepared by the Special Initiative for Rebuilding and Resiliency



New York City has had a climate change mitigation and adaptation plan in place since 2007, with a major update in 2011. This report is a response to the devastation of Hurricane Sandy and is a continuation of the work already done with the additional consideration of resiliency and the impacts of climate change in the near and long-term future. The report includes over 250 initiatives aimed at protecting coastline, strengthening buildings and other infrastructure, and rebuilding the communities most affected by Hurricane Sandy. As stated: “The underlying goal of this report is resiliency. That is, to adapt our city to the impacts of climate change and to seek to ensure that, when nature overwhelms our defenses from time to time, we are able to recover more quickly.”

The plan includes nearly 200 initiatives in the following categories:

Climate Analysis
Coastal Protection
Buildings
Economic Recovery
Insurance
Utilities
Liquid Fuels
Healthcare
Community Preparedness
Telecommunications
Transportation
Parks
Environmental Protection and Remediation
Water and Wastewater
Food Supply
Solid Waste
Resilient Design Strategies


GREEN BUILDING AND CLIMATE RESILIENCE

Understanding impacts and preparing for changing conditions

University of Michigan

U.S. Green Building Council

With support from

National
Green Building and Climate Resilience:
Understanding impacts and preparing for changing conditions (2011)
University of Michigan and the U.S. Green Building Council

Green Building and Climate Resilience is a comprehensive reporting of research on the impacts of climate change on the built environment and links impacts to migration strategies on a regional basis. It is divided into two primary sections, Understanding Climate Change: Global, Regional, and Local Impacts and Climate Change Impacts on the Building Environment. In addition, it has three appendices. The third, Appendix C: Adaptation Strategies is a catalog of, "…basic strategies to help design, construction, and/or operations and maintenance team to incorporate adaptation principles into its projects." Strategies are organized by category, and include a standard list of information.

Category:

Envelope
Site and Landscape
Heating, Cooling, Lighting
Water and Waste
Equipment
Process and Operations

Standard Information:

Objective
Description
Regional Priority
Primary/Secondary Impact
Measured Effect of Strategy
Level
Duration
Control
Associated LEED Credits
Related Strategies
Additional Information

Summary

The recommended action items from the early adopter cities planning and research reports were categorized and combined with the adaptation strategies from Green Building and Climate Resilience, a research document from the University of Michigan and the US Green Building Council. The combined list of actions and strategies were sorted into building systems and services. They guided the exploration and modifications to the building prototypes developed

Massing and Programming
Orientation optimized for daylighting, ventilation
Solar zoning
Thermal zoning
Interior and exterior shading devices to prevent solar heat gain in warm months
Enhanced roof access to inspect and maintain roof and drainage system
Increased insulation values of all envelope elements
Advanced framing wall techniques
Thermal mass
'Cool' building materials
Green walls

Façade
Design with wind patterns for natural ventilation
Design buildings to survive extreme winds
Pressure neutral rain screen
Cross ventilation
Insulated glazing
Glazing tuned to façade for solar heat gain

Heating, Cooling, Ventilation
Elevate mechanical and electrical equipment to avoid damage from flooding
Design for dual-mode operation – normal mode and emergency passive mode
Stack ventilation
Thermal energy storage
Redundant systems or system components
Insulate water systems
Install ceiling fans
Groundwater cooling using aquifers or surface water
Increased ventilation and removing heat using fresh air

Lighting / Plug Loads
Limit internal gains by specifying efficient lighting and equipment
Design for optimized daylighting
High efficiency emergency and egress lighting
Emergency and egress lighting wired to emergency circuit
Light stairwells and hallways during blackout

Energy Generation
Provide site-generated electricity from renewable energy
Critical system backup
Co-generation and renewable system designed to run during blackouts
Install easy hookups for temporary power
Prioritize critical system backups
Maintain systems
Ensure system redundancy
Insulate refrigeration equipment

Energy Storage
Battery storage capacity matched to critical load
Thermal mass energy storage

Potable Water
Specify water-efficient fixtures and appliances
Provide solar hot water
Insulate water system
Develop agreements for secondary water sources
Supply drinking water with back-up power sources for pumping
Ensure toilets and sinks function without power
Rainwater harvest from building roof for potable uses,
Pre-treat rainwater harvest with green roof system
Oversize roof drains to accommodate anticipated increase in intensity of rain events
Storage cistern
Elevate water storage and treatment equipment to avoid damage from flooding

Storm water (Site)
Utilize natural systems
Minimize impervious surfaces
Retention ponds
Infiltration gallery / French drain
Bioswales
Natural or constructed wetlands
Storage tanks
Grade site to slow runoff
Regular maintenance
Manage flood pathways and eliminate pinch points

Greywater
Plumb buildings for greywater separation and reuse
Storage tank
Treatment system

Blackwater
Backflow prevention valves on all sewer lines
Living machine / eco machine on site

Shelter
Provide areas of refuge within building
Build sheltered spaces using design specifications FEMA361

Structure
Enhance building structural elements to withstand extreme loads including wind
Enhance building foundation to minimize structural damage
Resist intrusion of termites as hardiness zones move north

Site
Create cool ground surfaces
Hazard resilient landscape design with consideration of risk factors such as flash floods and high winds
Flood and wind resistant landscape design
Select and maintain appropriate trees and shrubs species for current and predicted climate zone
Provide shade for building, cooling equipment, parking lots

Food
Storage space for food
Distribution strategy

Transport
Plan and zone communities to maintain functionality without power
Redundant and human-powered transportation
Elevator with backup power or automatic return

The impacts of these strategies on both the day-to-day operation and disaster response of the buildings studied are reported in each building section.

SECTION 3 - METHODOLOGY

The research project explored the following hypothesis: “A building adapted to replicate a regenerative system state will be both sustainable and resilient.” The regenerative systems model utilized was defined by John Tillman Lyle in 1994, and is discussed in the introduction to this report. The process to probe resilience in parallel with regenerative outcomes utilizes a vulnerability assessment process to identify critical functions, environmental risks, and opportunities for mitigation in the assessment of two building prototypes. The two prototypes are a library (community hub) and a multifamily residential building (shelter in place). An examination of seasonal impacts based on hazard potential was also conducted. A scenario planning process was used to test underlying assumptions with an advisory group. The scenarios were based on disruption of critical functions (power, water, etc.) rather than specific natural or man made disasters.

The vulnerability assessment used for this study draws on research from the Strategic Environmental Research and Development Program (SERDP), a research program of the Department of Defense in collaboration with the Department of Energy and the Environmental Protection Agency. SERDP performed scenario planning that reviewed disruptions to military installations in response to climate change impacts. Their process utilized the following steps to assess vulnerability including objectives for building capacity and climate risk management[1]:

1. Consideration of critical function
2. Exposure to risk
3. Identification of weakness and adaptation needs
4. Identification of adaptation strategies

Critical functions considered in this study include energy source, potable water and sanitation, and shelter. These resilience functions are mapped to the regenerative system state (figure 4). In adapting this process to identify weakness in the prototype buildings, the team used disruptions in services potentially caused by disaster events, rather than specific disasters scenarios, (tornado, ice storm, flood etc.) to test the prototypes. The three service disruptions used were:

- Disruption of energy supplied by the electrical grid and natural gas service
- Disruption from municipal water supply and wastewater removal
- Disruption from vehicle transportation

Disruptions were assumed to last ten days with “relief” coming after four days with supplies of food and water. This determination was made based on the recovery and relief efforts of recent catastrophic storm events.

In addition to mapping the resilience goals to the goals of a regenerative systems state, it was necessary to develop macro strategies and real-world outcomes that Lyle’s conceptual diagram does not address. This was achieved by translating resilient and regenerative goals such as “renewable sources of energy” into specific outcomes, strategies and services provided by an energy system, for example maintain habitable temperature, store energy, and operate the building in low power mode (figure 4). Second, these outcomes needed to be connected to actionable micro-strategies for integration into the building prototypes to improve system resilience in response to disruptions and therefore improve resilience in the buildings.

---

[1] SERDP and ESTCP Webinar Series, “DoD Decision Making and Climate Change”, October 20, 2016.

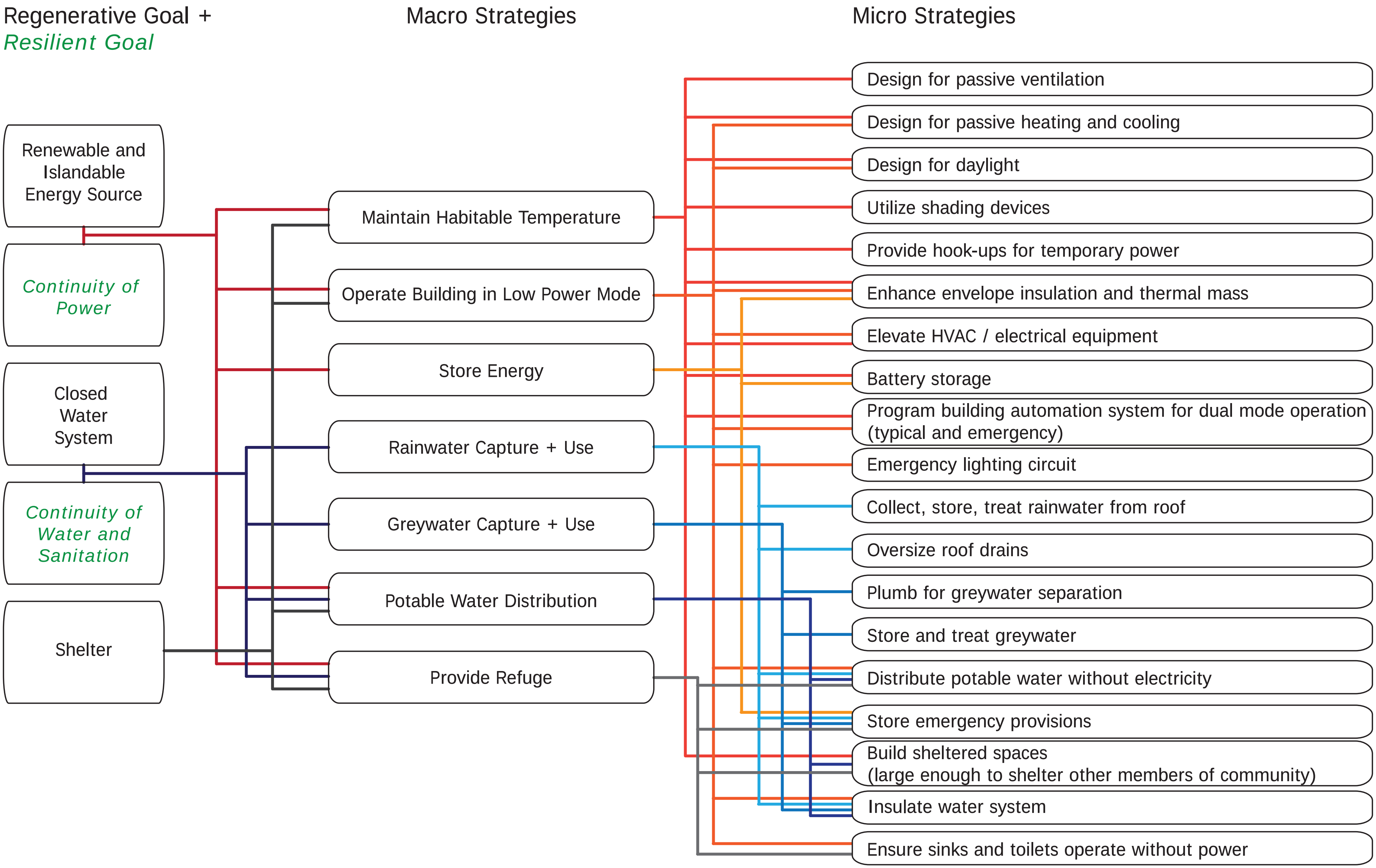


Figure 3: Regenerative and Resilient Goals and Strategies Map

The two building prototypes were considered to allow for the exploration of two fundamentally different approaches to hazard mitigations: community hub and shelter in place. A 40,000 sf library is representative of a typical community or neighborhood library in a metropolitan area or a main library in suburban or greater Minnesota communities. This building type was selected for testing because it could serve as a hub for a neighborhood or surrounding community during disasters. Furthermore, in larger communities library systems have a network of buildings, which could serve as emergency hubs during a disaster. Other potential infrastructure networks that could be utilized include schools or recreation buildings.

A four-story, 50 unit, 68,000 square foot multi-family housing building was also used as a prototype. This building type is representative of recent affordable housing developments in Minnesota. It represents a building type where occupants could shelter in pace during a disaster and presents different needs than the library as a municipal building operating as an emergency hub.

The baseline building prototypes were adapted with regenerative strategies, outcomes and micro-features such as energy and water storage, enhanced thermal envelopes, solar panels and rainwater capture. The buildings were tested and analyzed without regard to social or community interactions due to the compounding complexity and unpredictability of co-mingling soft (social) and hard (infrastructure) recommendations.

A workshop with a group of local experts was held to examine the prototype buildings. The group included Ariane Laxo and Molly Eagen from HGA and Doug Pierce from Perkins+ Will, who are all members of the Upper Midwest Resilience Studio of the National Resilience Initiative of the American Institute of Architects. The participants ran scenarios to probe the function and operation of the buildings during a disruption of energy supply, water supply and waste removal and vehicle transport over ten days. Each disruption was considered individually and reviewed in combination. In addition, the disruptions were considered both during summer and winter conditions. The outcomes informed the final solutions and learning reflected in the following sections and exposed uncertainties that could lead to future research.

Limitations

As noted above, this scope of this research does not include examination of social and community networks on resilience. This was done to more readily understand the physical building infrastructure, and in no way discounts the critical roles social structures and community organizations play in the creation of resilient and regenerative communities'.[1] For example, the Neighborhood Empowerment Network (NEN) in San Francisco focuses on grassroots efforts to improve the resilience of their neighborhoods through tools, resources and engagement. A truly resilient community needs not only the social structure and organization like NEN, but also a built environment that can support those structures. This project focuses on the built environment/infrastructure component of resilience.

---

[1] Building Research and Information. 2012. 40 (Special Issue on Regenerative Design).

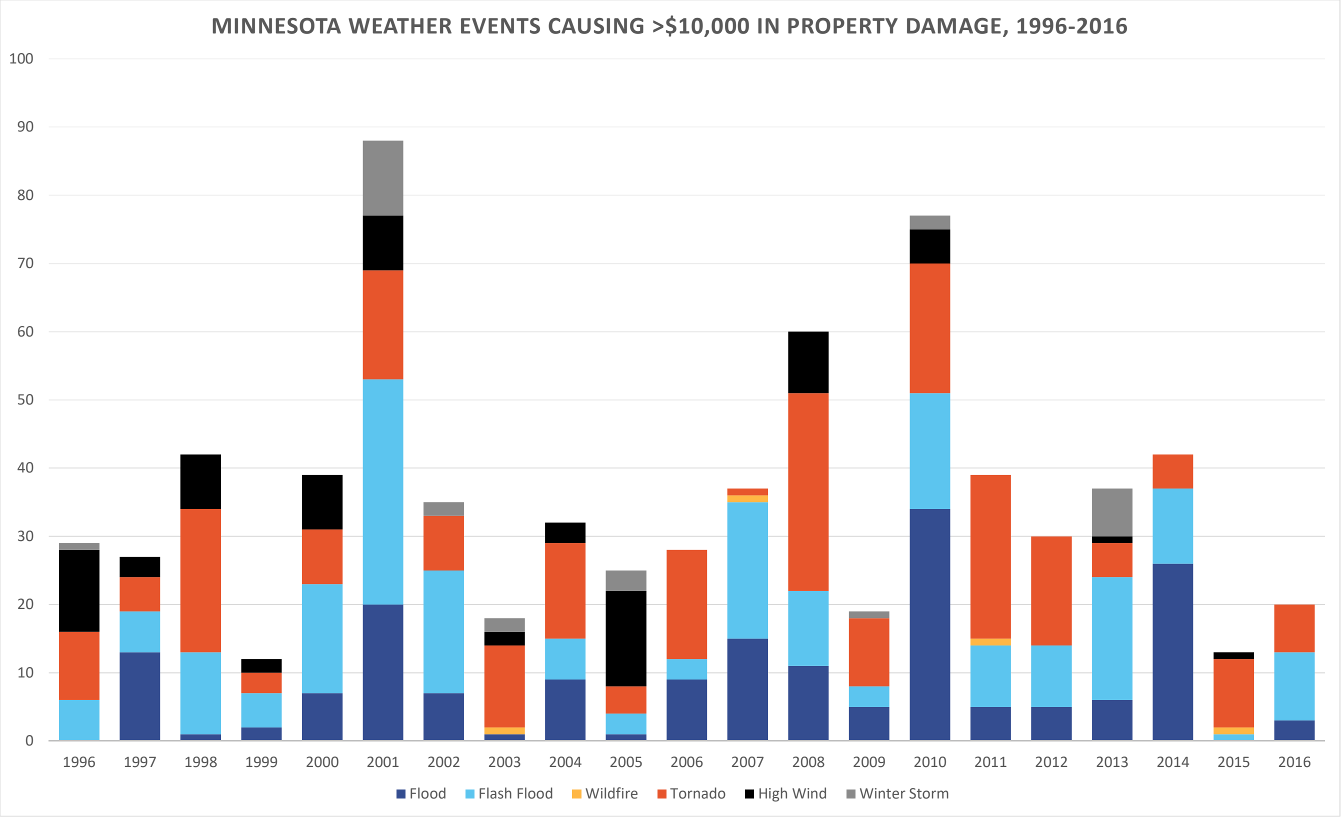


Figure 4: Weather Events Causing Significant Damage in Minnesota

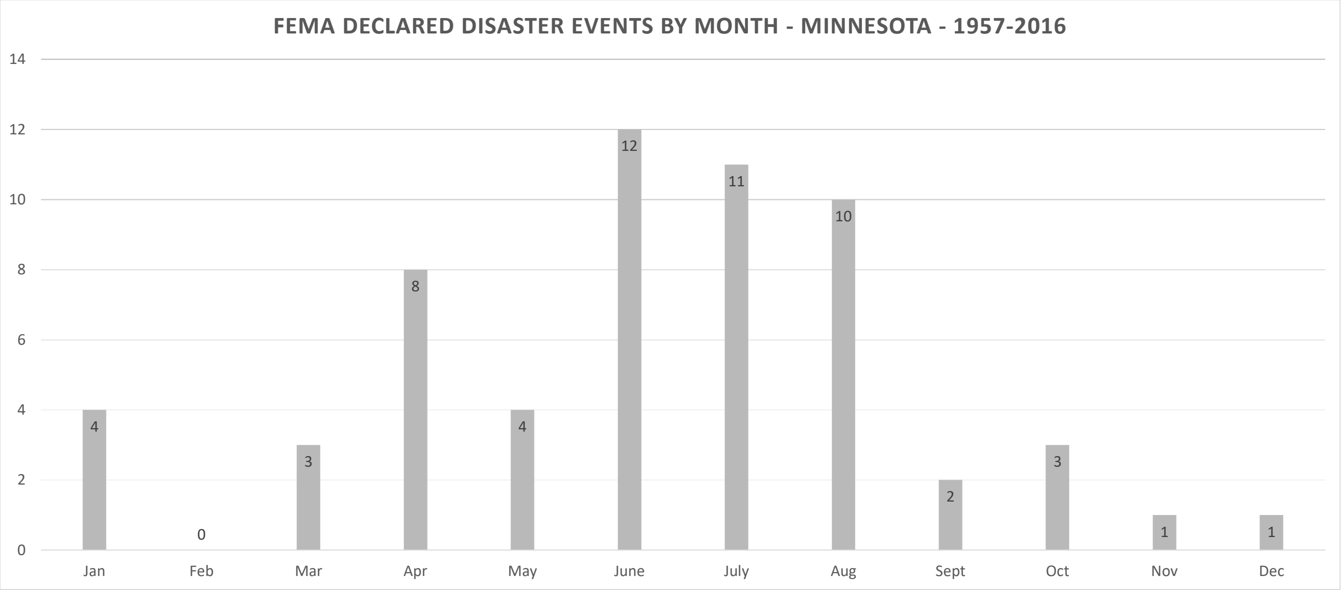


Figure 5: FEMA Disaster Declarations by Month

Though Minnesota is protected from devastating weather events such as hurricanes and earthquakes, there have been a significant number of weather events with serious financial and social repercussions (figure 5)[1].

Due to Minnesota's continental climate, seasonal consideration was also necessary for planning based on hazard potential. Minnesota has had 60 disasters declared by FEMA since 1953 (figure 6)[2], and the majority of disasters have been severe storms in the summer that produce tornadoes and flash floods.

Based on this history, the seasonal scenario used in testing was a summer storm event followed by high heat and humidity conditions with an extended loss of power. Winter conditions were also reviewed, although extended service disruption is less likely during the winter months.

---

[1] NOAA / NCEI Storm Event Database: https://www.ncdc.noaa.gov/stormevents/

[2] FEMA Data Visualizations: https://www.fema.gov/data-visualization-disaster-declarations-states-and-counties

SECTION 4 – FUTURE WEATHER FILES

Weather files used in energy modeling are created using past weather data for specific locations, often with weather data at least 10 years old.[1] When used, these files limit the ability to assess the impact of future climate change, as they do not reflect future weather conditions. Future-looking weather data is therefore necessary in order to assess the resilience of buildings in a changing climate. A collaboration between IES, Arup, and Argos Analytics has made location-specific future weather data available to designers and researchers. Limitations in use of these files is similar to conventional weather files, in that they cannot assess specific micro climates or regional factors that may affect local conditions.

Weather files provide hourly values for several weather variables resulting in a representative meteorological year. The files capture variability, instead of simple extremes and averages. This data is then ‘morphed’ to reflect future climate projections, while maintaining the hourly variations of historic data. Variables are transformed in different ways depending on the weather variable in question. Some are simply additive, some are multiplicative, some, such as relative humidity, are more complicated. The following variables are morphed in future weather files:

- Mean daily temperature
- Maximum daily temperature
- Minimum daily temperature
- Relative humidity
- Daily total solar irradiance
- Wind speed
- Atmospheric pressure
- Precipitation

Two future weather scenarios were conducted as part of this research. They are based on Representative Concentration Pathway 8.5[2], the current ‘business-as-usual scenario’ for greenhouse gas emissions. RCP 8.5 had been considered the worst-case scenario; it now seems to be the most likely future[3]. Weather files for the years 2030 (representing years 2021-2040) and 2040 (years 2031-2050) were selected, as transformed weather files beyond 2040 were considered by the project team to be too speculative. For each year, three weather files were provided representing the 10th, 50th, and 90th percentiles of future warming. For the purposes of this research, the 50th percentile files were used.

Future weather files were compared against the ‘current’ weather file for Minneapolis / Saint Paul to understand the magnitude of the predicted change in temperature and humidity (figures 7 and 8).

---

[1] TMY3 Weather Data - https://energyplus.net/weather/sources#TMY3

[2] Representative Concentration Pathway: a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change in 2014. Of the four possible climate futures adopted, RCP 8.5 refers to the highest predicted emissions levels over time.

[3] Dickinson, R., & Brannon, B. (2016). Generating Future Weather Files for Resilience.

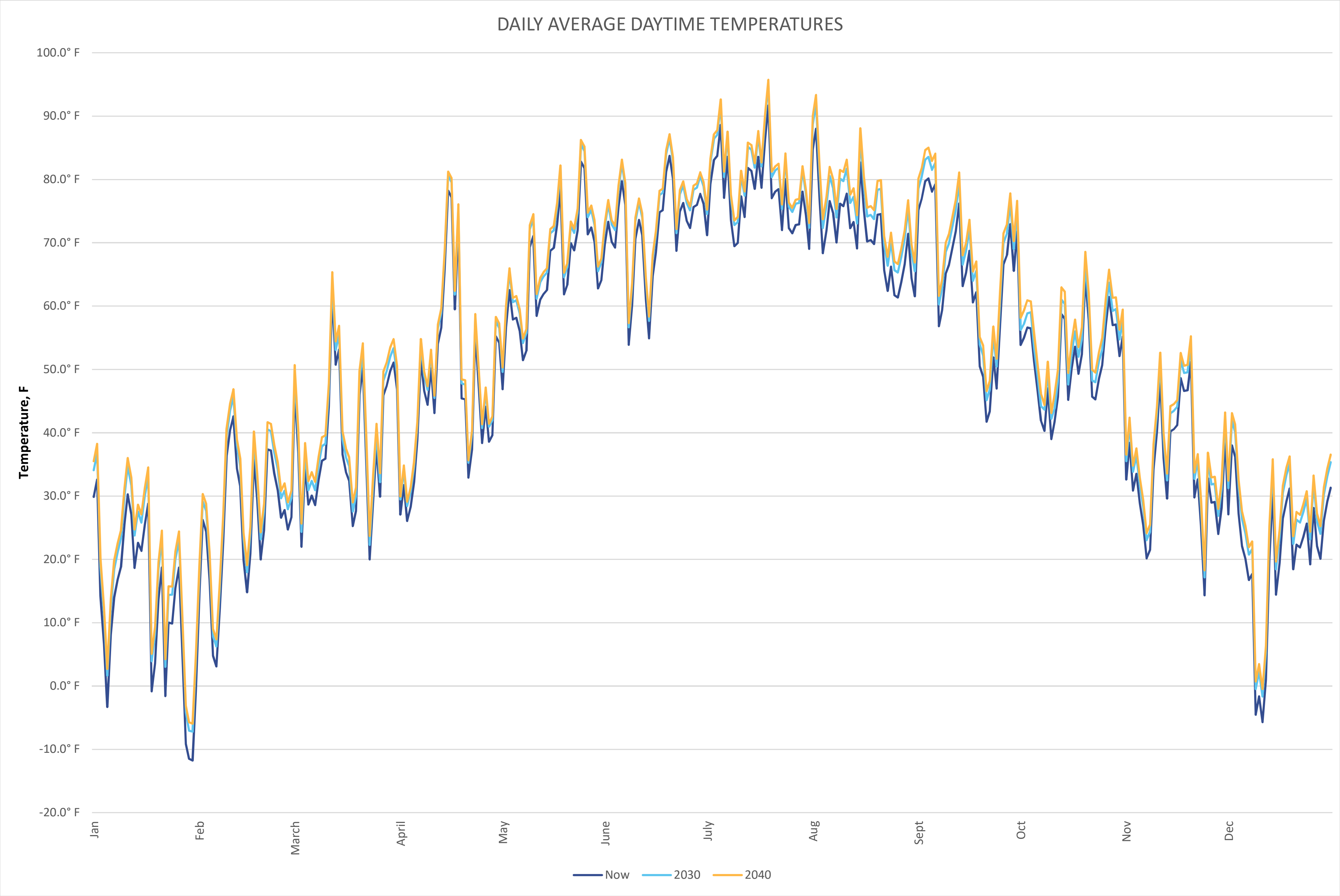


Figure 6: Average Daily Daytime Temperatures, MSP Airport Weather Station

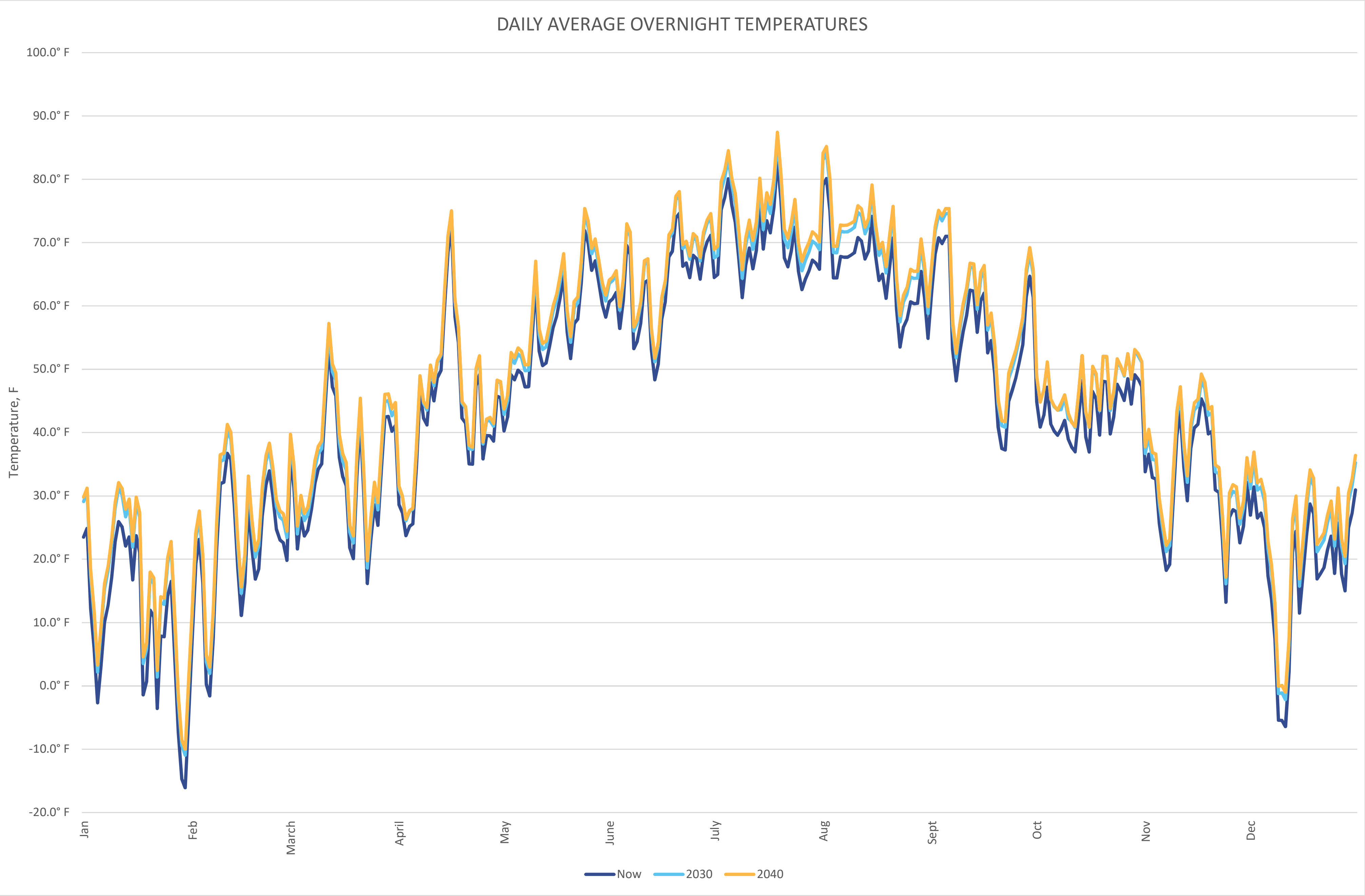


Figure 7: Average Daily Overnight Temperatures, MSP Airport Weather Station

Strategy	Hours: Actual and Percentage					
	Now		2030		2040	
Comfort	942	11%	885	10%	936	11%
Sun Shading of Windows	586	7%	778	9%	817	9%
High Thermal Mass	154	2%	217	2%	240	3%
High Thermal Mass Night Flushed	154	2%	228	3%	256	3%
Direct Evaporative Cooling	109	1%	179	2%	198	2%
Two-Stage Evaporative Cooling	111	1%	192	2%	216	2%
Natural Ventilation Cooling	104	1%	162	2%	170	2%
Fan-Forced Ventilation Cooling	72	1%	104	1%	106	1%
Internal Heat Gain	1589	18%	1353	15%	1361	16%
Passive Solar Direct Gain Low Mass	899	10%	826	9%	796	9%
Passive Solar Direct Gain High Mass	624	7%	559	6%	539	6%
Wind Protection of Outdoor Spaces	259	3%	254	3%	249	3%
Humidification Only	0	0%	0	0%	0	0%
Dehumidification Only	491	6%	659	8%	692	8%
Cooling, add dehumidification if needed	305	3%	549	6%	604	7%
Heating, add humidification if needed	4791	55%	4545	52%	4436	51%

Figure 8: Climate Consultant Strategies Effectiveness - Current, 2030, 2040

This data indicates warming trends throughout the year, with a slightly greater increase in the overnight temperatures. This will affect the potential of nighttime cooling or nighttime flush strategies in existing and future buildings. This also extends the need for cooling systems into shoulder seasons, and decreases the need for heating systems during shoulder seasons.

As weather patterns shift, the effectiveness of passive strategies to provide thermal comfort will shift seasonally. The chart above (figure 9) indicates the effectiveness of several passive and active strategies using current and future weather data. The strategies are measured in hours of the year the strategy provides comfort. For example, the use of shades on windows in current weather conditions provides 586 hours of thermal comfort out of the 8670 hours of the year. (Thermal comfort as calculated based on ASHRAE Standard 55.) These predictions come from the software Climate Consultant, specifically the psychrometric chart tool.

Annual energy models were run to assess the energy impact on buildings operating in standard or everyday mode with predicted weather in 2030 and 2040. This provided insight into the impacts, particularly on energy use, of climate change in the near future.

Multifamily Future Energy Use

The annual energy use of the mid-rise multifamily building changes very little when simulated with future-looking weather files, moving from an EUI of 15.5 with the current weather file to an EUI of 15.6 with a predictive weather file for 2040. (figures 9-12). The seasonal impact is a decrease in heating loads (19% to 16%) and an increase cooling loads (8% to 11%). Energy models run with a code-based building and predictive weather files results in an overall energy demand increase of 13% from present day to 2040. This modeling indicates that energy conservation measures taken now to reduce energy use and ensure resilience also contribute to 'future-proofing' the building against a changing climate.

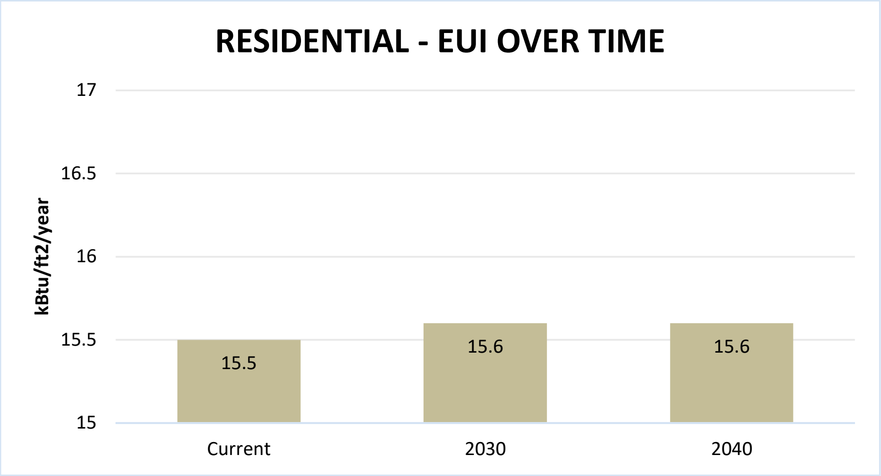


Figure 9: Multi-Family Residential Building Annual Energy Over Time

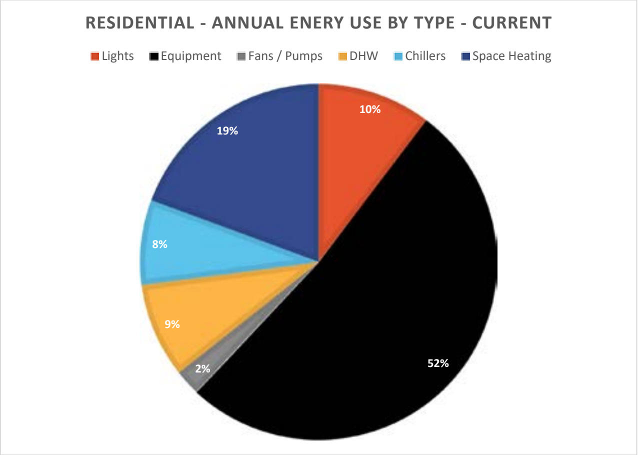


Figure 10: Multi-Family Residential Building Annual Energy Use by Type

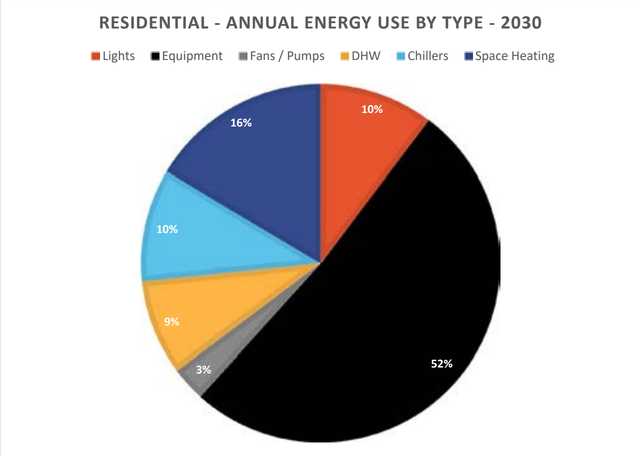


Figure 11: Multi-Family Residential Building Annual Energy Use by Type - 2030

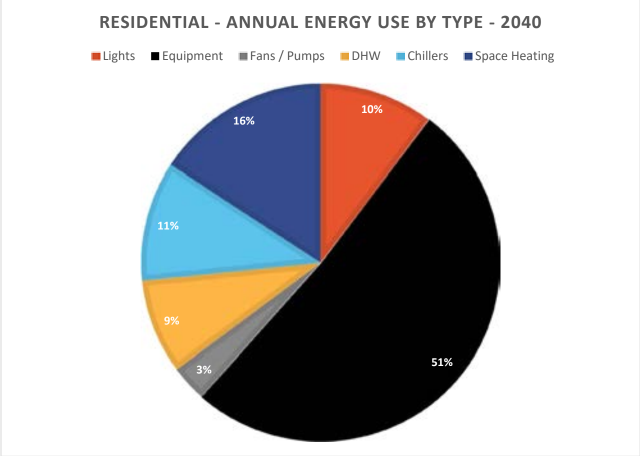


Figure 12: Multi-Family Residential Building Annual Energy Use by Type - 2040

Library Future Energy Use

The overall, annual energy use of the library increases very slightly (~3%) over the predicted 50 year period. The end uses, however, shift. As the outdoor temperature rises across the year, heating demand is reduced (21% to 16%) while cooling demand increases (15% to 20%). This may have implications for sizing heating and cooling equipment to accommodate these shifts in load (figures 15-17). Energy models run with a code-based building and predictive weather files results in an overall energy demand increase of 14% from present day to 2040. This modeling indicates that energy conservation measures taken now to reduce energy use and ensure resilience also contribute to 'future-proofing' the building against a changing climate.

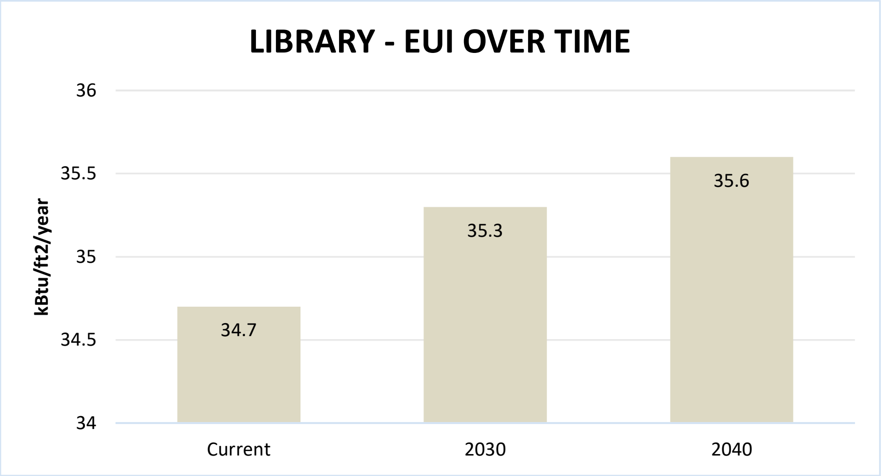


Figure 13: Library Building Annual Energy Over Time

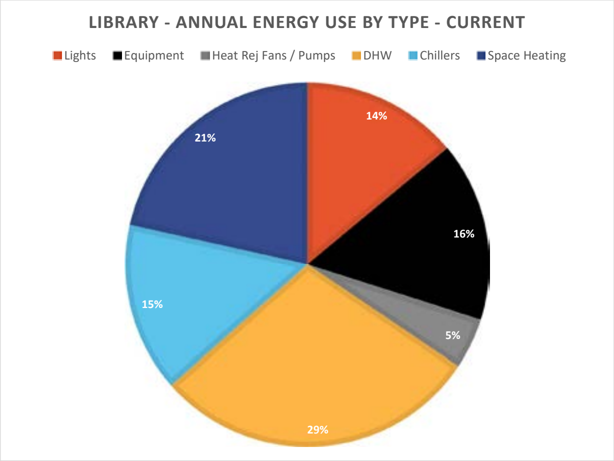


Figure 14: Library Building Annual Energy Use by Type

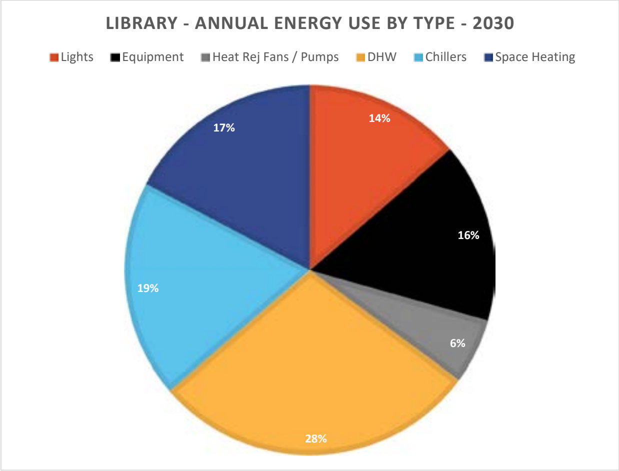


Figure 15: Library Building Annual Energy Use by Type - 2030

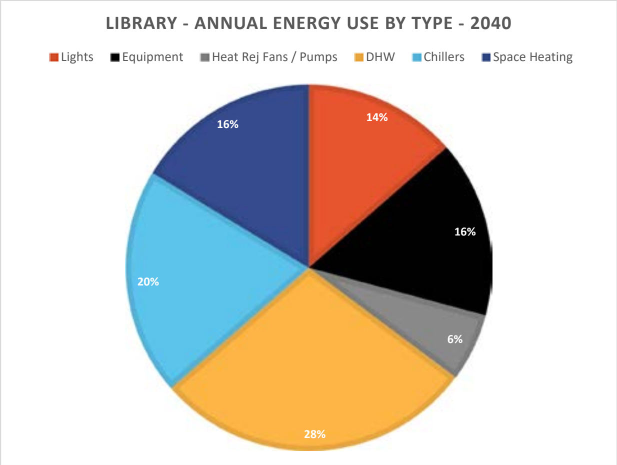


Figure 16: Library Building Annual Energy Use by Type - 2040

SECTION 5 - MULTIFAMILY RESILIENCE: SHELTER IN PLACE

The multifamily mid-rise apartment building provides a platform for the exploration of a shelter in place scenario during infrastructure disruption in medium density residential context. The resiliency outcomes discussed above and tested in this exercise can be grouped into three general areas for a residential setting; habitable temperature and refuge; energy storage and low power operations mode; and potable water distribution or access including rainwater and greywater capture and use. There are dependencies between the areas, which will be discussed below. The fourth factor, shelter, is at the heart of the multifamily scenario. Another consideration discussed is how resiliency outcomes can improve day-to-day operation and performance of the buildings.

A key challenge in the residential sector is balancing density with site capacity. Depending on building size, configuration, and population this building type challenges the limits for net zero energy and water scenarios beyond capacity to the point of failure. The scale and density of 4 to 5 story mid-rise residential building is ideal for exploring resiliency strategies in less than ideal conditions, since it pushes the limits of site capacity. This pressure dictates the necessity to explore multiple energy and fuel types with the potential for redundancy to create greater resilience.

The baseline prototype[1] was developed based on the current practice in subsidized affordable housing, which exceeds the State of Minnesota building code. All new construction projects funded by Minnesota Housing through the Low Income Housing Tax Credit (LIHTC) program are required to meet the Green Communities Criteria with the Minnesota Overlay. These requirements include whole building Energy Star level performance, use Energy Star rated appliance and lighting (LED), and water conserving fixtures that exceed code requirements. An Energy Star building is a minimum of 15% better than the current code (site code). Many projects exceed this level of energy reduction. Projects tracked by the Center for Sustainable Building Research regularly achieve savings of 30-40% (energy use intensities of 50 kBtu/sf-yr as compared to code base building from 80 to 110 kBtu/sf-yr). In addition to the energy and water requirements, projects must meet a threshold of sustainability for site, materials, health, and operations. The current version includes consideration of resilience.[2] The baseline prototype building is modeled to reflect Energy Star level construction. The building has conventional heating and cooling mechanical systems with an improved envelope. It is grid tied utilizing natural gas, electricity and potable water from municipal infrastructure.

Modification of the baseline prototype to net zero energy and water performance was done using two methods; a Passive House Institute U.S (PHUIS) certification compliant path and a conventional high performance process. Both prototypes targeted net-zero energy and assumed grid tied roof mounted photovoltaic arrays. Neither prototype achieves the target on an annual basis due to the assumed level of density and site capacity for energy production.

---

[1] Baseline and high performance housing prototypes with funding provided by The McKnight Foundation.

[2] Enterprise Green Communities Criteria 2015- www.enterprisecommunity.org/solutions-and-innovation/green-communities.

The site capacity for the residential prototypes was assessed based on energy production potential and water capture for a typical building. This capacity determines the energy and water budgets in disaster scenarios, in which the energy and water on site may be the only resources available.

The roof area for energy production was calculated based on 70% of a typical flat roof assembly[1] utilizing x W/sf with an efficiency factor of 18%. The net-zero energy budget based on the annual production is 13.32 kBtu/sf /yr and 10.66 kBtu/sf/yr for a four and five story building respectively (Figure 18).

The rainwater catchment area is 100% of roof area with a 70% capture rate. Similar to the net-energy scenarios, net-zero water on an annual basis at the building scale is not attainable for mid-rise multifamily buildings due to the density of residents. It could be achieved at a district scale with an integrated greywater and black water system assuming a mixed-use development. At the building scale, the sizing of collection and storage will vary depending on project specific goals (Figure 19).

Generally, two types of modifications were made to the energy and water systems to create resilience: strategies that modified or made additions to conventional or existing building systems, and new systems needed to ensure access to power and water during disruptions.

Solar Energy Generation Potential - Multi-Family Housing Site

Site
923,829 kWh / year
22.31 kWh / ft2 / year
76.12 kBtu / ft2 / year

4 Story Building - Flat Roof
13.32 kBtu / ft2 / year

5 Story Building - Flat Roof
10.66 kBtu / ft2 / year

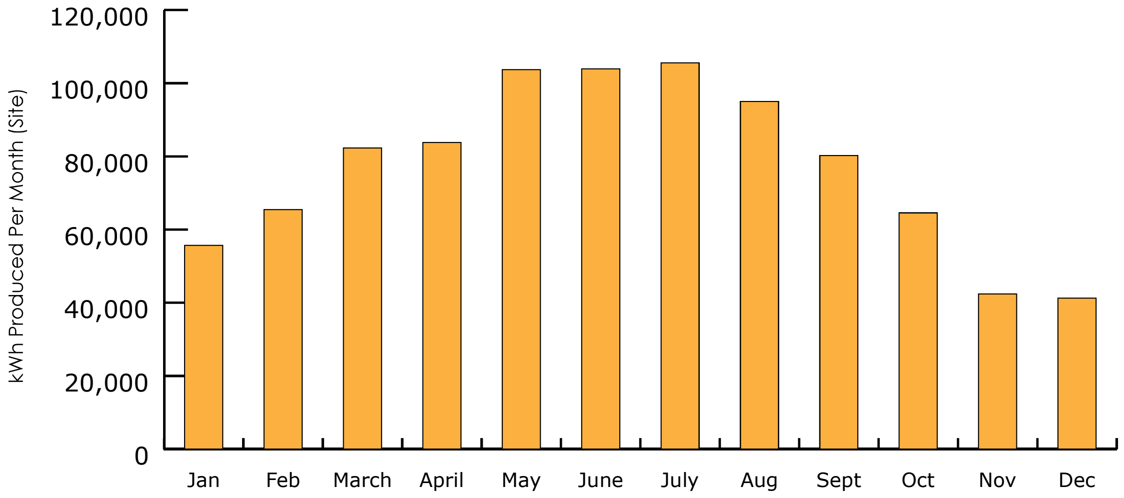
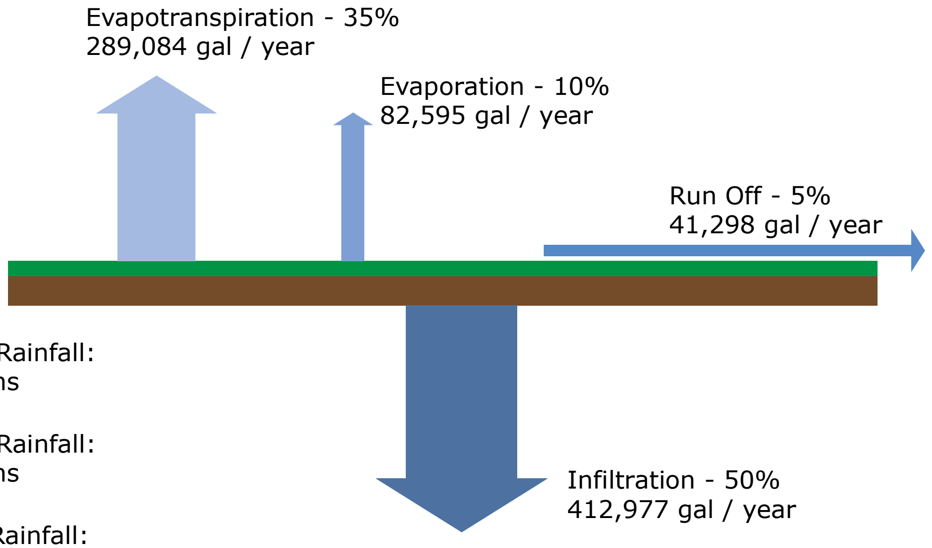


Figure 17: Potential Annual Production of Solar Panels in Minneapolis / Saint Paul

Annual Precipitation on Multi-Family Housing Site:
32" or 825,954 Gallons



One Year Storm 24-Hour Rainfall:
2.25" or 58,064 US Gallons

Five Year Storm 24-Hour Rainfall:
3.50" or 90,321 US Gallons

Ten Year Storm 24-Hour Rainfall:
4.10" or 105,805 US Gallons

Figure 18: Annual Pre-Development Precipitation and Rain Distribution Minneapolis / Saint Paul

---

[1] Calculated with http://pvwatts.nrel.gov/

HABITABLE TEMPERATURE AND REFUGE

In the process of creating a high-performance building prototype, envelope insulation was increased and a highly efficient mechanical system was selected. Wall constructions are modeled as R-49, a 160% increase over the minimum insulation value prescribed by ASHRAE 90.1-2010. The roof is modeled as R-96, a 150% increase over code. Glazing U value went from U-0.35 to U-0.24, an increase of approximately 170%, and the floor slab insulation stayed approximately the same (R-20) between cases. These envelope insulation values were determined by creating a Passive House compliant model using WUFI software.

The heating and cooling system selected utilizes a water source heat pump with high efficiency. (Figure 21) The ventilation system is split from the heating and cooling system and includes heat recovery. (Figure 22) These systems are very low-power, and can operate with expanded temperature and humidity set points to ensure a livable temperature in the building with minimal electricity use.

ENERGY STORAGE AND LOW POWER OPERATIONS MODE

Access to electricity is critical to maintaining health and safety during an extended outage regardless of the time of year. Electricity generation and storage can provide continuity of power during a utility disruption.

Energy systems design should maximize on site capacity for photovoltaic arrays, and include battery storage to provide power for critical systems for 10 days. The system must be islandable to maintain power supply to the building during a grid outage. An example of such an energy system is shown in figure 20.

Key Modifications To Maintain Power
- Energy generation - Photovoltaic array with battery back-up
- Islandable inverters installed to allow continuity of power in building or district during outage
- Install easy hookups for temporary power
- Back-up generator (natural gas, propane or diesel) to power fire suppression systems, and serve as secondary back-up during outage.
- All electric building design
- Critical system backup
- Co-generation and renewable system designed to run during blackouts
- Prioritize critical systems for backup
- Ensure system redundancy
- Locate battery storage and inverters above ground level

A low power mode scenario to test critical loads was conducted for a 10-day period in June, because the frequency of power outage in Minnesota is highest during the summer months. Critical loads are those most vital to health and safety, and will vary across building types and individual buildings. The planning process for continuity of service and determination of critical loads is crucial for resilient building design. For this building, in June, this includes cooling and ventilation, hot water, water pumping, lighting, refrigeration, and elevator operation. The cooling, ventilation, and lighting systems have the potential to operate in a low-power mode to maintain functionality while reducing the energy required as compared to day-to-day operation.

ELECTRICITY

Multifamily Residence

① Roof Mounted PV Panels

② DC Battery Storage

③ Inverter

④ Connection to Electric Grid

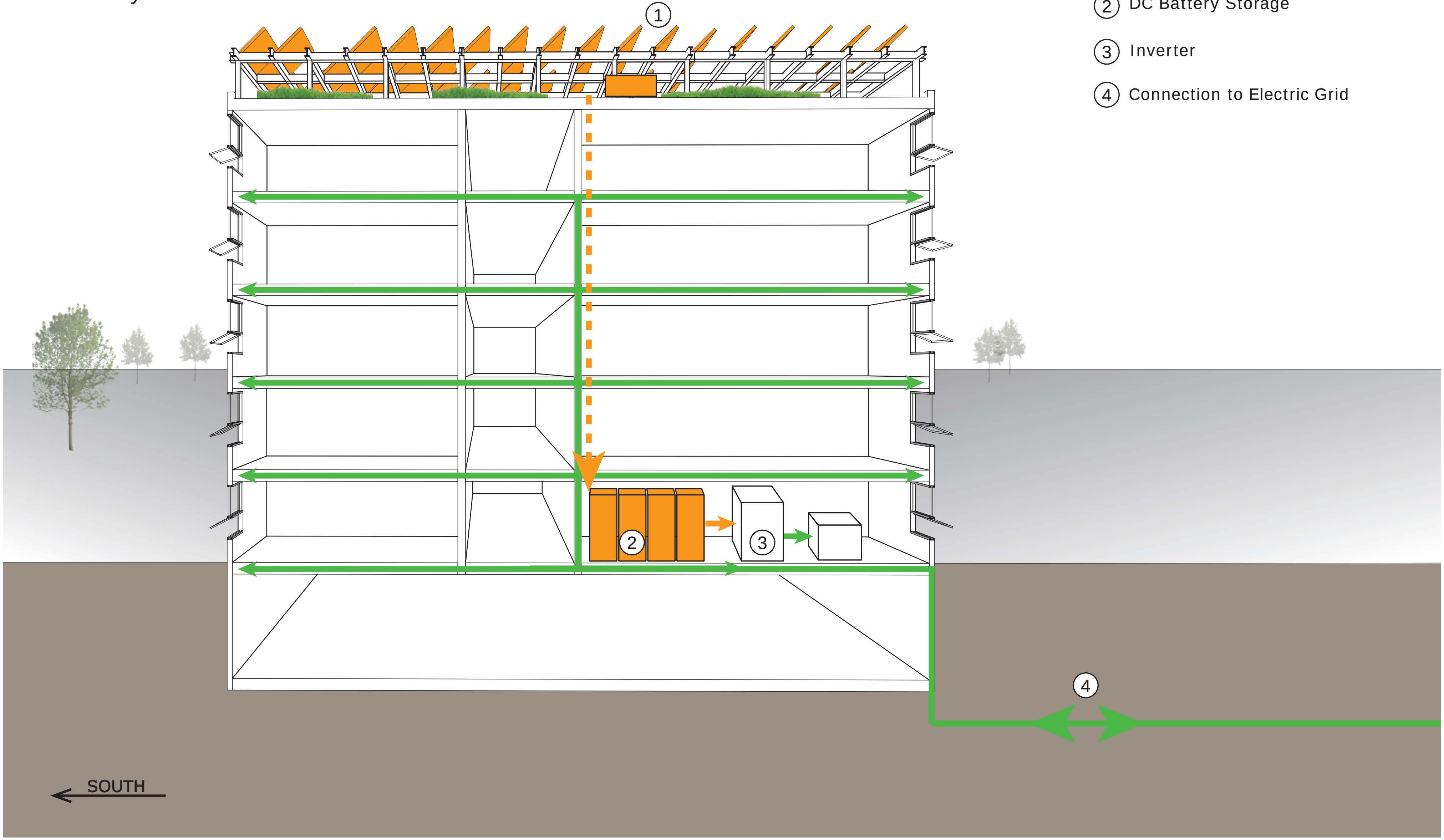


Figure19: Multi-Family Residential Building Energy Generation and Storage Diagram

HEATING AND COOLING

Multifamily Residence

① Circulating Water Storage

② Distribution

③ In-Unit Heat Pump

④ Heat Exchanger and Geothermal Well

⑤ Geothermal Wells

⑥ Operable Windows

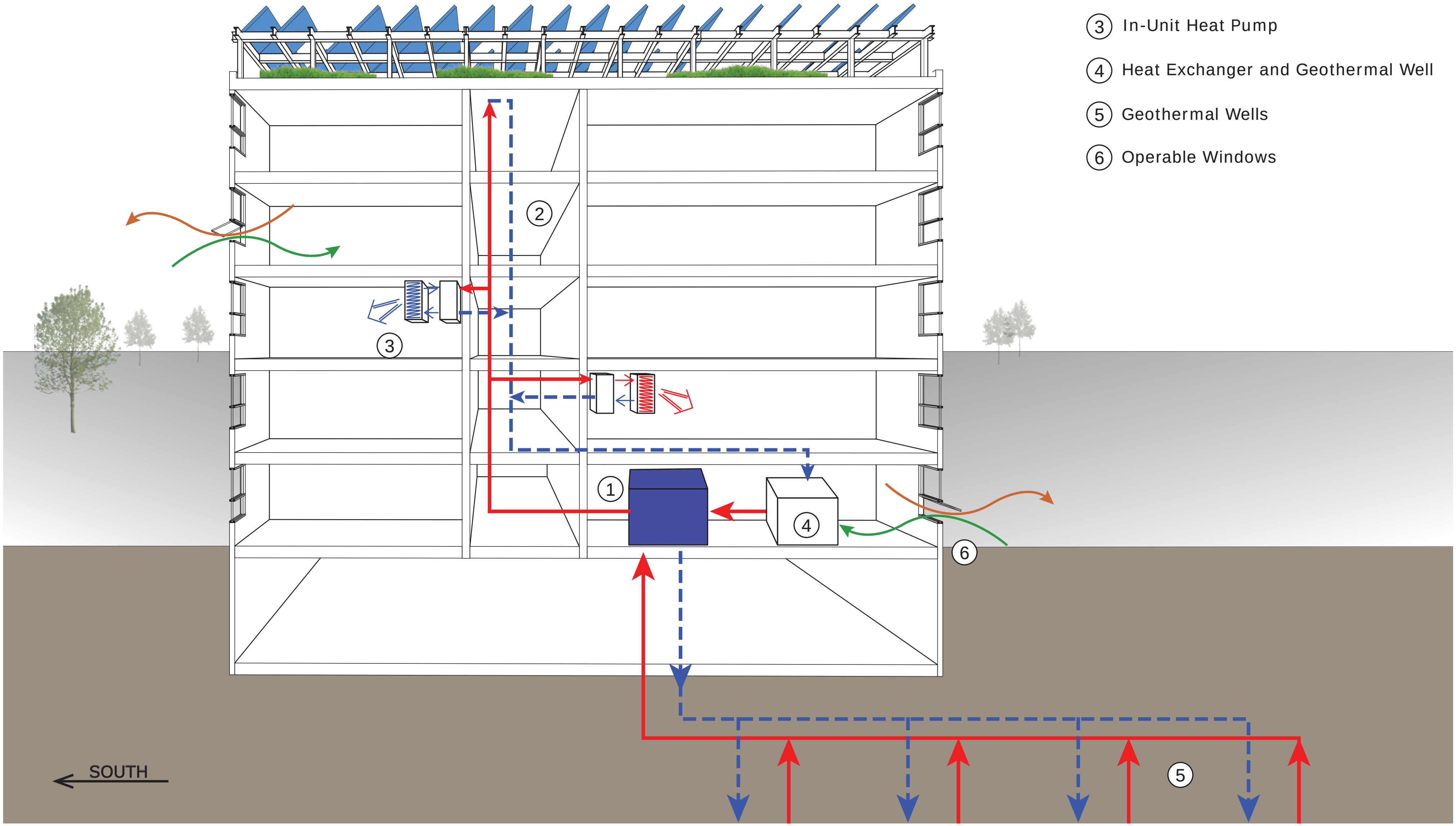
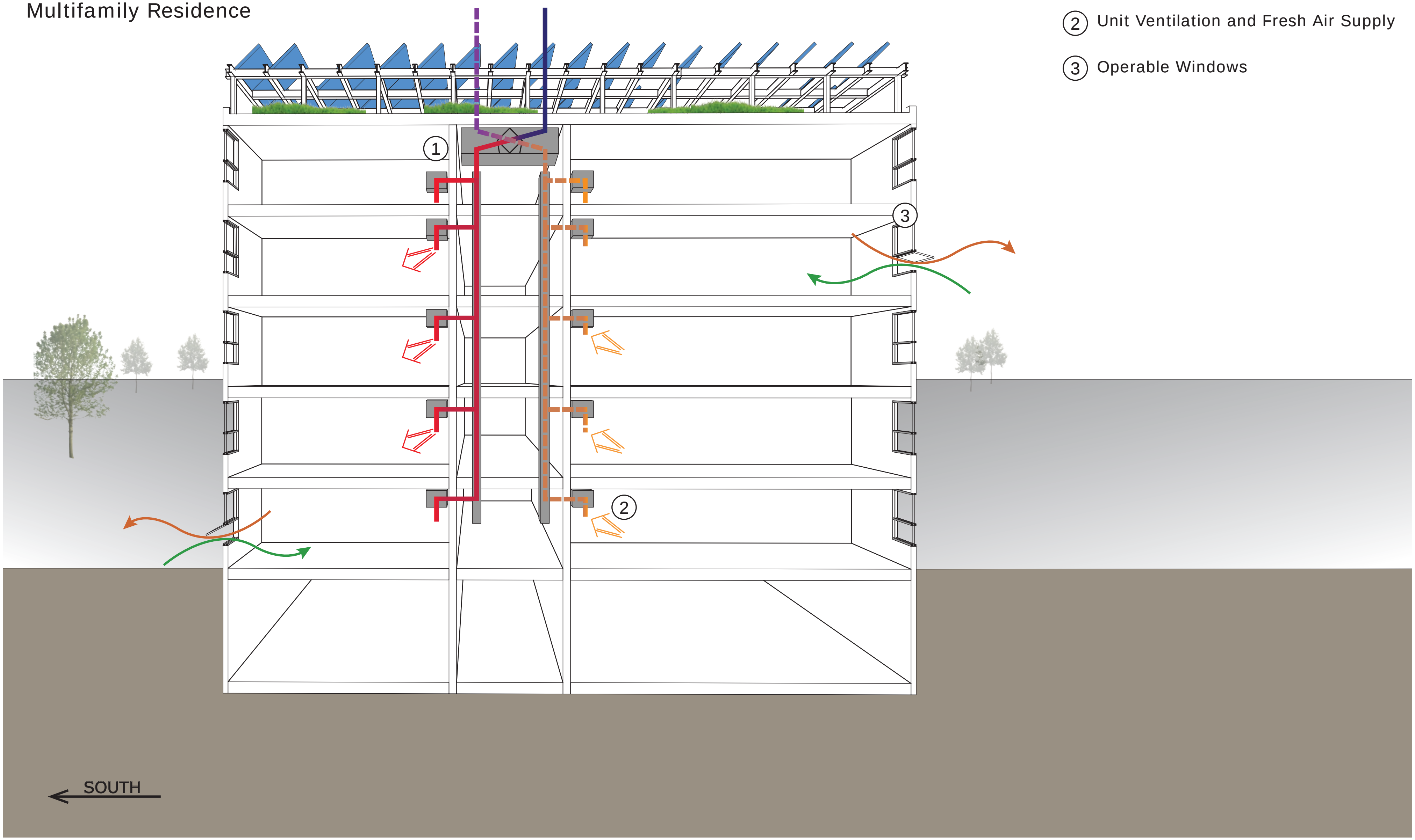


Figure 20: Multi-Family Residential Building Heating and Cooling Diagram

VENTILATION

Multifamily Residence



① Energy Recovery Ventilator

② Unit Ventilation and Fresh Air Supply

③ Operable Windows

Figure 21: Multi-Family Residential Building Ventilation Diagram

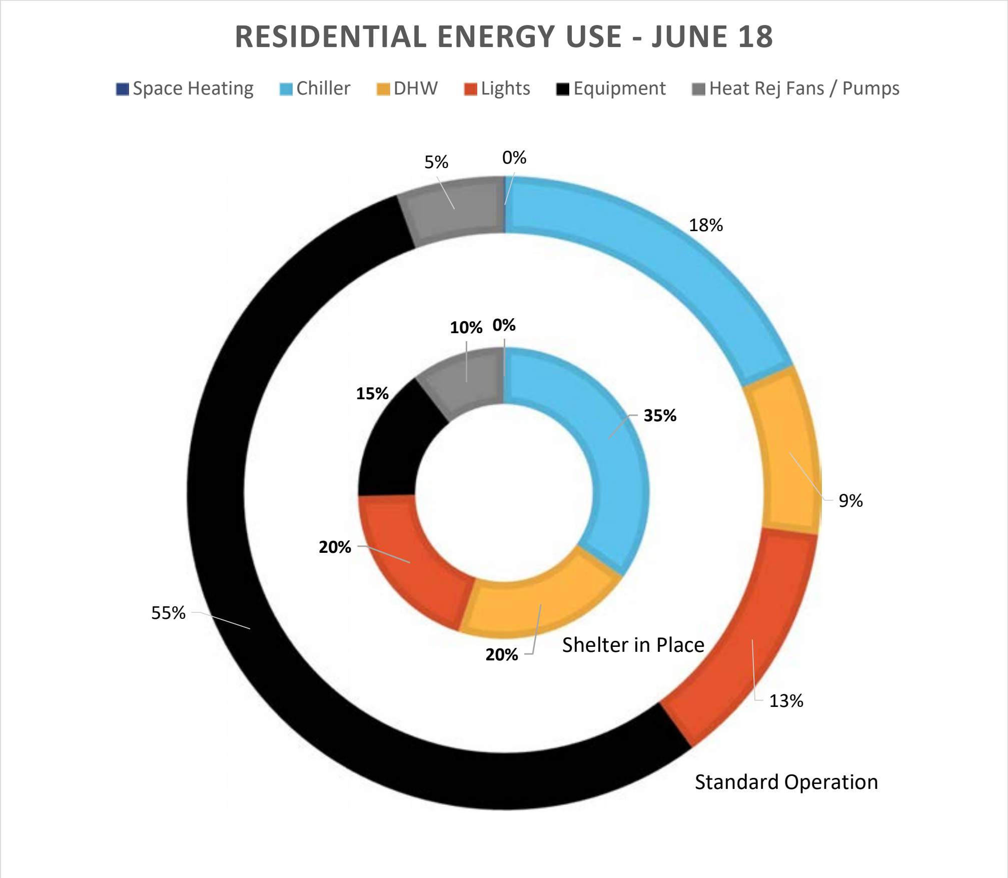


Figure 22: Multi-Family Residential Energy Use By Type, Standard and Shelter in Place Modes

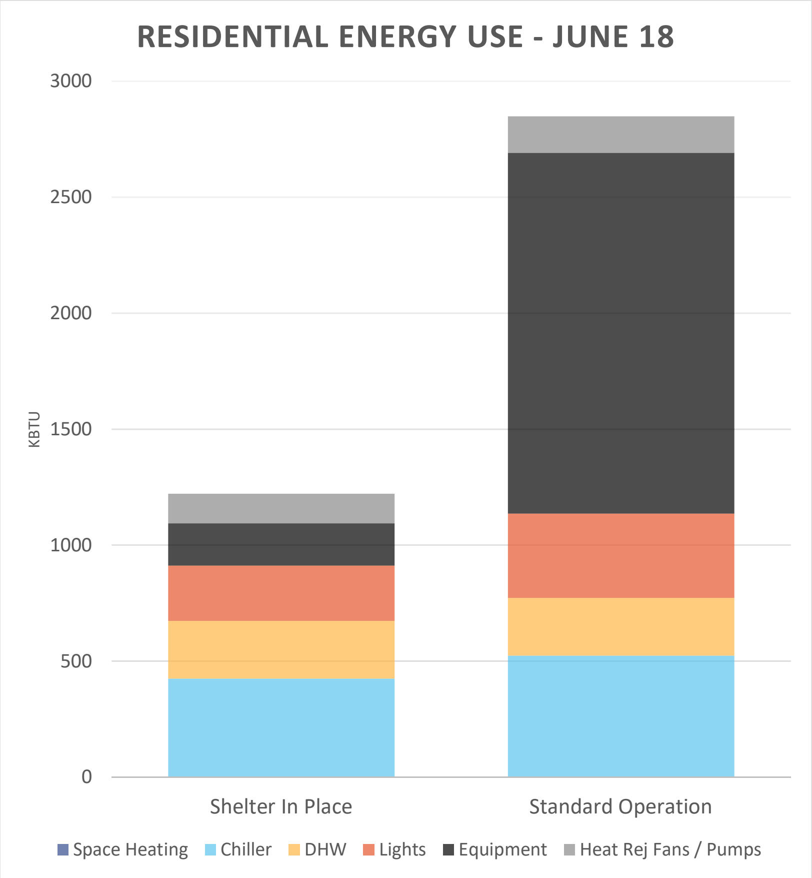


Figure 23: Multi-Family Residential Energy Use By Type, Standard and Shelter in Place Modes

The disaster scenario was simulated using the software IES-VE. The models were initially utilized to simulate the day-to-day operation and then adjusted to run in a low power or disaster mode.

The units, offices, and public spaces in the multi-family residential building was modeled to run with a cooling set point of 74˚F and a relative humidity max of 70%, which results in a maximum heat index of 74˚F. These set points are continuous. Corridors and storage spaces were modeled with a cooling set point of 80˚F and a maximum relative humidity of 70%. Ventilation rates remained the same as day-to-day operation, 0.06 CFM / ft2 of floor area. The number of occupants was assumed to stay the same, but with continuous occupation rather than the variable occupancy modeled in standard operation. Domestic hot water use was unchanged between modes to maintain the health and safety of residents during a power disruption. Lighting in all corridors and mechanical spaces was left at the standard operation because these spaces are fully interior and need to maintain safe light levels for egress. In residential units, offices, and other public spaces, lighting power consumption is reduced to 1/3 of the standard use. Elevators and in-unit refrigeration were set to operate as they did in standard mode, and all other plug-loads were considered non-essential and non-operational in a disaster scenario.

During standard operation plug loads, cooling, and lighting dominate the energy demand. In low-power mode, cooling and lighting are still dominant and domestic hot water becomes a larger proportion of the demand (see figures 23 and 24 for shifts in demand by end use). Overall energy use is reduced from 2850 kBtu in standard operation to 1220 kBtu in low-power mode. These reductions come mainly from plug loads and lighting loads.

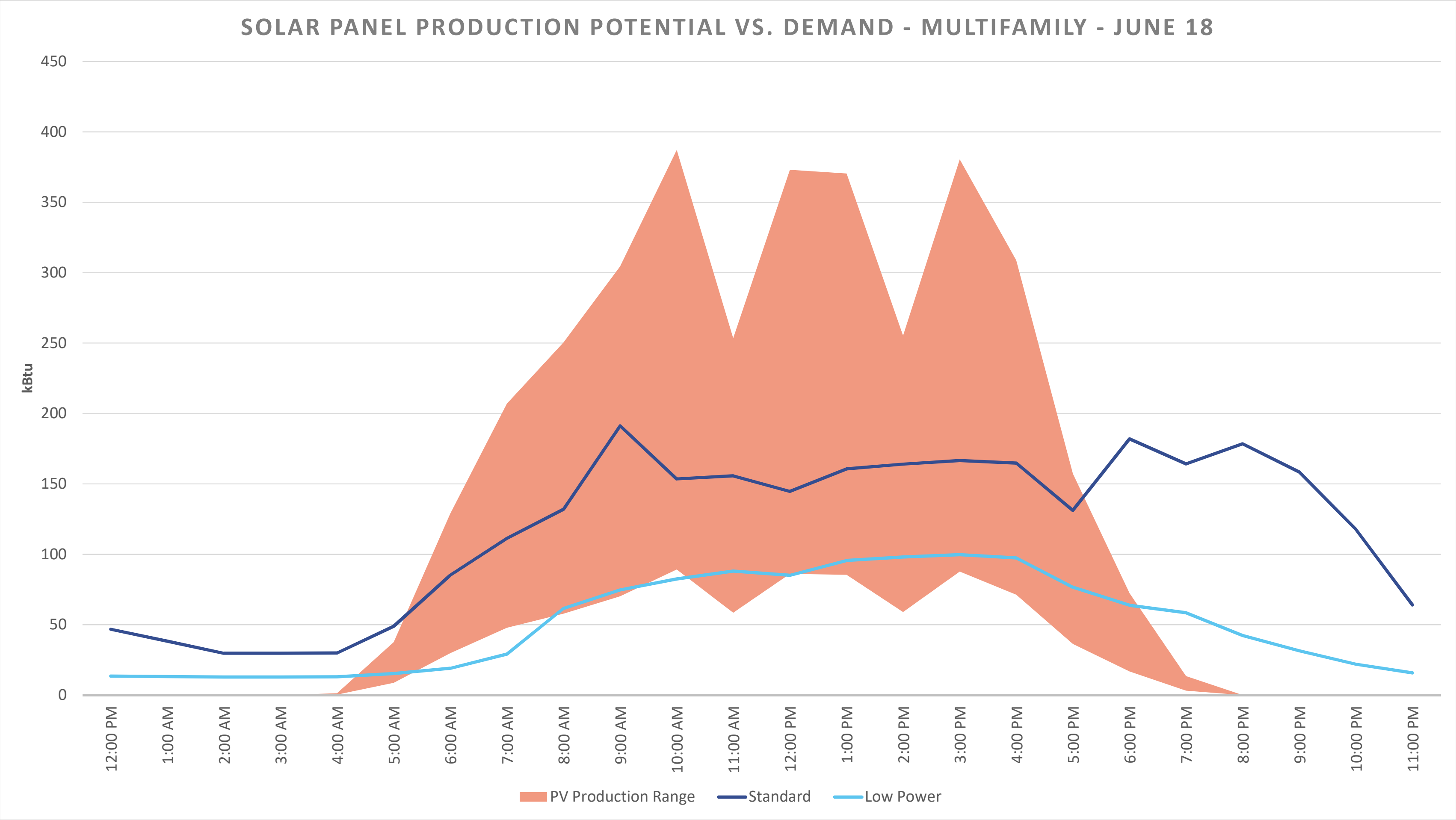


Figure 24: Multi-Family Residential PV Production and Energy Use

The decreased energy demand in emergency shelter mode utilizes 27% of the production capacity of the rooftop PV on a daily basis. However, the demand exceeds the generation in overnight hours and vice-versa during daylight hours. This underscores the need for a battery storage system in the building to provide uninterrupted power during a grid outage regardless of time of day or weather. The remaining 73% of generated energy creates a budget for plug loads and could be used for additional services such as charging cell phones or other communication networks, and could be exported to other buildings in a micro-grid that may not have the same generation capacity or may have higher use in an emergency, such as a hospital. In determining the critical loads for a building, consideration should be given to vulnerable populations and the adverse and disproportional impact temperature and humidity have on them.

Key Modification Low Power Mode
· Identification of critical systems
· If using a building automation system program low power mode
· Install automatic or manual interlock/transfer switch

The active systems of the high performance prototype could be powered by a combination of natural gas and electricity. Redundant energy systems based with a mix of fuels improves overall resilience. As noted above a key modification for resilience is the need to shift to all-electric building, which allows primary mechanical systems to remain operational using site generated power. Regardless of system design and fuel types used, an understanding of building operation during disruptions is a critical. Design of the heating, cooling and ventilation systems should separate air tempering and ventilation. This results in greater energy efficiency during normal operation and flexibility during disruptions.

Observations
· Summer energy use and on site energy production are nearly equal (running at net zero)for themulti-family building prototype—which can provide continuity of power even during short (1 – 6 hours) or extended power outages caused by storm events that occur primarily in the summer.

· Use of a gas fired (propane or natural gas) back up generator to be used in conjunction with rooftop solar should be a major consideration. Generator power is more compatible with pump loads to sustain fire suppression and can serve as primary back up to charge batteries on sunless days or if a storm event damages the on-site solar array.

POTABLE WATER DISTRIBUTION, RAINWATER AND GREYWATER CAPTURE AND USE

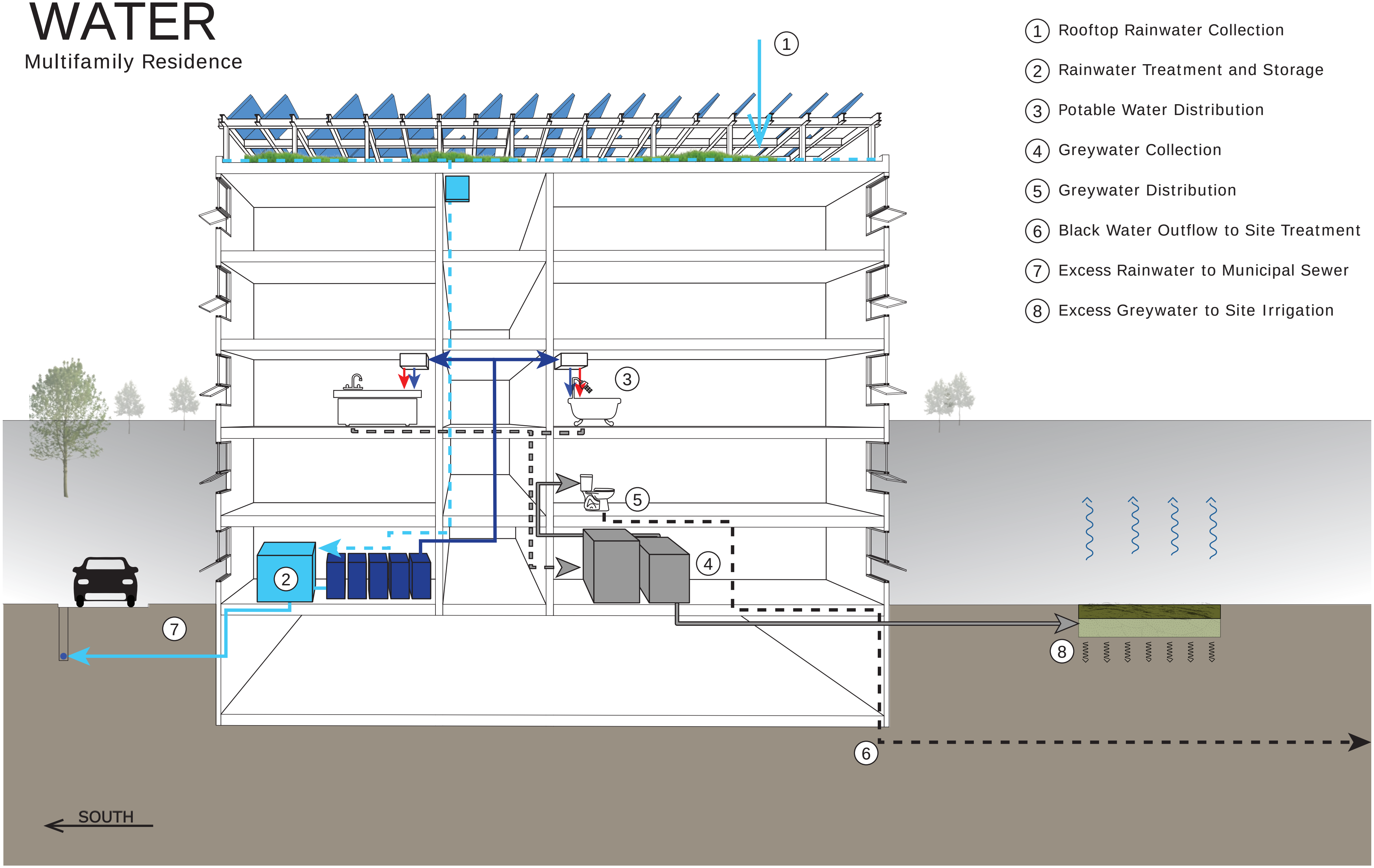
Access to water is critical to maintaining health and safety during an extended outage regardless of the time of year. While drinking water is likely to be brought in during the first wave of relief during a disaster recovery effort, consideration to on-site water collection and consumption for other uses should be considered as part of any resiliency planning.

As noted there are two types of adaptation for resilience: new systems and modifications to existing systems. In addition to conservation, insuring continuity of potable water requires new systems. The primary strategy to insure potable supply during service disruption is the capture and storage of rainwater for use. Regenerative design is possible also if the system collects, uses, treats, and infiltrates water on site to mimic a natural system. An example of such a system is demonstrated in figure 25.

Key Modifications to Ensure Access to Potable Water
- Specify water-efficient fixtures and appliances
- Provide solar hot water
- Insulate water system
- Develop agreements for secondary water sources
- Supply drinking water without power
- Ensure toilets and sinks function without power

WATER

Multifamily Residence



① Rooftop Rainwater Collection
② Rainwater Treatment and Storage
③ Potable Water Distribution
④ Greywater Collection
⑤ Greywater Distribution
⑥ Black Water Outflow to Site Treatment
⑦ Excess Rainwater to Municipal Sewer
⑧ Excess Greywater to Site Irrigation

Figure 25: Water Collection, Use, and Reuse Diagram

SECTION 6 – LIBRARY RESILIENCE: DISASTER HUB

The library building offers an opportunity to explore a disaster or emergency hub scenario during infrastructure interruption. Libraries and recreation centers are often located in residential neighborhoods, and have the potential to serve thousands of nearby residents. According to one study, there are nearly 17,500 public library outlets across the United States, with 98% of all counties having at least one library and a mean county average of five.[1] Libraries can provide a wide variety of services in a disaster situation – from shelter to communication. The distribution of these civic buildings means nearly every resident of Saint Paul and Minneapolis lives within one mile of a potential disaster hub (figure 27). These buildings can be tuned to better accommodate the needs of their neighborhoods in an emergency hub situation, and increase the resilience of the community as a whole.

---

[1] Veil, S., & Bishop, B. (2014). Opportunities and Challenges for Public Libraries to Enhance Community Resilience

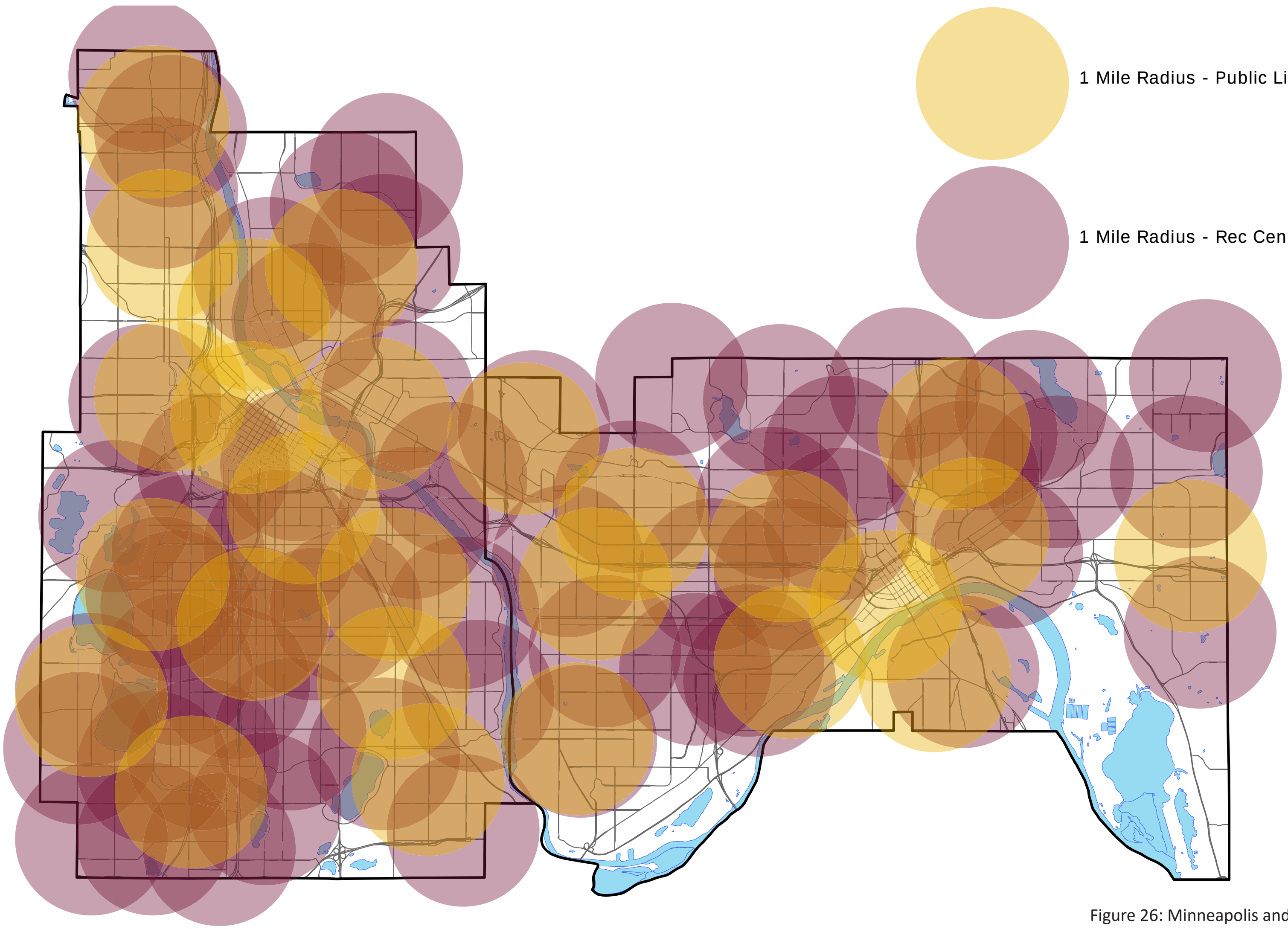


Figure 26: Minneapolis and Saint Paul Community Hubs

Figure 27: Example Hub Catchment Area

Average Number of Residents within 1/2 mile radius of library
Saint Paul - 4,567 people
Minneapolis - 6,013 people

The library prototype can support roughly 550 people in emergency disaster hub mode, approximately 10% of the population living within 1/2 mile in an average urban neighborhood.

Statistically, the supported population will include approximately:
64 people with a disability
125 people living within 150% of the poverty line
42 children under the age of 5
52 people over the age of 65

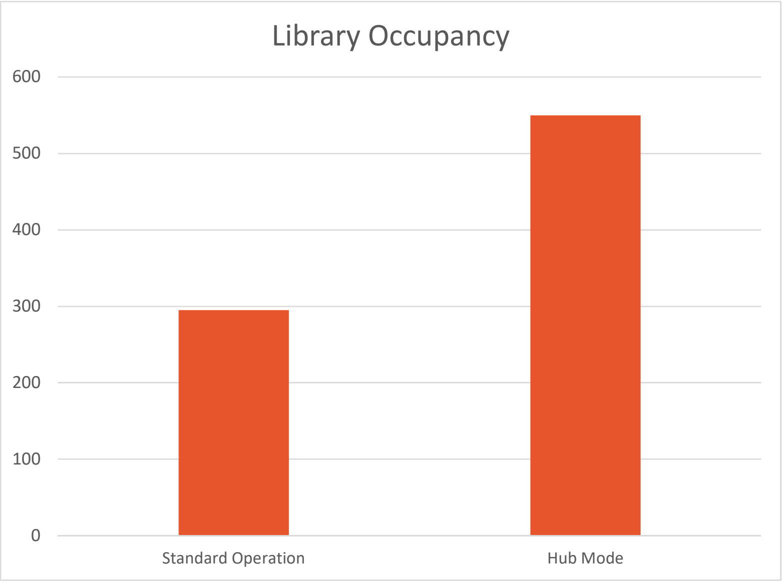


Figure 28: Library Occupancy During Standard and Hub Operation

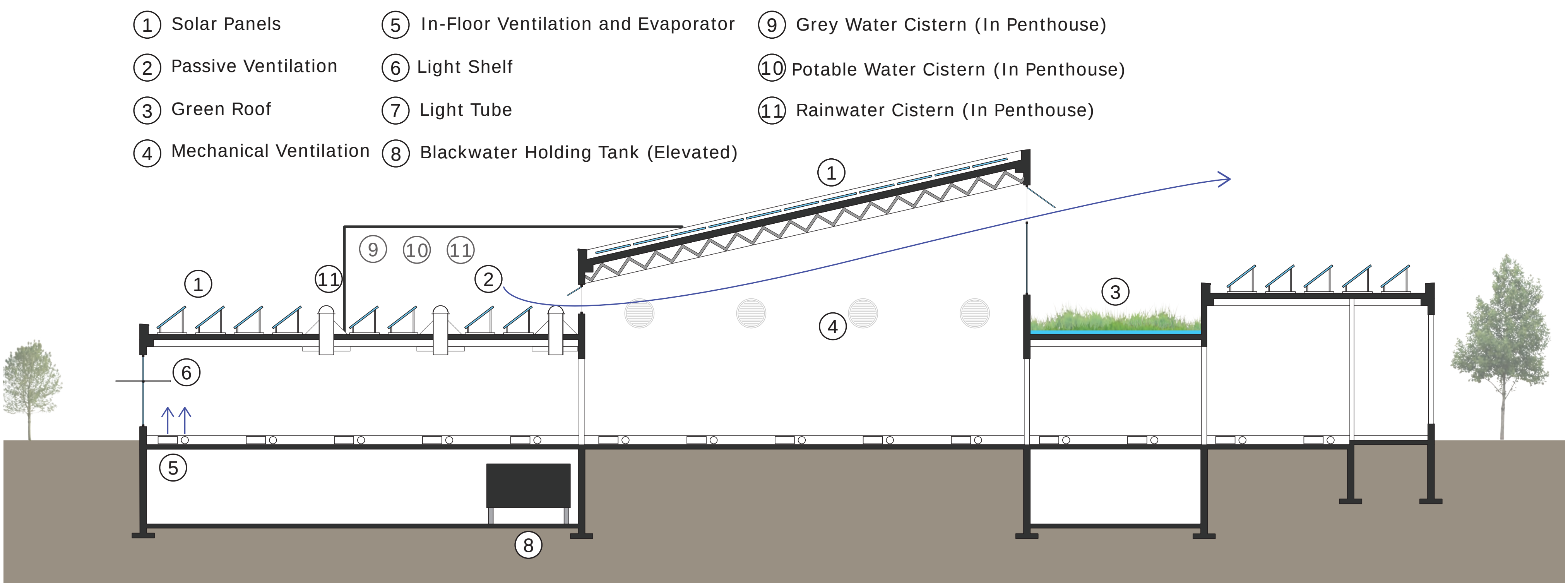


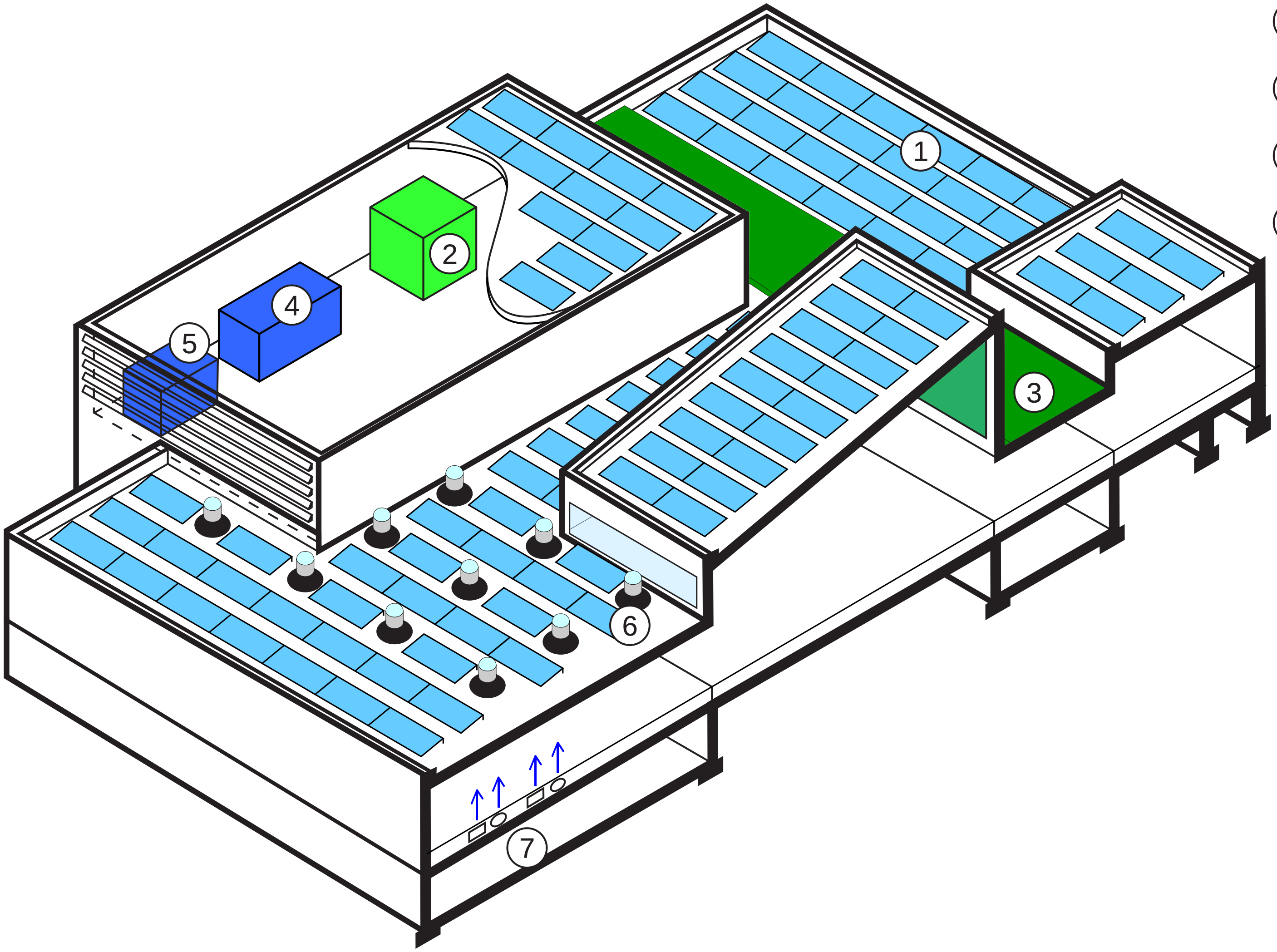
Figure 29: Library Prototype Section

The primary resilience outcomes for a hub building include maintaining habitable temperature, low-power operation and energy storage, and rainwater and greywater capture and use / reuse. These outcomes are complicated by the consideration that a library building functioning as a hub building will have a higher occupancy than during normal use. The active hours will also be extended. The building will have higher heating, cooling, ventilation, and lighting energy demand and higher water usage at times when those infrastructures may be compromised.

The baseline library building is based on a local project, constructed in 2016. The building is compliant with SB 2030 guidelines, meaning it uses 70% less energy than a typical building of its type in Minnesota in 2002, and is designed for an Energy Use Intensity of 40 kBtU/sf/year. This level of energy performance was achieved with improved insulation of the walls and roof and with an efficient HVAC system.

This baseline was modified to a net-zero energy standard using a conventional high-performance process (figure 30). Net-zero energy is achievable on this project with the assumption of grid-tied roof mounted photovoltaic arrays. The PV panels are assumed to cover 70% of the roof area and operate with an 18% efficiency factor. This configuration will generate more electricity than is needed, particularly during summer months, which pushes the building to net-positive for energy. The water system assumes rooftop collection and storage and treatment in the basement.

Further modifications were made to the prototype building to accomplish resiliency goals, especially those related to life safety and the continuity of power and water service. Some strategies take the form of additions and modifications to existing building systems, while others are completely new systems added into the building.



① Solar Panels

② DC Battery Storage and Inverter

③ Green Roof

④ Air Exchanger with Heat Recovery

⑤ Condensor

⑥ Light Tubes

⑦ In-Floor Ventilation and Evaporator

Figure 30: Library Prototype

MAINTAIN HABITABLE TEMPERATURE

To meet the goal of a net-zero building, the exterior insulation was increased from a code baseline. This has the added benefit of helping maintain a habitable temperature in the event of a power disruption. Exterior surfaces with more insulation will slow the heat loss from the building, requiring less energy to heat the space. The wall construction is modeled to have an R-value of 39, a 190% increase over the ASHRAE 90.1 – 2010 prescriptive value. The roof is modeled with an R-value of 38, also a 190% increase over the code baseline. Glazing U-value is improved from U-0.55 to U-0.38, an increase of 145%. The floor slab insulation is increased to R-16.5, an increase of 130%. These insulation values were determined by a series of parametric models testing the effectiveness of increasing the insulation values of individual elements.
The HVAC system in the high performance library building was modeled as a multi-split system with heat pumps for heating and cooling. This system requires much less energy to produce habitable temperatures than the baseline system of a packaged variable air volume system.

Key modifications to maintain habitable temperatures:
- Interior and exterior shading devices to prevent solar heat gain in warm months
- Increased insulation values of all envelope elements
- Advanced framing wall techniques
- Thermal mass
- Design with wind patterns for natural ventilation
- Insulated glazing

ENERGY STORAGE AND LOW POWER OPERATION

The previously mentioned photovoltaic panels can be used to provide continuity of power during a disruption. This requires that the electricity generation system is able to function when the electrical grid does not, and requires batteries within the building to ensure continuous supply over nighttime or low-production hours.

Key modifications for energy storage and low power operation:
- Energy generation – photovoltaic array with battery back-up
- Islandable inverters installed to allow continuity of power in building or district during outage
- Back-up generator to power fire suppression systems, and serve as secondary site-generated energy source
- Easy hook-ups for backup generators
- Critical system backup
- Co-generation and renewable system designed to run during blackouts
- Battery storage and inverters above flood levels

To test the potential of the optimized building to function as a disaster hub, critical loads analysis and energy modeling was done. Critical loads are those most vital to health and safety, and will vary across building types and individual buildings. The planning process for continuity of service and determination of critical loads is crucial for resilient building design. For this building, in June, this includes cooling and ventilation, hot water, lighting, and refrigeration. The cooling, ventilation, and lighting systems have the potential to operate in a low-power mode to maintain functionality while reducing the energy required as compared to day-to-day operation.

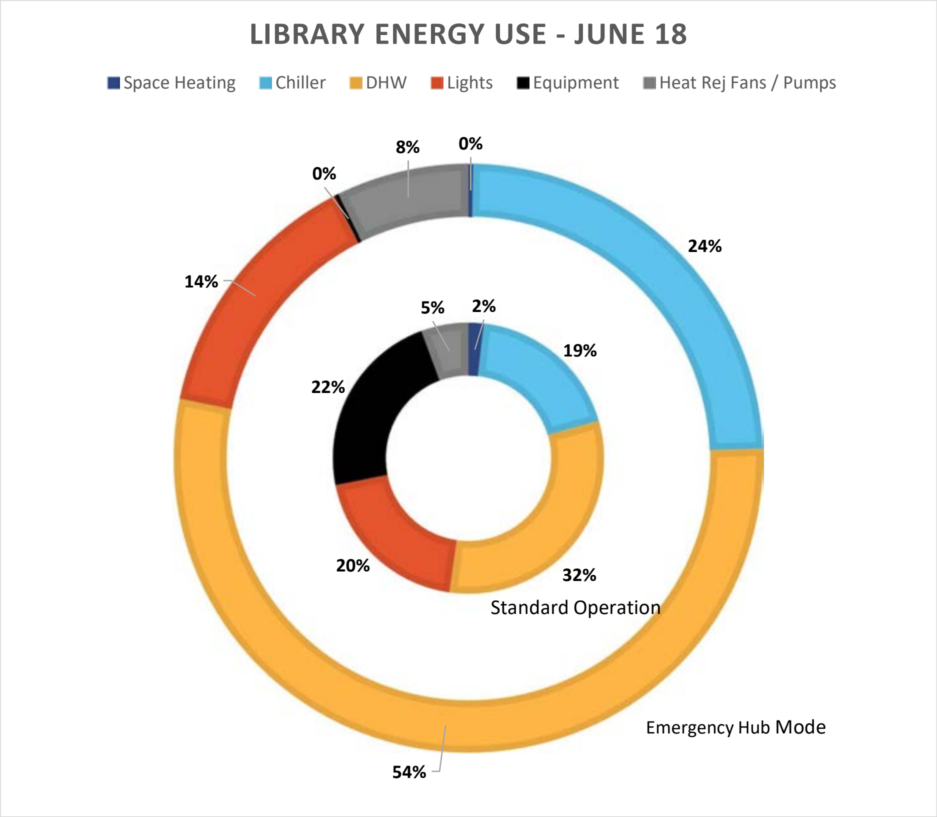


Figure 31: Library Energy Use By Type, Standard and Emergency Hub Modes

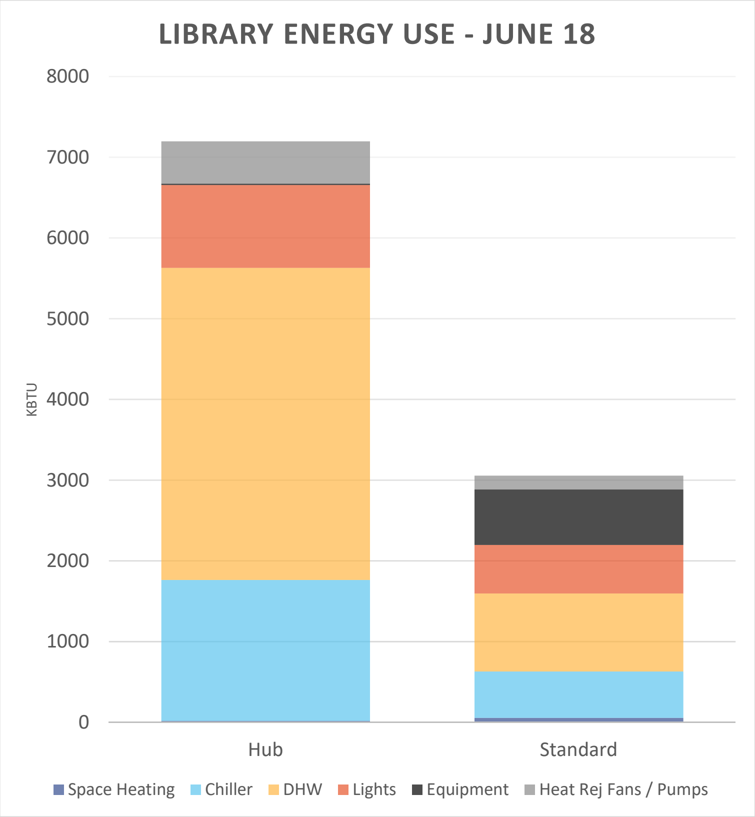


Figure 32: Library Energy Use By Type, Standard and Emergency Hub Modes

The building energy model was manipulated to reflect the previously discussed shifts in occupancy and operating hours. The library building was modeled to run with a cooling set point of 74˚F and a relative humidity max of 70%, which results in a maximum heat index of 74˚F. These set points are constant because when in use as a shelter, people will be in the building continuously. Ventilation rates were increased, because when the building is acting as a shelter the density of occupants will increase over normal building use. The outdoor air rate was set at 0.30 CFM / ft2 of floor area, the ASHRAE recommended rate for assembly spaces. These attributes were applied to all spaces in the library with the exception of mechanical and storage spaces. The library lighting is already very efficient and utilizes daylight dimming during regular operation, which is maintained in disaster mode with the addition of overnight lighting in every third fixture, which is standard emergency operation. The lighting power consumption was set to 1/3 of the typical operation for overnight hours, and was left the same in daylight hours. Due to the increased occupancy, power for pumping and use of water was increased by 180% and is assumed to be used primarily for washing hands and some food preparation. It was assumed that there were two refrigerators in the building, and their operation remained constant to store necessary medications and food for those using the building. All other plug loads were considered non-essential and non-operational in a disaster scenario.

Figures 32 and 33 represent the energy consumption for one day – Friday, June 18th – in a day-to-day operation mode, and in an emergency shelter mode. The pumping of domestic water and chiller loads increase significantly, while the energy use by lights drops and the energy use for equipment all but disappears. The energy use also increases from standard operation to emergency shelter operation, going from 3000 kBtu in standard operation to 7200 kBtu in emergency mode. This increase comes primarily from the increased use of water by increased and continuous occupants.

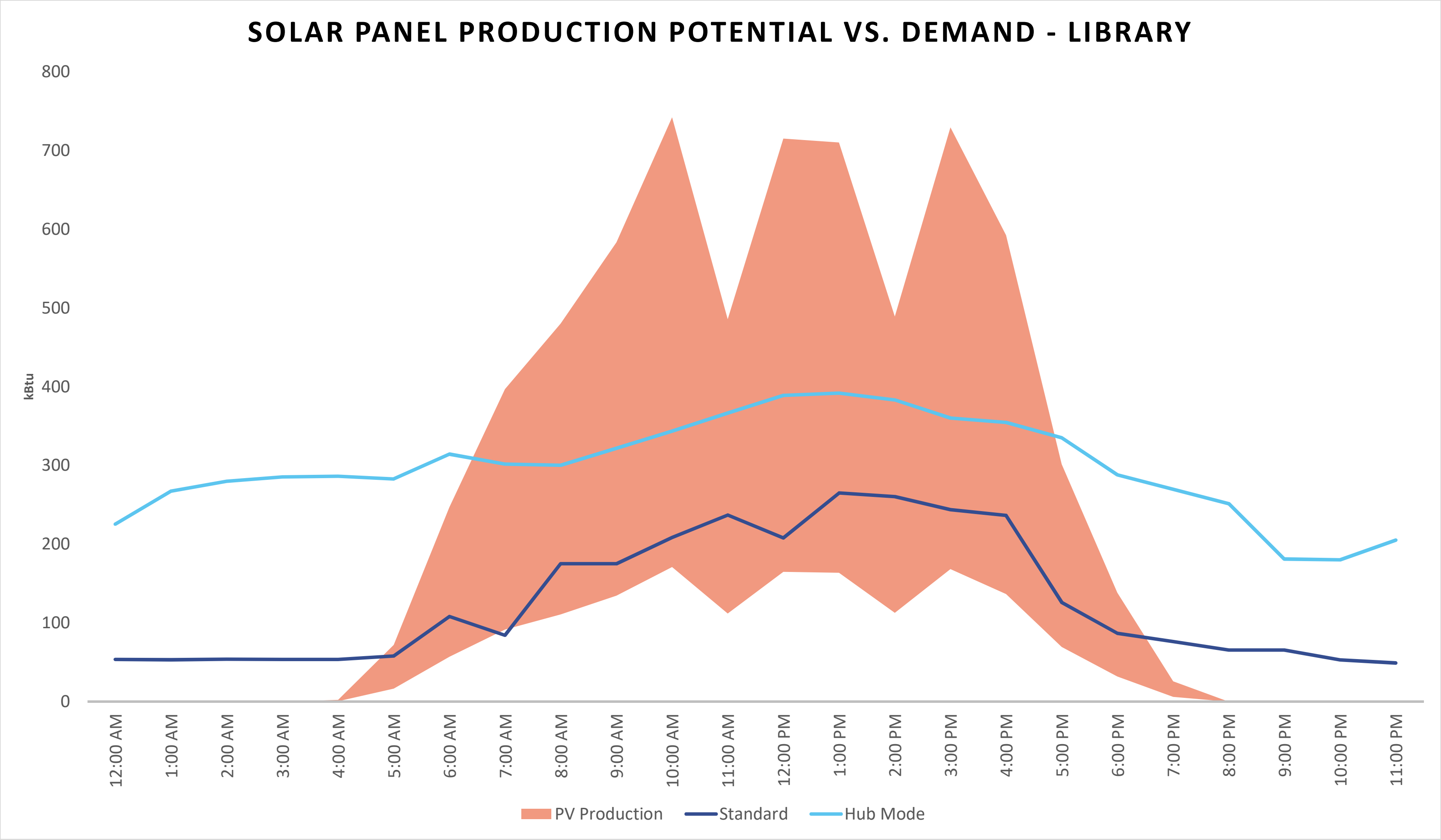


Figure 33: Library PV Production and Energy Use

The increased energy demand in emergency shelter mode utilizes 82% of the production capacity of the rooftop PV on a daily basis. In standard operation, the energy demand utilizes 35% of the production capacity. As this graph illustrates, however, in overnight hours the demand exceeds the generation and vice-versa during daylight hours. This illustrates the need for a battery storage system in the building in the case of the electrical grid being unable to provide back-up power during times of no generation. The remaining 18% of generated energy creates a budget for plug loads and could be used for things like charging cell phones or preparing food.

Key Modifications to Enable Low-Power Mode:

- Identification of critical systems
- Building automation system with low-power presets
- Emergency circuiting

RAINWATER + GREYWATER CAPTURE AND USE

Modifications to the building include a rainwater catchment and collection system. Rainwater is directed from the roof to storage tanks in the partial-basement, where the water is treated through a series of filters and stored for use. This benefits the building in day-to-day use by lowering the demand for municipal water for things like flushing toilets and watering landscaping, and becomes crucial in a disaster situation in which the municipal water supply becomes unavailable. While not currently allowed by building code, rainwater can be treated to a potable water level and used for drinking, cooking, and washing, and could be implemented under future code revisions or variances.

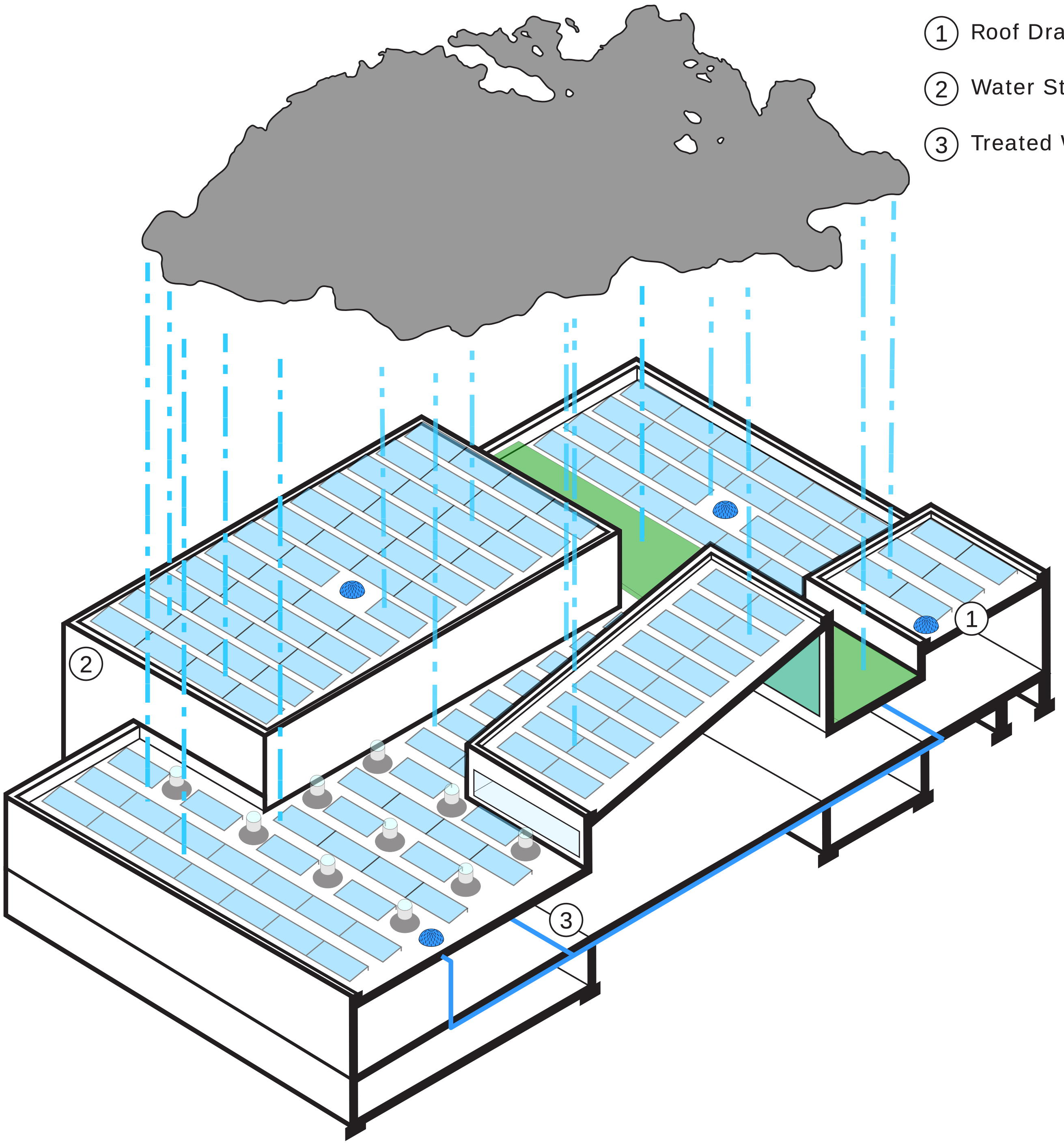
Key Modifications for Rainwater and Greywater Capture and Use:
- Harvest rainwater on roof, pre-treat through green roof system
- Oversize roof drains to accommodate anticipated increase in intensity of rain events
- Rainwater storage cistern
- Plumb buildings for greywater separation and reuse
- Greywater storage tank
- Greywater and rainwater treatment system

Potable Water Distribution

It may become necessary to treat collected water to a potable water standard if supply is interrupted for an extended period of time. It is necessary to collect, treat to potable quality, and store and adequate supply of water for an increased occupancy over several days. This can be accomplished through rainwater and greywater capture and treatment. Fixtures should be high-efficiency to decrease the amount of water used while still meeting the water needs.

Key modifications for potable water supply and distribution:
- Specify water-efficient fixtures and appliances
- Insulate water system
- Develop agreements for secondary water sources

These modifications to library buildings will allow them to function as places of refuge, information centers, and distribution points, command centers, and provide entertainment during disaster events. Centralized locations will ensure access even when transportation networks are disrupted and capable staff will ensure successful operation to create a resilient hub for a community.



① Roof Drains for Rainwater Collection

② Water Storage and Treatment (In Penthouse)

③ Treated Water Distribution for Use

Figure 34: Library Water System

SECTION 7 – B3 IMPLICATIONS

Buildings, Benchmarks, and Beyond (B3) is a set of tools and programs designed to make building more energy efficient and sustainable. The B3 programs have been developed for and are required on all state-funded projects in Minnesota. The B3 Guidelines for new buildings and qualifying renovations has five sections, performance management, site and water, energy and atmosphere, indoor air quality, and materials and waste. The Sustainable Building 2030 Energy Standard is a stand-alone used to achieve the energy use goals when using B3.

Site + Water

New guidelines for the Site and Water section of B3 are soon to be released, including criteria that have resiliency benefits. These include:
- Flood Prevention: If the building is constructed within a flood plain, the project shall follow the Regulatory Flood Protection Elevation requirements of FEMA. However building in a floodplain is prohibited unless essential to the program of the project. The site must also be designed so it will not flood in the event of a ten-year 24-hour rainfall.
- Stormwater Management: The project site will manage stormwater to result in site infiltration, evapotranspiration, on-site reuse, and run off in amounts according to the soil type on site.
- Potable water use reductions: a 50% reduction from code maximum use. This can be achieved with low or no-flow fixtures, or recycled rainwater and greywater.

These measures make progress in protecting the building from flooding that may cause system failures, and incorporate water systems that will operate in a disaster situation and allow the building to remain habitable.

Energy & Atmosphere

The Sustainable Building 2030 Energy Standard required for B3 is a progressive standard leading to net-zero carbon buildings in 2030. The requirements benefit resiliency goals by lowering the critical load demand, day to day energy use in buildings, and the size of on-site renewable energy and battery storage need to achieve net-zero energy.

Current requirements are:
- Energy efficiency: Projects must meet the MN SB 2030 energy standards, which is based on building type and location. Current requirement is a 70% reduction in energy use from the reference building)
- Provide at least 2% of energy needs with on-site solar or wind renewable sources
- Efficient equipment and appliances

Indoor Environmental Quality

Similar to the Energy and Atmosphere requirements, some Indoor Environmental Quality guidelines create resiliency benefits. These include:
- Thermal Comfort – maintain indoor ambient temperature between 64° and 80˚
- Quality Lighting – electric lighting must be operable in multiple modes
- Daylight – 75% of floor area of continuously occupied spaces must have a daylight factor of at least 1%.

These measures create embedded systems that are compatible with the critical load low-power mode, and reduce the energy required to meet these critical loads.

Future Additional Guidelines for Resiliency

While the B3 guidelines provide a good base for a resilient building, there is opportunity to expand the guidelines to create more robust buildings that are better able to handle a disaster situation. Some measures should be modified, and some new measures should be incorporated.

- Modified measures:
    - Storage for recycled rainwater, sized to support daily use over some length of time
    - Use on-site renewables to generate energy needed to meet critical loads, instead of flat 2%
- New measures:
    - Include battery storage in renewable energy system, capable of storing critical load energy demand for some length of time
    - Maximize passive strategies for thermal comfort – ‘free’ heating, cooling, ventilation
    - Elevate mechanical and electrical equipment to avoid flood damage
    - Elevate buildings on sites with high risk of flash flooding
    - Design for dual-mode operation – day-to-day and emergency low-power including water pumping within building for power outage even if municipal water supply remains available, and electronic ignitions for any natural gas powered equipment.
    - Greywater capture, treatment, and re-use
    - Enhance structure and façade elements and site landscape to withstand extreme weather events

Inclusion of these measures will lead to buildings and building users better able to deal with disaster events and emergencies.

SECTION 8 - FUTURE RESEARCH

Additional research is needed to integrate the findings of this report into the B3 Guidelines. A key finding of the report is that there are elements of the current green building approach that could be improved to make high-performance buildings more resilient. The list of modified and additional guidelines incorporated into the building prototypes should be a high priority for inclusion into the guidelines. The next phase of research will need to study the following:

- Specific sizing requirements for water and energy storage
- Financial review of when the 2% energy generation will occur on projects and how that generation capacity relates to critical loads
- Integration of passive and active strategies to improve sustainability and resilience.
- Recommendations for critical equipment locations in response to frequent disruptions including flash flooding
- Criteria for emergency and regular operations modes including revised assessment of critical loads
- Estimates of additional capital expenditures
- Return on investment for resilience features that include an estimate of societal benefits
- Ranges of anticipated solar power generation based on potential cloud cover during disaster and aftermath days 1-10
- Impact of corn sweat on humidity/dew points for disaster scenario
- Length of time need potable water to replace municipal water supply based on experience in recent disasters (availability of water to building vs. availability of pumping to move water within building due to power failure)
- Explore different time frames for provision of various needs – power (including water pumping, minimal food preparation, equipment charging), water supply, food supply, communications (if mobile networks fail)
- Extent of vulnerable populations having access to the building and needing to be served by it and what are critical loads necessary to do this
- Impact of down-burst levels on water available for capture, flash flooding potential (ability of site to infiltrate or runoff away from facility instead of flood), storage needs, treatment needs, other trade-offs and potential issues
- Resilience to property damage of structural components and systems (e.g. wind resilience of advanced framing)
- Level of critical plug loads needed to provide communications (cell phone charging, internet router, computer(s) charging), canned/boxed food preparation at a minimum, command center, entertainment of occupants to prevent conflict, etc.
- Energy and water demands of common medical devices that may need to remain operational during a supply disruption
- Actual site capacity for all-electric vs. benefits of additional reliance on natural gas and experience in recent disasters of continuity of natural gas vs. other power sources

Funding has been provided to CSBR to explore the incorporation of resilience in the B3 guidelines in the current fiscal year. Requirements should be drafted by June 2018 for inclusion in the guidelines by the fall of 2019.

SECTION 9 - BIBLIOGRAPHY

American Institute of Architects. (2017). Disaster Assistance Handbook, Third Edition. Washington D.C.

Brown, C., & Wilby, R. (2012). An alternate approach to assessing climate risks. Eos, Transactions American Geophysical Union, 93(41), 401-402.

Brown, C., Weatherly, J., Mearns, L., Steinschneider, S., Wi, S., Case, M., . . . McCrary, R. (2016). Decision Scaling: A Decision Framework for DoD Climate Risk and Adaptation Planning (Tech.). Fort Belvoir, VA: Defense Technical Information Center.

Chicago (Ill.), Chicago Climate Task Force. (2008). Chicago Climate Action Plan: Our City, Our Future. Chicago, IL: City of Chicago.

Dave, M., Varshney, A., & Graham, P. (2012). Assessing the Climate Change Adaptability of Buildings (Rep.). Sydney, AUS: City Futures Research Centre.

Dickinson, R., & Brannon, B. (2016). Generating Future Weather Files for Resilience. In PLEA 2016 - 32nd International Conference on Passive and Low Energy Architecture (Vol. 1, pp. 17-23). Los Angeles, CA: PLEA.

Dircke, P., Aerts, J. C., Molenaar, A., & Ikert, M. (2010). Connecting Delta Cities: Resilient Cities and Climate Adaptation Strategies. Amsterdam: VU University Press.

Enterprise Green Communities. (n.d.). Ready To Respond: Strategies for Multifamily Building Resilience (Rep.). Washington, DC: Enterprise Community Partners, Inc.

Federal Emergency Management Agency. (2013). Local Mitigation Planning Handbook (Rep.). Washington, DC: FEMA.

Federal Emergency Management Agency, & American Red Cross. (2004). Food and Water in an Emergency [Pamphlet]. Washington, DC: FEMA.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., & Rockstrom, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. Ecology and Society, 15(4),

Gething, B. (2010). Design for Future Climate (Rep.). Swindon, UK: Technology Strategy Board.

Lehmann, S. (2009). Developing a Holistic Pathway to Climate-Adaptive Buildings. Journal of Green Building, 4(3), 91-102.

Linnean Solutions, The Built Environment Coalition, The Resilient Design Institute. (2013). Building Resilience in Boston. Boston.

Lyle, J. (1994). Regenerative design for sustainable development (Wiley series in sustainable design). New York: John Wiley.

McAllister, T. (2013). Developing Guidelines and Standards for Disaster Resilience of the Built Environment: A Research Needs Assessment (Tech.). Gaithersburg, MD: National Institute of Standards and Technology.

Moffatt, S., & Kohler, N. (2008). Conceptualizing the built environment as a social–ecological system. Building Research & Information, 36(3), 248-268.

Morrow, B. (1999). Identifying and Mapping Community Vulnerability. Disasters, 23(1), 1-18.

One PGH - Resilient Pittsburgh (Rep.). (2017). Pittsburgh, PA.

PlaNYC. (2013). A Stronger, More Resilient New York. New York City.

Tyler, S., & Moench, M. (2012). A Framework for Urban Climate Resilience. Climate and Development, 4(4), 311-326. http://dx.doi.org/10.1080/17565529.2012.745389

Shaw, R., Colley, M., & Connell, R. (2007). Climate Change Adaptation by Design - A Guide for Sustainable Communities (Rep.). London: TCPA.

United States. Department of Homeland Security, issuing body. (2013). Threat and Hazard Identification and Risk Assessment Guide.

United States, Homeland Security and Emergency Management, Minnesota. (2011). Minnesota All-Hazard Mitigation Plan Update. Saint Paul, MN: Minnesota Division of Homeland Security Emergency Management.

United States, Minnesota Department of Health, Minnesota Climate and Health Program. (2014). Minnesota Climate Change Vulnerability Assessment. Saint Paul, MN.

United States, Minnesota Pollution Control Agency, Climate Adaptation Team. (2014). MPCA Climate Adaptation Strategy and Proposed Near-Term Actions. Saint Paul, MN.

University of Michigan, U.S. Green Building Council. (2011). Green Building and Climate Resilience: Understand Impacts and Preparing for Changing Conditions. Ann Arbor.

Urban Green Council, New York Chapter of the U.S. Green Building Council. (2013). Building Resiliency Task Force. New York City.

Veil, S., & Bishop, B. (2014). Opportunities and Challenges for Public Libraries to Enhance Community Resilience. Risk Analysis, 34(4), 721-734.

Wilson, A. (2006, January). A Call of Passive Survivability. HPAC Engineering, 7-10.

END NOTES