



TECHNOLOGIES INTEGRATION TO ACHIEVE RESILIENT, LOW-ENERGY MILITARY INSTALLATIONS

**ESTCP Project # EW18-D5281
Energy and Water Projects**

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14. ABSTRACT This work demonstrated the energy master planning (EMP) concept that meets installation/community's framing energy goals and integrates development of a highly resilient "backbone" of energy systems that allow communities to maintain critical missions and service operations during extended outages over a range of emergency scenarios. The Energy Resilience of Interacting Networks (ERIN) tool, developed to support this process, allows the assessment of the resilience of energy supply systems to various Design Basis Threats. The tool operates over networks that supply both individual buildings and districts. Although ERIN is a valuable standalone tool for assessing arbitrary energy networks for energy resilience, it was designed for use with other tools and processes. ERIN was demonstrated at two Army installations (Fort Leonard Wood and Fort Wainwright) in conjunction with a web-based application created for energy managers, master planners, and policymakers to allow them to simplify the analysis and reduce the time required to ~35% of that required by the alternative current best practice. Lessons learned from the project were used to clarify the EMP process and to make many user interface changes to facilitate the process, ease data entry, and produce useful relevant output reports.					
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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The goal of the project was to develop guidelines and a tool that support the planning of Net-Zero Energy Resilient Public Communities and to demonstrate those products at two Department of Defense (DoD) installations with the following objectives:

- To collect, analyze, and document information about best practice community-wide energy master planning (EMP) processes and recommend how they can be improved
- To develop energy, cost, and resilience targets and constraints
- To develop a database of power and thermal energy generation, distribution and storage technologies, and system architectures
- To develop guidance for Energy Master Planning for Net-Zero Energy Resilient Public Communities
- To collect and describe the business and financial aspects and legal requirements and constraints that can be used for the implementation of energy master plans for public communities in participating countries
- To integrate the targets, constraints, enhanced system architectures the technology database, and resilience analysis into an interactive modeling and optimization tool

Two Department of Defense (DoD) installations: Fort Leonard Wood, MO and Fort Wainwright, AK were selected for this demonstration based in part on the fact that their missions allow the collection of the baseline data needed for analysis. The results on that analysis guided the development of an EMP process for evaluating requirements for thermal and electric energy systems resilience of mission-critical facilities. The developed process is supported by a standalone calculation module with standardized input/output for use with existing community planning tools, including the System Master Planning Tool/Net Zero Planner (SMPL/NZP) Tool.

TECHNOLOGY DESCRIPTION

ERDC enhanced its energy master planning (EMP) concept by augmenting it with the capability to perform a resiliency analysis of energy systems, using an automated Energy Resilience of Interacting Networks (ERIN) tool that supports U.S. Department of Defense (DoD) energy policy. The EMP concept minimizes energy use at the building level, improves the efficiency of energy conversion and distribution, and uses energy from renewable sources to balance fossil fuel-based energy to achieve a net-zero fossil fuel energy status during normal operations. The tool analyzes if energy systems used for normal operations have sufficient resilience to support mission-critical operations during extended outages over a range of emergency scenarios, whether caused by weather, manmade events or aging infrastructure. Additionally, the tool evaluates whether emergency technologies or enhanced energy systems will be required to meet energy resilience requirements. This project also developed a database of advanced energy system architectures and the technologies with their technical, economic and resiliency characteristics to inform the analysis of the baseline systems and different alternatives.

DEMONSTRATION RESULTS

Until recently, most planners of public communities in the United States and in several other countries have addressed the design and acquisition of energy systems for new facilities or for a major renovation on an individual facility without consideration of community-wide goals regarding energy sources, renewable energy, energy storage, or the need for future energy generation. In general, new construction and building retrofits of public buildings typically do not address energy needs beyond those addressed in meeting minimum code requirements. It can consequently be difficult if not impossible under those conditions to achieve community-level targets on a building-by-building basis. Nevertheless, in today's resource-constrained environment, public communities are looking for creative ways to improve efficiencies in energy use and to reduce associated costs. A synergistic approach to a diversified building cluster portfolio, for example, would allow for the storage and further use of a wide range of energy streams that would otherwise be wasted.

Building-centric planning also falls short of delivering community-level resilience. For example, many building code requirements focus principally on increasing resilience by hardening buildings to withstand specific threats, but a multi-building community may contain only a few mission-critical buildings that require such hardening. Furthermore, hardening is only one aspect of resilience. Recovery and adaptation should also be considered effective energy resilience solutions.

Best practices from around the world collected under this project and summarized in the Book of Case studies (Annex 73 2022) have shown that holistic Energy Master Planning (EMP) can be a key activity in identifying cost-effective solutions for energy systems. Moreover, the EMP process can be applied to different scales of communities, e.g., to a group of buildings, a campus, a city, a region, or to an entire nation.

Energy master planning is especially valuable and critical when working with community and campus-scale district energy systems that use a centralized plant for generating heating, cooling, and even power; and for distributing these utilities via a network to serve the aggregate heating, cooling, and power loads of multiple buildings. Such planning enables these district energy systems to better size generation capacity by leveraging the diversity of loads across different building types, enhancing economies of scale, and increasing energy efficiency relative to each building by supporting its local generation. The scale of district energy systems also enables the use of lower-carbon resources such as biomass, and lake and seawater cooling, which are not feasible at a building scale.

While the integration of Energy Master Planning into the Community Master Planning process has its challenges, it also provides significant opportunities to support energy-efficient and resilient community concepts, including increased budgets for investments derived from energy savings, more resilient and cost-effective systems, increased comfort and quality of life, and local production that boosts local economies.

Research conducted under the ESTCP EW18-5281 project (ESTCP 2018) leveraged the results from the IEA EBC Annex 73 research to create a solid base for Energy Master Planning toward Net Zero Energy Resilient Public Communities Guide (Annex 73 2022), which provides a deeper

understanding of the EMP process through the lens of best practices and lessons learned from case studies from across the globe. The Guide helps establish objectives and constraints for energy planning, delineates and describes available technologies and their application, and illustrates energy system architectures designed to satisfy a diverse set of local energy supply and demand considerations. The Guide introduces concepts and metrics for methodologies to improve energy system resilience, and discusses the business and financial models used to implement Energy Master Plans.

Based on these energy system architectures and on an extensive technology database that includes prime movers, network distribution components, and auxiliary equipment needed in a system, researchers developed the ERIN tool as a part of this project. ERIN provides energy planners, energy engineers, system and building developers, political leaders, building owners, and city planners the information needed to better analyze and address their local circumstances.

The ERIN tool was developed to support the EMP process, which in turn supports the assessment of the resilience of energy supply systems to various Design Basis Threats. The tool simulates energy flows through an interacting network of district energy system components. This tool can be used in two ways.

1. The first involves the manual construction of an input file in which the user creates an input file using the TOML (Tom's Obvious Minimal Language) format. The TOML file is split up into different sections: buildings and their load files, simulation details, components, energy sources, the fuel system, distributions, failure modes, networks, and scenarios. Although manual creation of an ERIN input file is simple enough for very small networks, it quickly becomes infeasible when working with hundreds of buildings and complex networks. Study 1 demonstrated this version of the tool using a study conducted for Fort Leonard Wood, MO.
2. The second method involves creating the model via the SMPL user interface. This interface simplifies the process by creating a user-friendly workflow for the construction of the TOML and associated load files. The TOML file creation is hidden from the user, as are most of the inner workings of ERIN. This increases the program's usability, as building the TOML file requires specialized expertise and can be both tedious and error prone. This tool application has been demonstrated using the study conducted for Fort Wainwright, which shows ERIN's ability to evaluate the effectiveness and applicability of mitigation strategies. It also shows how the integrated user interface within SMPL 2 allows the modeling of much larger networks by more easily manipulating data and creating easily understood charts and graphs. Directly viewing the requested and achieved energy for a facility allows a quicker diagnosis of an outage's cause so the planning process can continue efficiently.

The Guide described formed the basis for the compilation of two additional Guides, the *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates* (ASHRAE 2021a) and *Guide for Resilient Thermal Energy Systems Design in Hot and Humid Climate* (ERDC 2022), which address the extremely important issue of requirements for thermal energy system resilience in extreme climates.

IMPLEMENTATION ISSUES

The EMP and resiliency analysis processes require the definition of installation specific energy goals, of important constraints and community priorities, and of requirements for energy system resilience. Our experience shows that it can be challenging to obtain such information because current mandates do not address individual building or building community energy goals, and do not stipulate specific requirements for energy systems resilience. During the course of this project, DoD did provide clarification regarding the requirements for resilience (OSD [2021] and Executive Order 14057 “Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability”), but a clear interpretation of these requirements, especially as they relate to specific mission-critical functions, is still needed.

DoD services, U.S. Army Corps of Engineers (USACE), or Directorate of Public Works (DPW) typically either develop Installation Master Plans in-house or subcontract the development to National Laboratories or private sector companies. ERIN and SMPL tools can be used either by in-house personnel or by contractors. An interface for the SMPL tool developed through ESTCP project EW18-5291 (ESTCP 2018) and the U.S. Army project 633734 “Secure and resilient power generation in cold region environments” allows the use of this tool by a broader group of users. However, all potential contractors involved in EMP will require training to apply the proposed concept and use of the new SMPL 2 planning tool to best advantage.

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LIST OF ACRONYMS

Abbreviation	Term
AEWRS	Army Energy and Water Reporting System
AFM	Alternative Financing Mechanisms
ATS	Automatic Transfer Switch
CAPEX	Costs and Capital Expenditures
CHP	Combined Heat and Power
CHPP	Central Heating and Power Plant
DCI	Defense Critical Infrastructure
DHW	Domestic Hot Water
DoD	Department of Defense
DPW	Directorate of Public Works
EA	Energy Availability
ECBCS	Energy Conservation in Buildings and Community Systems
ECM	Energy Conservation Measure
EEM	Energy Efficiency Measure
EMP	Energy Master Plan
EQ	Energy Quality
ER	Energy System Robustness
ERA	Energy Resilience Analysis
ERCIP	Energy Resilience and Conservation Investment Program
ERDC	Engineer Research and Development Center
ERIN	Energy Resilience of Interacting Networks
ESCO	Energy Service Companies
ESMAP	Energy Sector Management Assistance Program
ESPC	Energy Savings Performing Contract
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity
GUI	Graphical User Interface
HTHW	High Temperature Hot Water
HVAC	Heating, Ventilating, and Air-Conditioning
IAQ	Indoor Air Quality
IEA	International Energy Agency
IEWP	Installation Energy and Water Plan
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCOE	Levelized Cost of Electricity
MC	Mission Critical
MCDA	Multicriteria Decision Analysis
MILCON	Military Construction
MTBF	Mean Time Between Failure

Abbreviation	Term
MTTR	Mean Time To Repair
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NZP	Net Zero Planner (Tool)
O&M	Operations and Maintenance
OA	Outside Air
OASA	Office of the Assistant Secretary of the Army
ODB	Outdoor Dry Bulb
OPEX	Operating Expenditures
PREP	Power Reliability Enhancement Program
PV	Photo Voltaic
PWT	Project Working Team
ROI	Return on Investment
SME	Subject Matter Expert
SMPL	System Master Planning
TDT	Thermal Decay Test
TES	Thermal Energy Storage
TOML	Tom's Obvious Minimal Language
UESC	Utility Energy Service Contract
UI	User Interface
UPS	Uninterruptable Power Supply
USACE	U.S. Army Corps of Engineers

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1.0 INTRODUCTION

Over the past 2 decades, the frequency and duration of regional power outages from weather, manmade events, and aging infrastructure have increased. Major disruptions of electric and thermal energy have degraded critical mission capabilities and caused significant economic impacts at military installations. There is a need to develop a highly resilient “backbone” of energy systems (communications, water supply, emergency response, etc.) to maintain critical mission and service operations effectively during such extended power outages over a range of emerging scenarios. This issue is even more important for communities located in extreme (cold, and hot and humid) climates.

Currently, U.S. Department of Defense (DoD) components include Installation Energy Plans as integral updates to their Installation Master Plans. Environmental Security Technology Certification Program (ESTCP) project EW-201240 (ESTCP 2016) demonstrated the Energy Master Planning (EMP) concept and the automated Net Zero Planner (NZP) Tool developed by the ERDC at two military installations; this tool has subsequently been used at 60+ military installations. Although the NZP Tool helps optimize the selection of building, generation, and distribution technologies for normal operations, it does not specifically address resilience. Also, it requires the offline computation of thermal and electrical network characteristics and does not offer sufficient visualization of different scenarios to support resilience decisions without significant post-processing. There is still an acute need for approaches to energy management that are less vulnerable to disruption, and that can better ensure critical mission capabilities.

Although the integration of the energy master planning into the community master planning process may be a challenging task, it also provides significant opportunities to support energy efficiency and community resilience by increasing budgets for investments derived from energy savings, by providing more resilient and cost-effective systems, by increasing comfort and quality of life, and by stimulating local production, which boosts local economies.

In addition to this report, research conducted under the ESTCP EW18-5281 project, IEA EBC Program Annex 73 (IEA EBC 2021) and under the U.S. Army project 633734 “Secure and Resilient Power Generation in Cold Region Environments,” resulted in the *Energy Master Planning toward Net-Zero Energy Resilient Public Communities Guide* (IEA EBC 2022). This Guide formed the basis for the compilation of two additional Guides, the *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates* (ASHRAE 2021) and *Guide for Resilient Thermal Energy Systems Design in Hot and Humid Climate* (ERDC 2022), which address the critical issue of requirements for thermal energy system resilience in extreme climates. These documents include a detailed description of the EMP concept along with extensive supporting information, including establishing requirements for energy systems resilience, and creating databases of energy systems architectures and technologies, business, and financial models for implementation of EMPs that are easy to understand and execute.

1.1 Background

Most national and international research and policy energy-related efforts in the built environment focus on renewable energy sources and energy efficiency in single buildings. Organizations that have made the first efforts to evaluate and analyze international experiences in planning and

implementation of low-energy communities include the International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems (ECBCS) Annex 51 (2013), the German-funded project EnEff Stadt (EnEff 2022) (a comprehensive approach to urban areas with local and district heating networks), the World Bank Energy Sector Management Assistance Program (ESMAP) Energy Efficient Cities initiative (Bose 2010), and the Clinton Climate Initiative C40 program (C40CITIES 2011). Starting in 2010 the U.S. Army pioneered a “Net-Zero Installations” program (ASA[IE&E] 2010, 2014) for selected installations, which surpassed zero energy to include zero waste and zero water initiatives.

1.2 Objective of the Demonstration

The objectives of this project were:

- To establish guidelines for installation and community managers to assess and implement installation and community energy security and resilience, while improving their ability to efficiently and cost effectively maintain overall critical mission operations, and to overcome emerging threats, both natural and manmade.
- To develop a methodology to integrate resilience into the EMP process and enhance the SMPL Tool (former name NZP Tool) in such a way that will make energy supply solutions more resilient,
- To integrate a capability for computation of thermal and electrical network characteristics, and to provide sufficient visualization of different scenarios to support resilience decisions without significant post-processing
- To develop a database of energy supply scenarios that includes data on limitations and economic analyses and that will help end users establish well-defined boundary conditions required to select optimum mission support scenarios.

1.3 Regulatory Drivers

Federal government agencies are required by law (10 CFR part 433) to design Federal buildings to achieve energy consumption levels that are at least 30% below the levels set by the most recently adopted version of ASHRAE Standard 90.1-2019. When it is not life cycle cost (LCC) effective to design new Federal buildings to exceed ASHRAE Standard 90.1 performance levels by 30%, new Federal buildings must be designed to exceed the ASHRAE Standard 90.1 performance levels up to the percentage that is LCC effective (10 CFR 433.100(c)). Furthermore, new Federal buildings must, at minimum, be designed to achieve the baseline standards established in ASHRAE Standard 90.1.

Executive Order (EO) 14057, “Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability” (White House 2021a) focuses on catalyzing American clean energy industries and jobs through Federal sustainability and the accompanying Federal Sustainability Plan (referred to hereafter as “The Federal Sustainability Plan”). EO 14057 includes the following government-wide goals:

- Net-zero emissions by 2050,
- One hundred percent carbon pollution-free electricity on a net annual basis by 2030, including 50% 24/7 carbon pollution-free electricity,

- A net-zero emissions building portfolio by 2045, including a 50% emissions reduction by 2032,
- A 65% reduction in scope 1 and 2 greenhouse gas emissions from Federal operations by 2030 from 2008 levels,
- Climate-resilient infrastructure and operations, and
- A climate- and sustainability-focused Federal workforce.

The 2019 National Defense Authorization Act (Congress.gov 2018) requires that, in every installation's master plan, all military branches must include an examination of energy and climate resilience while ensuring mission-critical operations. While individual military bases have been installing microgrids and preparing for storms and floods on a case-by-case basis for years now, the new law requires every military base to take steps to protect against these disasters as part of its master plan. These requirements have recently been reinforced by EO 14008, "Tackling the Climate Crisis at Home and Abroad" (White House 2021b) and the new DOD *Climate Adaptation Plan* (DoD 2021). These mandates and subsequent initiatives require that the security implications of climate change be incorporated into analyses for military strategy, planning, and programming.

In compliance with EO 13834, "Efficient Federal Operations" (White House 2018), DoD is working to increase efficiency, optimize performance, eliminate unnecessary use of resources, and protect the environment by reducing waste, cutting costs, enhancing infrastructure, and increasing operational resilience.

Other significant drivers relevant to energy efficiency in DoD and other Federal buildings include:

- "Metrics and Standards for Energy Resilience at Military Installations," DoD Memorandum dated May 20, 2021 (DoD 2021b).
- *Guiding Principles for Sustainable Federal Buildings and Associated Instructions* (CEQ 2020).
- *High Performance and Sustainable Building Requirements*. Unified Facilities Criteria (UFC) 1-200-02 (NAVFAC 2020).
- *Energy Security and Sustainability (ES2) Strategy* (HQDA 2015).
- "Sustainable Design and Development Policy Update (Environmental and Energy Performance)." Office of the Assistant Secretary of the Army (OASA) Memorandum dated January 17, 2021 (OASA 2021b).

2.0 TECHNOLOGY DESCRIPTION

2.1 Technology Overview

In most countries, community energy plans have been high-level strategy documents rather than planning documents. The synergy between community and energy planning becomes essential and critical for developing energy-efficient, sustainable, more resilient communities that provide incentives for the use of large-scale renewable energy sources and that encourage the use of community-scale generation, distribution, and energy storage technologies, which in turn results in increased resilience to natural and manmade threats to energy (thermal and electric) systems, and boosts local economies.

Building-centric planning also falls short of delivering community-level resilience. For example, many building code requirements focus principally on hardening buildings to withstand specific threats, but a multi-building community may contain only a few mission-critical buildings that require such hardening. Furthermore, hardening is only one aspect of resilience. Recovery and adaptation should also be considered effective energy resilience solutions. Over the past 2 decades, the frequency and duration of regional power outages from weather, manmade events, and aging infrastructure have increased. Major disruptions of electric and thermal energy have degraded critical mission capabilities and have caused significant economic impacts at military installations. There is a need to develop a highly resilient “backbone” of energy systems to maintain effective critical mission and service operations during such extended power outages over a range of emerging scenarios.

ESTCP-funded project EW-201240 resulted in the development and demonstration of the energy master planning automated Net Zero Planner (NZP) Tool allowing analysts to execute the Energy Master Planning (EMP) process quickly, efficiently, at lower cost, and with a high level of repeatability in an integrated single program structure. This tool has been later enhanced and became a web-based application called the System Master Planning (SMPL) tool. Created for energy managers, master planners, and policymakers, SMPL provides a graphical interface that allows users to evaluate energy, water, waste, and storm water scenarios for military installations, districts, and campuses. The current ESTCP-funded project EW18-5281 resulted in the development of additional modeling capability, the energy resilience simulation tool ERIN, which allows for the assessment of arbitrary energy networks for their energy resilience and is meant to be used in conjunction with other tools and processes.

The updated SMPL tool (version 2) will be made available inside the U.S. Department of Defense to government users, and outside of DoD to the private sector as a commercial product offered by Big Ladder under another name. This integration of ERIN with SMPL serves as an example of how ERIN can be integrated with other energy planning tools.

2.2 Lessons Learned from Case Studies

Experience from case studies (IEA EBC 2021) shows that Energy Master Planning that includes both demand and supply systems can cost effectively increase energy efficiency on the national level by maximizing the use of combined heat and power and by recycling all heat from waste incineration. Case studies from North American universities have demonstrated the cost

effectiveness of upgrading district steam and district cooling systems on campus and building levels by taking advantage of the fact that all renovation costs and operational benefits are attributed to a single university budget.

Energy master plans described in the case studies were formulated with a variety of different objectives, from such simple economic objectives as reducing operating costs, to improving the resilience of energy systems, achieving net-zero emissions at the building and campus levels, and avoiding CO₂ taxes. Experience with the first energy-neutral town in the world showed that a transition to a 100% renewable energy supply (Güssing 2011) can triple tax incomes and thus boost the local economy within 15 years. Analysis of case studies (IEA EBC 2021) collected and summarized as a part of the Annex 73 project highlights the following observations:

- Typically, energy master plans allow total life-cycle costs to be minimized, support the decarbonization of the process of supplying energy to end users, and increase the resilience of thermal and power energy supply systems.
- In some cases, increases in the density of the built environment, the increased use of mechanical ventilation, and the implementation of new requirements for building cooling systems due to rising outdoor air temperatures and improved environmental quality standards can increase both energy costs and the community's energy use, resulting in a need for additional power generation and greater required heating and cooling capacity.
- The implementation of novel and more efficient end-use technologies, Building Energy Management Systems, and energy supply solutions, including thermal energy storage, Combined Heating, Cooling, and Power generation, reversible heat pumps, and broader use and integration of energy generation from renewable energy sources into distribution grids can help to slow down or even reverse the increase in energy demand, can reduce the size of energy generation equipment by shaving peak loads (in particular the cooling peak in warm climates), and can make energy systems more resilient to the growing number of different natural and manmade threats and hazards. Existing thermal and power distribution networks can be expanded or combined to integrate existing energy generation equipment dedicated to individual buildings and building clusters; this results in improved operational efficiency, provides additional capacity required for peaking loads, and provides generation and distribution redundancy, which in turn results in the enhanced resilience of energy systems.
- Integrated energy systems can function as so-called “virtual batteries.” District heating can be provided by a combined heat and power (CHP) plant, heat pumps, electric boilers, and thermal energy storage (TES) units—measures that allow scheduling of equipment operation in response to weekly, even daily, fluctuations of prices in the electricity market that can be affected by such factors as the variations in wind. A number of case studies (primarily from Germany and Denmark) illustrate current trends in the replacement of old inefficient steam systems and superheated water with modern state-of-the-art district hot water systems. Such improvements reduce operating costs; increase overall system efficiency; integrate the use of waste heat from industry and renewable energy sources (both directly and via heat pumps); and generally improve system resilience. Measures such as these could be adapted to U.S. campuses and military installations, where 95% of all campus heating systems are steam-based. Note that this modernization and conversion would involve major capital outlays and business disruptions, particularly for converting buildings from steam to hot water systems; such changes are often undertaken in a phased implementation based on the state of each system.

- Although water-based systems are currently the lead district energy generation technologies due to their flexibility and lower temperature efficiencies, steam systems still represent viable and efficient methods for heating buildings. Some hospitals and laboratory buildings, for example, require access to the higher temperatures associated with steam for the purposes of sanitization. Steam is also highly pressurized, which allows it to use smaller distribution pipes and to move heat in high-rise buildings better. Existing steam systems may also be paired with hot water as the system expands and adds new customers/users.
- Buildings configurations that include such improvements as well-insulated building envelopes; efficient heating, ventilating, and air-conditioning (HVAC) systems with large surface radiant heating and cooling technologies (e.g., floor or ceiling mounted heating and cooling); and the use of building core activation that can exploit smaller temperature differences between supply and return water used for heating and cooling, all support the use of district systems with low-temperature heating and high-temperature cooling. This in turn enables the use of low exergy sources, e.g., ground (geothermal), solar thermal and groundwater, river or lake water, heat from sewer systems, etc. This also increases the resilience of building thermal energy systems, which can be decoupled from thermal energy sources for a relatively longer time.
- Case studies from Finland and Denmark show a trend toward the combination of heating and cooling. In highly efficient buildings, cooling may become a necessity where it may not have been before; the two thermal systems can be integrated to share the thermal energy in return water from the complementary heating/cooling system.
- In campuses where all buildings share a single owner, e.g., university campuses, medical centers, and military installations, energy efficiency measures made to individual buildings (e.g., building envelope renovation, replacing HVAC equipment and lighting systems with more efficient ones) can be used to reduce community-wide peak demand. When such projects are planned and scheduled as a part of a holistic Energy Master Plan, they can improve the cost effectiveness of the plan by improving building environmental conditions, better using resources, and enhancing system resilience. This approach requires collaboration between all stakeholders and strategic timing of different projects (HTF Stuttgart, Germany). In one instance, where the energy supply system was owned by the city (e.g., Case Study for Copenhagen, Denmark), the utility company was able to minimize energy cost to all consumers. Single-owner campuses are better situated to this use approach than are local communities with numerous building owners since single-owner campuses can optimally time the building renovation for all campus buildings.
- Emergency power backup solutions are typically limited to the use of emergency diesel or gas-fueled generators that are maintained for use only during power loss from the grid. Typically, they provide power to mission-critical operations and support life and safety needs. For example, some cost-effective microgrids implemented in the United States have connected critical users to gas-fueled CHP plants to provide energy assurance when the power grid performance degrades.
- Similarly, peak boilers for the district heating system can be located close to critical consumers, e.g., a hospital, to ensure a more resilient heat supply (Vestforbrænding, Denmark).
- Micro grids are not common in European countries, where most of the power grids are reliable. However, in some cases (e.g., at the Technical University of Denmark) microgrids are used to avoid distribution tariffs since the costs of operating their own low voltage grid is lower than the distribution tariff from the utility. In such cases, even large gas-driven CHP

plants located on the campus are not connected to the campus grid but are rather connected to the utility grid and operated based on market energy prices.

2.3 Energy Planning as a Part of the Community Master Plan

For existing large areas, the planning process is complex. The process includes consideration of future use and energy costs as well as of maintenance and operation of existing infrastructure. Implementation plans for energy systems cover many years of actions to increase efficiency, resilience, and reliability. These plans are important to provide the scope, schedule, and security to projects funded either directly or using third-party financing.

The process of building efficient, sustainable, resilient communities requires careful coordination between stakeholders, including master planners, energy planners, and building designers. These stakeholders work at differing levels of detail and use different planning horizons, which may lead to suboptimal decisions for the community as a whole. Coordinating the myriad stakeholders involved in community planning can be a challenge.

Three levels of stakeholders can readily be identified. At the highest level of abstraction, master planners think in terms of long-term sustainability goals, including national energy strategy, community layout, transportation, and street design; in this stage, planners work to break down barriers between sectors and cities. To address sustainability, master planners must look at the society as a whole and extend the length of their view to 25 years or more (Case et al. 2015). Energy managers fall within the middle tier of abstraction; the focus of their work is on the local community or campus projects, which may vary between longer-term energy infrastructure projects, such as district energy systems, to medium- or near-term projects, such as building retrofits designed to meet community energy goals. Finally, the building (or infrastructure) designer's efforts occupy the most detailed level of abstraction. These engineers must create designs for a specific project that are demonstrably effective, buildable, biddable, and cost effective.

Integration of energy planning into community planning requires a holistic approach to the planning process and relies on new concepts, instruments, and tools, all of which must be made available to master planners, energy managers, decision-makers, and stakeholders. Energy master planning is a complex process that includes cultural, organizational, technical, legal, and financial aspects.

2.4 Energy Master planning Concept

The objective of the community/installation Energy Plan is to produce a holistic roadmap that enables planners to work constructively towards various framing energy goals within defined community-specific constraints. The EMP concept described in this Guide differs from previously developed concepts (OASD 2016, Zhivov et al. 2014, Annex 51 2013) in that, in addition to meeting the community's framing energy goals, it integrates the development of a highly resilient "backbone" of energy systems that allow communities to maintain critical missions and service operations effectively during extended outages over a range of emergency scenarios, whether caused by weather, manmade events, or aging infrastructure (Figure 2-1).

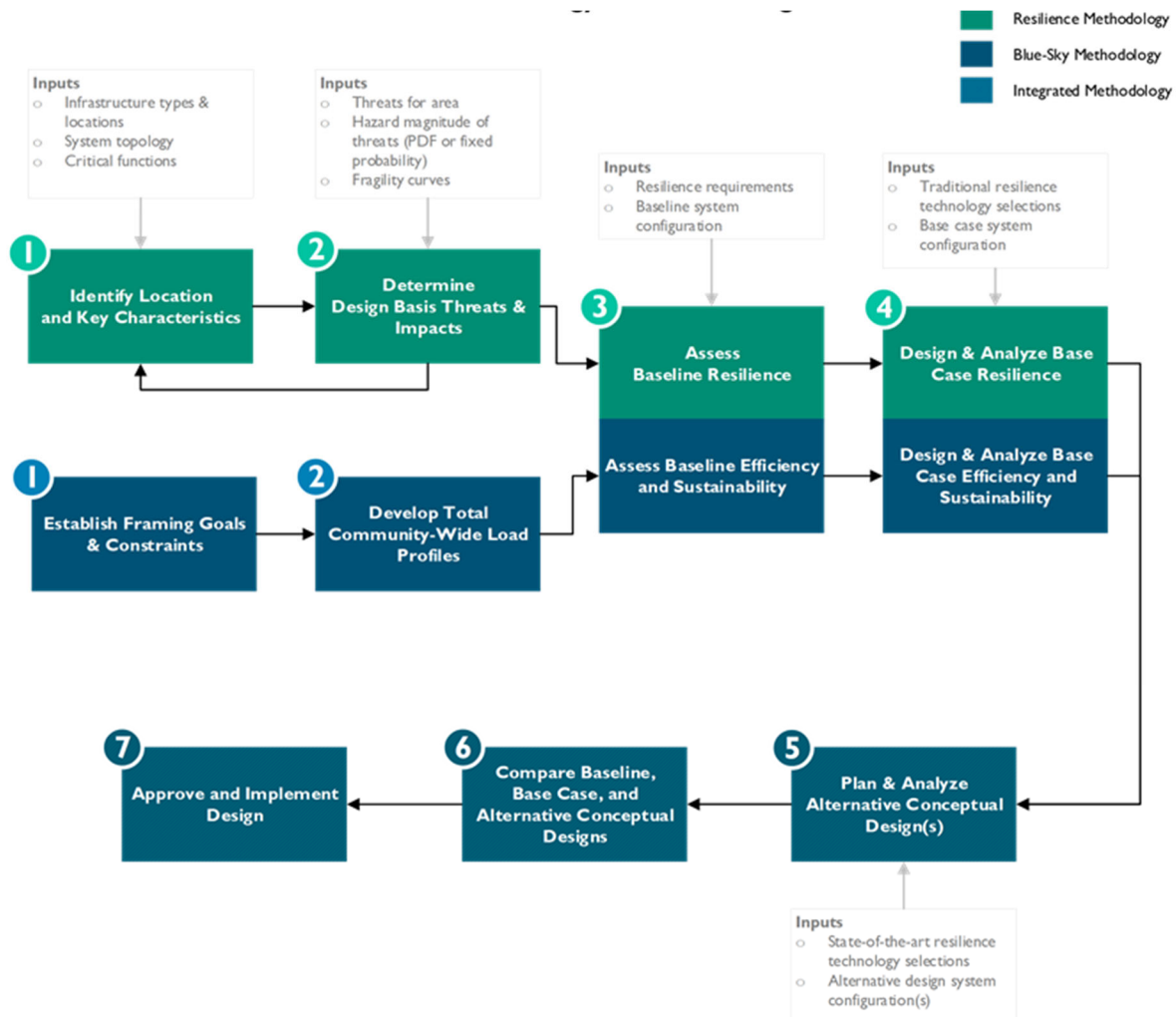


Figure 2-1. Integration of Energy Systems Resilience Analysis into Energy Master Plan.

The integrated approach described in this Guide results in cost-effective operation of energy systems under normal (blue sky) conditions and in a less vulnerable, more secure, and more resilient energy supply to the community’s critical mission functions during emergency (black sky) scenarios. It provides a framework for the planning process and outlines the main steps, which include: (1) establishment of energy framing goals and constraints, (2) assessment of a community’s critical missions and functions, (3) assessment of community specific threats, (4) establishment of energy requirements for normal and mission-critical functions, (5) assessment of the current situation (baseline) to understand existing gaps against framing goals and constraints, and (6) development of future alternatives, including “business as usual” (base case) and more advanced alternatives of energy systems.

Quantitative metrics should be used to compare baseline, base case, and future alternatives. “Blue sky” and “black sky” alternative architectures can be built upon the database of technologies and architectures summarized from internationally available best practices. Alternatives established under normal (blue sky) conditions consider energy goals, constraints, loads, and the operation of all buildings and systems. However, selection of architecture of different alternatives for energy systems during this phase of the planning process may already

consider the implication of their characteristics and their function on the resilience of systems serving mission-critical facilities under emergency conditions. The planning process for mission-critical buildings and functions addresses only critical loads under emergency (black sky) conditions. This part of the process includes steps that (1) allow planners to narrow down the scope of buildings and operations and their loads to those that are mission-critical, (2) that assess threats specific to locality and function of the installation and their impact on energy systems' degradation, and (3) that calculate energy requirements for mission-critical functions. Planners will evaluate gaps in existing systems' resilience and develop future alternatives of systems that provide the required level of energy assurance to mission-critical functions, including "business as usual" (Base Case) and more advanced alternatives of energy systems, which will consider, but not be limited to, those developed under the "blue sky" scenario. At this point of analysis, there is an opportunity for iteration between alternatives developed under these two scenarios.

Final steps of the integrated EMP process include the comparison of different alternatives against the framing goals established earlier using quantitative and qualitative metrics. At this point, iteration may be required to modify or create new alternatives if the goals were not met. Once decision-makers have selected a preferred alternative, they must prepare an implementation plan that includes an investment strategy and projects required to achieve the plan. Based on the situation at specific campuses, the breadth and depth of improvements under different alternatives may differ as a reflection of existing plans and timing for new construction, major and minor renovation of the building stock and utilities, criticality of their missions, and availability of resources. Also, the quality of the data available for development of the Baseline and the Base Case and energy requirements for mission-critical operations at specific installations may also vary. This may result in differences in the realization of the described concept at specific campuses.

2.5 Establishing Framing Goals and Constraints

At the beginning of a study, it is important to clearly define energy-related requirements and long- and short-term energy goals, and important constraints and community priorities. Energy use requirements are typically established by a country, state, local authority, project team, building owner, or other stakeholders. Requirements are "must achieve" for the project design. In contrast, targets (or goals) are often desires (what one would like to achieve) and may or may not lead to requirements. Energy goals that can be used in the comparison of alternatives may include:

- Energy use (site and primary)
- System resilience
- Use of renewables
- Environmental impact, e.g., greenhouse gas emissions
- System economics.

Energy constraints that can be used for system architectures and technology database down-selection may include:

- Connection (or no connection, e.g., in remote or island locations) to outside community, which guides categories of feasible system architectures
- Existing or potential energy supply from outside the community boundaries (which also affects categories of feasible system architectures): power, hot water, steam, chilled water

- Fuel available: gas, coal, fuel oil, biomass, biogas
- Available renewable energy sources: solar thermal, solar photo voltaic (PV), geothermal, sea/river water cooling, geothermal
- Current energy systems on the campus: centralized or decentralized (no distribution lines available)
- Future energy systems that can be considered (centralized or decentralized)
- Operational and personnel constraints, which is a consideration that some operators may not have the skills to operate certain types of systems
- Environmental constraints for using different types of technologies: e.g., water, emissions from CHP, etc.
- Building space constraints, e.g., no mechanical room for decentralized systems, thermal storage, etc.
- Community space constraints, e.g., for seasonal storage, PV, or thermal solar panels array
- Community layout constraints, e.g., for placing central heating or cooling systems pipes.

Table 2-1 lists examples of natural and imposed (manmade) constraints that impact selection of system architecture and technologies. Long-term energy goals can be expressed as the reduction by a desired percentage of site or source energy use against a Baseline by a given year, or the achievement of a Net-Zero site/source energy community within a given timeframe, for example. These goals lead to decision metrics that will be used to decide between alternative solutions. They help to focus the study and define “success.” It is entirely possible that the goals will turn out to be infeasible, in which case the goals can be adjusted once quantitative data are available. The most common energy requirements, goals, and constraints may be categorized as

- Community, building cluster and facility level
- Operational constraints
- Constraints based on natural threats
- Locational resources available: district chilled and hot water, steam, water, electricity grid, natural gas pipeline, liquid fuel
- Energy supply constraints: power supply limitations, gas supply limitations, availability of energy from renewable sources
- Requirements to energy systems resilience.

Table 2-1. Constraints that narrow energy system architecture and technologies options.

Natural Constraints		Imposed Constraints			
Category	Constraint	Category		Constraint	Category
1. Locational threats	Regional or local air quality	3. Energy and Water Distribution and Storage Systems		Natural Gas	5. Indoor Environment
	Low-lying area (flooding)			Electricity	
	Extreme temperatures			Fuel Oil	
	Extreme humidity			Chilled water	
	High winds			Hot water	
	Fire			Steam	
	Lighting			Water	6. Existing equipment in buildings and district systems
	Ground threats (volcano, mud slide, earthquakes)			Energy use (site)	
2. Local resources available	Solar	4. Building related	Energy	Energy use (primary)	
				Energy Efficiency	

Natural Constraints		Imposed Constraints			
Category	Constraint	Category	Constraint	Category	Constraint
	Wind	Environmental	Renewable energy		Humidity control
	Biomass		Emissions		Water heating
	Land or roof area available for renewable energy technologies installation	Operational	Resilience		Food preparation
	Natural gas		Financial/costs		Waste handling
	Electricity from the grid		Maintenance (e.g., simplicity, low cost)		Electricity generation
	Liquid fuels		Workforce limitations		District steam
	Hot water		Other building owner limitations		District hot water
	Chilled water				District chilled water

2.6 Energy System Resilience

The resilience of the energy system impacts the primary functionality of military installations, hospitals, and education campuses during disruptions. Throughout the history of energy systems, major disruptions of energy supply (both electrical and thermal) have degraded critical capabilities and caused significant social and economic impacts to private and public communities. Therefore, resilience must be an integral goal of the community-wide EMP process; and application of energy resilience principles is important during the design of new and the upgrade of existing energy systems. Best practices for resilient electric and thermal energy systems favor the use of installed energy sources rather than the use of emergency generation for short durations. Best practices also promote the use of multiple and diverse sources of energy, with an emphasis on favoring energy resources originating within the community (OUSD 2021).

Electric and thermal energy delivery may be visualized as having three delivery mechanisms or layers (Figure 2-2). The first delivery mechanism resides internally to the facility; it is the building-level power infrastructure for electric energy systems and building envelope and its mechanical systems for thermal energy supply. The second delivery mechanism is the emergency, or backup, energy systems directed to the facility from outside of the building but sourced from local infrastructure power and thermal energy generation. The third delivery mechanism is the full load delivered to the facility under normal operating conditions; this is commonly comprised of prime power or power delivery from an electric utility for electric systems; and steam, hot water, and/or chilled water delivered from the campus, building cluster, or some location outside the campus plant.

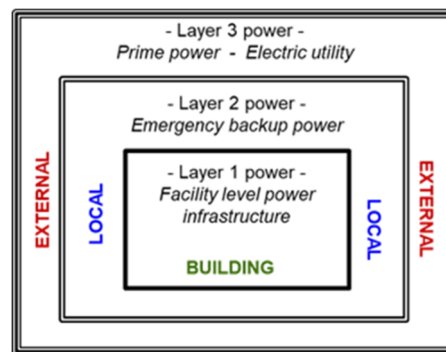


Figure 2-2. Layers of power supply to mission-critical facilities.

Two facility load levels are defined. The full electric and thermal power load is provided by Layer 3 system and serves the entire electrical/thermal load of the facility. The critical electrical load is provided by Layers 1 and 2, also referred to as backup power, and only serves the facility critical infrastructure. The facility critical infrastructure load results from the load shedding of all power connected equipment that is not critical for the continuity of the mission or missions housed in the facility. Layer 1 power for a facility is the electrical backup power that resides inside of the facility. Common components are an uninterruptible power supply (UPS) and an automatic transfer switch (ATS). Layer 1 backup power is the shortest duration of electrical power capacity of the three layers. The power delivery capacity can typically be from several minutes to several hours.

Layer 2 power for a facility is the electrical backup power that resides outside of the facility, but that is, at a minimum, partially dedicated to supplying the facility. Common components are generator sets and renewable energy systems such as solar arrays. Layer 2 backup power is of variable duration. The electrical power delivery capacity can range from several hours to days in duration. The electrical power delivery capacity is limited only by factors such as fuel storage capacity, battery rectifier capacity, etc. The Layer 2 power can also be supplied for an installation-wide or campus microgrid system. In such a case, the facility power is supplied from a microgrid system that also provides power to other facilities that reside at the same location as the facility in question.

Layer 3 for a facility is the electrical power that resides in the infrastructure of the prime power utility. Common components of the utility that serve electrical power to the facility are substations and the medium voltage power distribution system. Layer 3 is supplier of electrical power under normal conditions. Unlike Layers 1 and 2, Layer 3 is not maintained or repaired by the facility. An exception would be when an installation or campus uses distributed power generation in conjunction with connection to the prime power utility; the primary goal is lower cost of the distributed power generation or opportunities to sell energy to the utility grid to achieve a positive cost differential. Failure at Layer 3 requires a reliance on Layers 1 and 2 for continuity of mission operations.

In the case of thermal energy systems, Layer 1 can include the building envelope and the building-level thermal storage, while Layer 2 may include emergency boiler, mobile boiler, or an electric backup thermal system.

A variety of energy system options can be used to supply power, heating, and cooling to campuses; these options vary by the architectures and technologies used, and by whether they apply to individual buildings, building clusters, campuses, or even entire communities. Design and evaluation of these system resilience measures should be based on requirements established by mission operators, which are currently not well understood.

The quantitative approach described here allows for evaluation of both the ability of a system to absorb the impact of a disruption (robustness), and its ability to recover from that disruption.

Critical missions may employ extensive redundancy and protect vital system components to ensure continuity of the mission, even when faced with a significant natural or manmade disaster. For such systems, mission success is very highly probable, but is still a probability. Consequently, the

impact of an event can be considered to impact the probability of mission success. Some critical missions can withstand small disruptions as long as the system can recover quickly. In either case, overall resilience of the system can be quantified as a deviation in mission availability from baseline operations to some degraded system state following a disturbance.

A quantitative approach to resilience of system supplying energy to the building proposed in the Guide can include (but is not limited to) the following metrics:

- Energy System Robustness (ER)
- Energy System Recovery time or Maximum Time to Repair (MaxTTR)
- Energy Availability (EA)
- Energy Quality (EQ).

The first three parameters are critical for the selection of Layers 2 and 3 energy supply system architecture, and for technologies it is comprised of, to satisfy requirements related to energy system resilience. Requirements for Energy Availability and Energy System Recovery Time depend on:

- Criticality of the mission being served by the system,
- System reparability, which has significant dependence on remoteness of the facility hosting the mission, and
- Redundancy of facilities that can serve the same critical function and the Layer 1 energy system capacity.

Energy Quality is another important quantitative metric for the energy system that serves critical functions; energy quality should be considered as a design parameter for internal building (Layer 1) energy systems. Most of the mission-specific energy quality requirements, including limitation on short-term power interruptions, voltage and frequency variations, harmonics, etc. can be managed by the building-level energy systems. Building-level electric systems (nanogrids) generally include redundant or backup components and infrastructure for power supply, uninterruptible power supply, ATSS, data communications connections, and environmental controls (e.g., air-conditioning, fire suppression). Nanogrids also include various security devices that can be designed to provide power with a severe demand on the stability and level of the frequency, voltage, and waveform characteristics of the uninterruptable electrical power to mission-critical equipment, and that can operate in an islanded mode between 15 minutes and several hours. It is important to account for the latter capability when requirements for maximum energy supply downtime are established.

Using the Energy Robustness metric, we can quantify the overall resilience of a system in two phases: absorption of the event, and recovery (Figure 2-3). Immediately after the event, there is a sharp drop in the load available to the mission. For electric energy systems, the duration of phase one is much shorter than for thermal energy systems, unless thermal systems are used for processes using steam or hot water. This change from the Baseline to the degraded state represents the robustness of the system to that particular event. The time required to restore the system to its baseline state is referred to as recovery. The smaller the change in load available to the mission and the shorter the recovery time, the more robust the system.

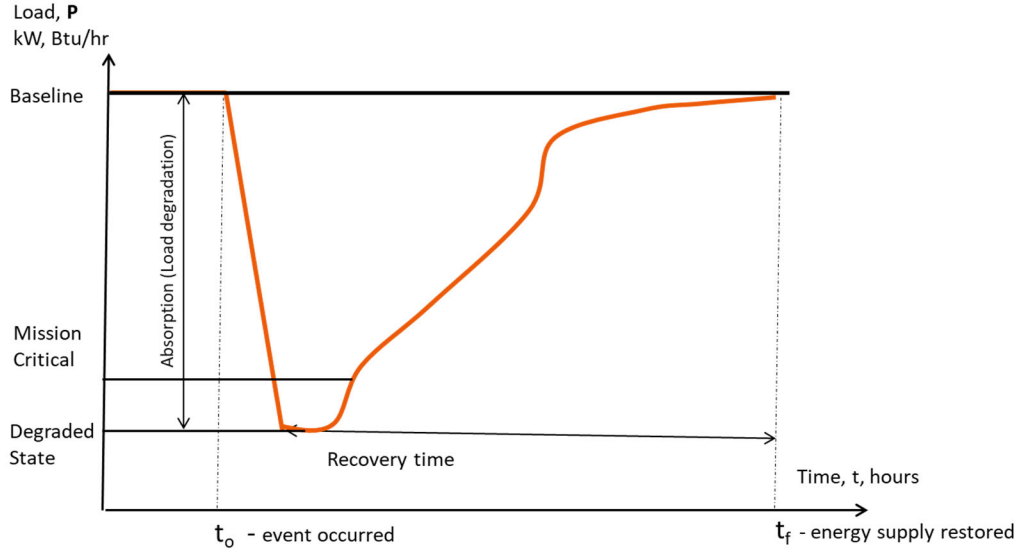


Figure 2-3. System response to a disruptive event.

The robustness, R , of the system to any particular event can be quantified using Equation 2-1 and is illustrated by the area between the line showing the baseline mission availability and the curve representing the actual mission performance over time. The smaller the area between the Baseline and the curve, the more resilient the system. Robustness will be measured on the scale between 0 and 1, where 1 is the most resilient system:

$$ER_{m.c.} = \frac{E_{event}}{E_{m.c.}} \quad (2-1a)$$

$$R_{baseline} = \frac{E_{event}}{E_{baseline}} \quad (2-1b)$$

where

$R_{m.c.}$ and $R_{baseline}$ are system robustness measured against the mission-critical load and the baseline load;

$E_{m.c.}$ and E_{event} are energy supplied to the building during the period of time between t_0 and t_f with the baseline load, mission-critical load and degraded due to even load:

$$E = \int_{t_0}^{t_f} P(t)dt \quad (2-2)$$

Depending on mission needs, it may be more important to prioritize either absorption or recovery.

Energy Availability is a measure of the readiness of a system or component to perform its required function and is usually expressed as a function of equipment downtime as shown in Equation 2-3.

$$EA = \frac{Uptime}{Uptime + Downtime} \quad (2-3)$$

This metric is used to evaluate the performance of the energy in terms of the percentage of time that it is available for the mission. For example, if an event occurs that reduces energy availability to 0.99, then the average expected weekly downtime of the mission is about 100 minutes. If the energy availability of a more resistant system is only reduced to 0.999, the expected weekly downtime for the mission is approximately 10 minutes. This essentially represents a tenfold difference in system performance.

The Guide offers a methodology that will help mission operators to determine requirements to Energy Availability and Recovery based on three factors: mission criticality, facility remoteness/repairability, and redundancy (Table 2-2).

Table 2-2. Determination of resilience requirements.

Resilience Metric Requirement	Resilience Phase	
	Availability	Recovery
Low	Criticality: Low-Mod Remoteness: Low Facility Redundancy: Yes	Criticality: Low Remoteness: Low-Moderate Facility Redundancy: Yes
Moderate	Criticality: Low-Mod Remoteness: Moderate-Significant Facility Redundancy: Yes	Criticality: Low-Mod Remoteness: Moderate Facility Redundancy: Yes
Significant	Criticality: Mod-High Remoteness: Significant-High Facility Redundancy: No	Criticality: Mod-Significant Remoteness: Significant-High Facility Redundancy: No
High	Criticality: Significant-High Remoteness: High Facility Redundancy: No	Criticality: High Remoteness: Significant-High Facility Redundancy: No

The Resilience Requirement listed in Table 2-3 stratifies each Resilience Metric listed in Table 2-2. Each Resilience Metric is split into two levels of facilities: Primary and Secondary, which in turn have two levels of requirements to energy system resilience ranging from Low (0) to High (4). Such stratification of each Resilience Metric creates more accurate scenario fitting to the facility and mission requirement.

The availability of multiple categories will facilitate the ability of design teams to identify the most correct resiliency requirement for the project at hand. The data in Tables 2-3 and 2-4 represent two category states for each of the four Resilience Metric. Expansions of tiers for Resilience Metric Requirements creates improves the process by providing:

- An additional level of granularity that enhances the ability to more accurately select the most appropriate category of resiliency.
- More flexibility for a project to identify the lowest Resilience Metric Requirement level that is appropriate (and to avoid inappropriate overdesign, which increases cost).

- Assistance to a project team to resist the temptation to invent a resilience level not represented in less granular criteria, ensuring that sufficient levels are provided to fit a wide variety of the target project.

Table 2-3. Recommended resilience requirements to power systems serving mission-critical facilities.

Resilience Metric	Facility Level	Resilience Sub-Metric	Category	Degraded State Availability	Acceptable Average Weekly Downtime (Minutes)	Maximum Single Event Downtime (Minutes)
Low	Primary	Low	LP/1	0.92	806.4	2,419
		Moderate	LP/1+	0.95	504	1,500
	Secondary	Low	LS/0	0.9	1008	3,024
		Moderate	LS/0+	0.92	806.4	2,419
Moderate	Primary	Low	MP/2	0.99	100.8	302
		Moderate	MP/2+	0.995	50.4	150
	Secondary	Low	MS/1	0.95	504	1,500
		Moderate	MS/1+	0.99	100.8	302
Significant	Primary	Moderate	SP/3	0.999	10.08	30
		Significant	SP/3+	0.9995	5.04	15
	Secondary	Moderate	MS/2	0.95	504	1,500
		Significant	MS/2+	0.99	100.8	302
High	Primary	Significant	HP/4	0.9999	1.008	3
		High	HP/4+	0.99999	0.1008	0.3
	Secondary	Significant	HS/3	0.9995	5.04	15
		High	HS/3+	0.9999	1.008	3
P = Primary Facility / Mission L = Low Resilience Metric S = Significant Resilience Metric + = Highest 10% of a Specific Resilience Metric Range 0 = Resilience Metric Range – Lowest Resilience Metric Range 1 = Resilience Metric Range – Scaled 0 to 4, with 4 the highest level of resilience metric 2 = Resilience Metric Range – Scaled 0 to 4, with 4 the highest level of resilience metric 3 = Resilience Metric Range – Scaled 0 to 4, with 4 the highest level of resilience metric 4 = Resilience Metric Range – Highest Resilience Metric Range S = Secondary Facility / Mission M = Moderate Resilience Metric H = High Resilience Metric						

For thermal energy systems, the acceptable Maximum Single Event Downtime can be defined in terms of how long the process can be maintained, how long the building remains habitable (habitability threshold), or how long the thermal environment shall be maintained above the sustainability threshold level to protect the building against damage from freezing of water pipes, sewer, or fire suppression system; to protect sensitive content; or to prevent the start of mold growth during extended loss of energy supply with extreme weather events. Results of Temperature Decay Tests along with parametric studies of indoor air temperature decay using EnergyPlus-based building energy modeling presented in the Guide, showed that high building mass contributes significantly to the thermal resilience of the building, as do greater building air tightness and higher thermal insulation (Table 2-4).

Table 2-4. Single event downtime for buildings with different mass, airtightness, and energy efficiency of the building's envelope.

Building Parameters	Temp Outdoor Dry Bulb (ODB)	Mass Building			Frame Building		
		Typical/Post 1980	Low Efficiency	High Efficiency	Typical/Post 1980	Low Efficiency	High Efficiency
Walls R-value, °Fft²hr/Btu ([m²K]/W)		20.5 (3.6)	40 (7.0)	50 (8.8)	20.5 (3.6)	40 (7.0)	50 (8.8)
Roof R-value, °Fft²hr/Btu, ([m²K]/W)		31.5 (5.5)	45 (7.9)	60 (10.6)	31.5 (5.5)	45 (7.9)	60 (10.6)
Air Leakage, cfm/ft2 at 0.3 in. w.g. (L/s.m2 @75Pa)		0.4 (2)	0.25 (1.25)	0.15 (0.75)	0.4 (2)	0.25 (1.25)	0.15 (0.75)
Window (R-value, °F ft²hr/Btu, U value, W/(m²K))		Double Pane; R = 1.78 / U = 0.56	Double Pane; R= 3.34 / U=0.3	Triple Pane; R= 5.25 / U=.19	Double Pane; R = 1.78 / U = 0.56	Double Pane; R= 3.34 / U=0.3	Triple Pane; R= 5.25 / U=0.19
MaxSEDt Hab. (60°F/15.6°C)	-60 °F -51.1 °C	< 1 hours	2 hours	5 hours	<< 1 hour	1 hours	2 hours
MaxSEDt Sust. (40°F/4.4°C)		9 hours	28 hours	41 hours	4 hours	14 hours	21 hours
MaxSEDt Hab. (60°F/15.6°C)	-40 °F -40 °C	1 hours	3 hours	10 hours	< 1 hour	2 hours	4 hours
MaxSEDt Sust. (40°F/4.4°C)		20 hours	36 hours	51 hours	10 hours	18 hours	24 hours
MaxSEDt Hab. (60°F/15.6°C)	-20 °F -28.9 °C	2 hours	6 hours	15 hours	1 hour	3 hours	6 hours
MaxSEDt Sust. (40°F/4.4°C)		31 hours	46 hours	60 hours	15 hours	22 hours	28 hours
MaxSEDt Hab. (60°F/15.6°C)	0 °F -17.8°C	3 hours	13 hours	29 hours	2 hours	5 hours	9 hours
MaxSEDt Sust. (40°F/4.4°C)		43 hours	59 hours	90 hours	21 hours	28 hours	33 hours
MaxSEDt Hab. (60°F/15.6°C)	20 °F -6.7°C	10 hours	28 hours	45 hours	3 hours	8 hours	15 hours
MaxSEDt Sust. (40°F/4.4°C)		60 hours	78 hours	95 hours	28 hours	35 hours	40 hours
MaxSEDt Hab. (60°F/15.6°C)	40 °F 4.4°C	29 hours	54 hours	72 hours	8 hours	17 hours	23 hours
MaxSEDt Sust. (40°F/4.4°C)		93 hours	112 hours	123 hours	41 hours	47 hours	50 hours

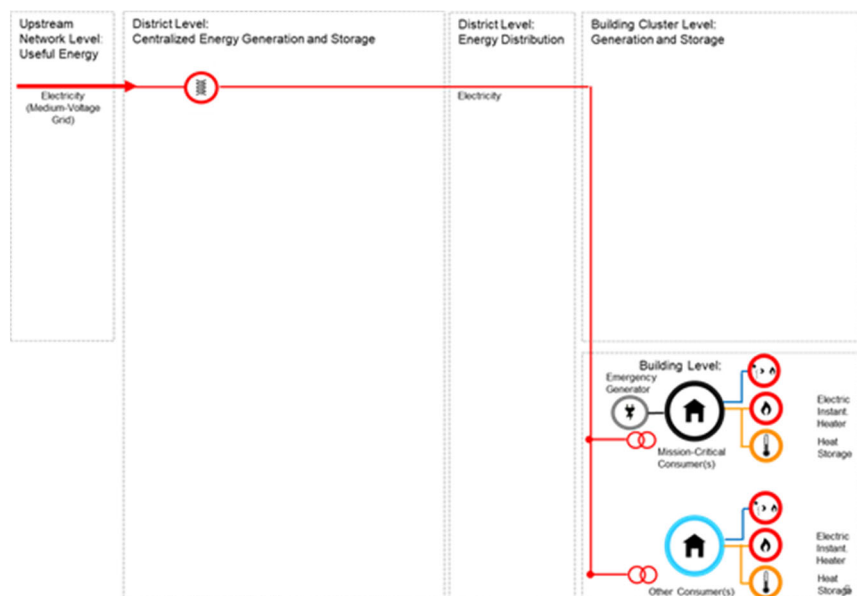
2.7 Selection of Energy System Architecture and Technologies

Selection of energy systems' architectures and types of technologies employed is important for detailed evaluation of the EMP baseline and of different alternatives, including the Base Case and more advanced concepts to be used in new development ("greenfield") and/or renovation/extension ("brownfield") projects. Different system options can be considered on the building level, building cluster level, or community level. Selection of these alternatives should consider the existing status

of these systems, and the goals and objectives of the project, including improvement in systems resilience, local constraints, and economic and non-economic co-benefits.

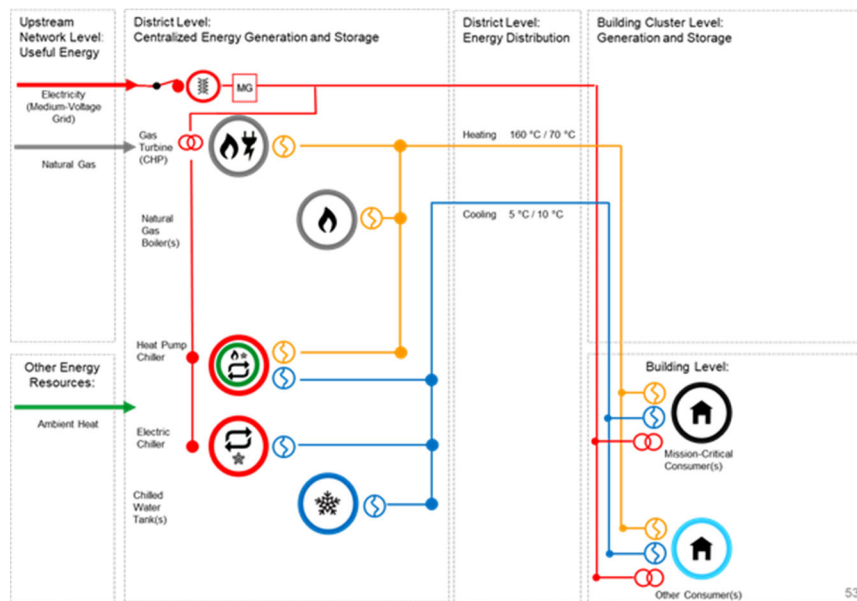
The architecture and technologies used in a specific system may include components from several system generations to accommodate the end user needs, whether those components include new development (greenfield) projects, expansion of an existing system, or modernization and renewal of an aging system. For example, some critical hospital buildings and pharmaceutical facilities may need to provide steam to accommodate certain end users, while most other end users may be sufficiently served by hot water service.

The Guide offers a library of more than 50 examples for energy system architectures generated based on experience gained from case studies and the Annex 73 team expertise, which cover centralized and decentralized, fossil-fuel-based, and renewable systems (see Figure 2-4 for examples). The library includes general solutions as well as solutions for special situations like remote locations/islands or solutions with electrical enhancements and microgrids to allow islanding power systems from the main electric network. The library offers energy system designs for different climate zones or fuels, for densely populated communities and small, remote communities, and for communities with or without critical buildings. To assist the EMP process, a library of system architecture templates includes a description of the application, and advantages and disadvantages for each template.

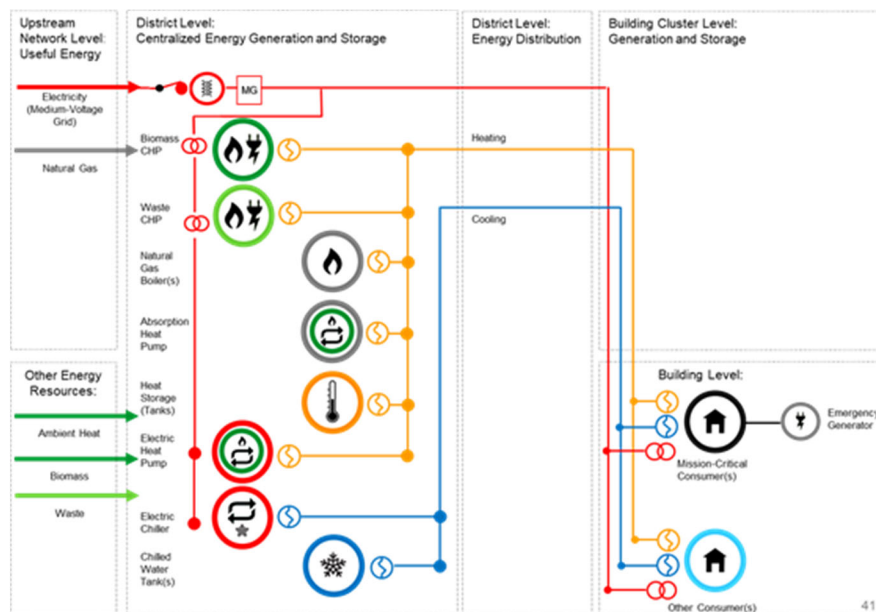


a. Generic power-only system with buildings heating and cooling using electric boilers and chillers.

Figure 2-4. Examples of energy systems architectures.

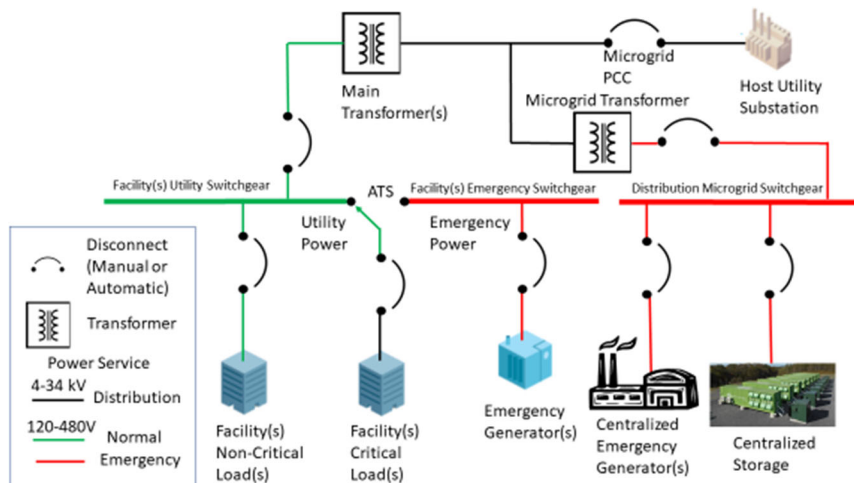


b. District heating, cooling and power systems (Case Study from UT Austin Medical Center).



c. Generic power, heating and cooling systems with CHP base-load generation seasonal storage, waste heat use, etc.

Figure 2-4. (Cont'd).



d. Notional microgrid with distribution-level centralized emergency generators and distribution-level centralized storage.

Figure 2-4. (Cont'd).

Technologies for each system architecture can be selected from a technology database that includes information on technical, economic, and reliability characteristics of different technology archetypes, along with a short technology description and application. Selection of technologies can be narrowed down by applying constraints related to the availability of different fuels and space for installation-specific technologies and plants.

The technologies database was developed based on the information available from various sources. These included the NZP/System Master Planning (SMPL) tool, MIT LL Energy Resilience Analysis (ERA) tool, REOpt tool, U.S. Department of Energy CHP factsheets, Danish Energy Agency Technology Catalogue and information provided by International District Energy Association (Danish Energy Agency 2019, 2020), EATON, Schneider Electric, TKDA, and GEF. The technology reliability data was provided by the U.S. Army Corps of Engineers Power Reliability Enhancement Program (PREP). The database is comprised of multiple energy conversion, distribution, and storage technologies that can be integrated by energy planners into energy system architectures.

The MS Word[®] version of the database with fixed values of technology characteristics presented in this Guide is complemented by an Excel[®] version that is integrated into the EMP tool. The Excel[®] database can be updated and adjusted based on specific fuel prices, currency, and national characteristics; it also includes text boxes and attachments for guidance. The MS Word[®] version is limited to fixed 2020 values regarding economic assumptions and does not include automatic calculations, e.g., the levelized cost of electricity (LCOE) calculation.

The database is structured (Figure 2-5) to include the following categories:

- • Electric systems
- • Heat supply systems
- • Chilled water systems
- • Natural gas systems
- • Miscellaneous.

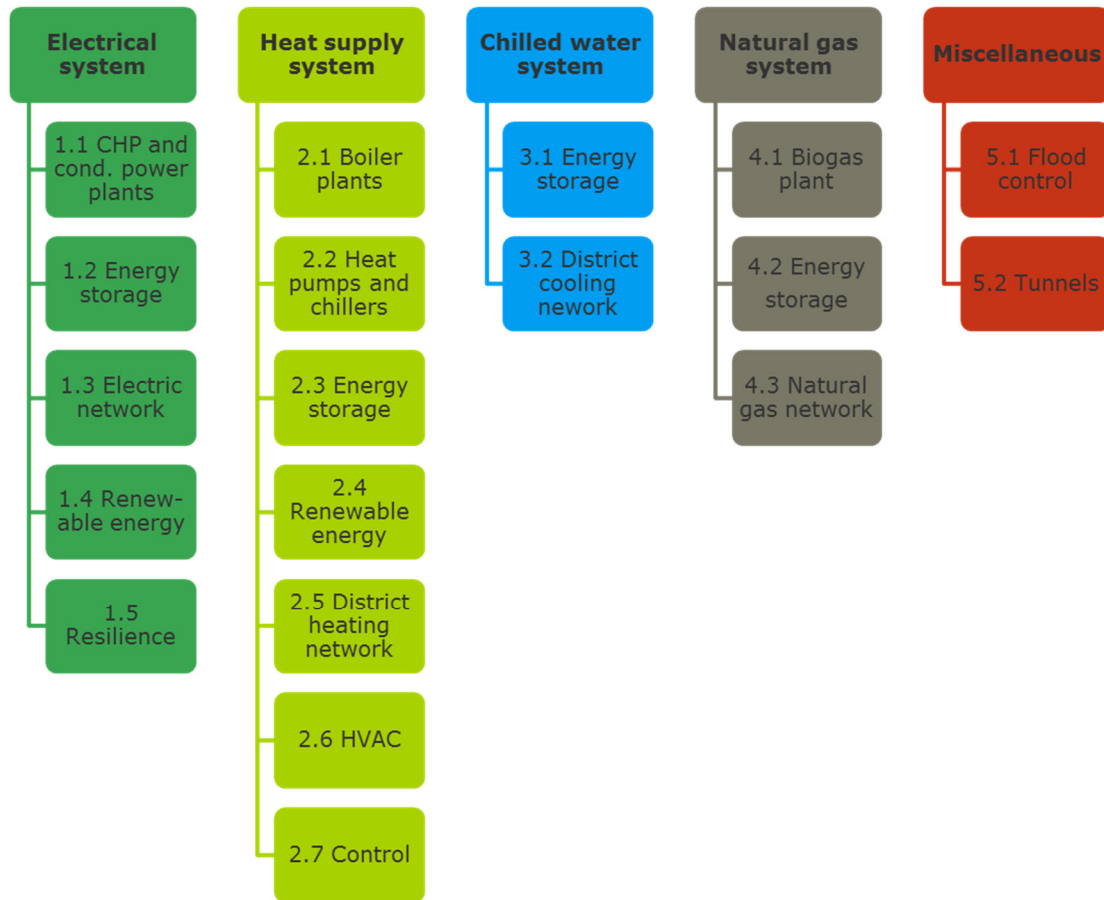


Figure 2-5. Database structure.

2.8 Energy Resilience of Interacting Networks (ERIN) Tool

2.8.1 General description

The ERIN tool was developed to support the EMP process that allows for the assessment of the resilience of energy supply systems to various Design Basis Threats. The tool simulates energy flows through a district energy system composed of an interacting network of components. Key features are that the tool:

- accounts for both reliability (failure and repair) and resilience to various scenarios (design basis threats)
- models topology and interaction between an open-ended number of energy networks
- provides key energy usage, resilience, and reliability metrics for the modeler/planner.

Figure 2-6 shows the information flow and process for using the calculation tool. The goal of the process is to help planners select appropriate architectures, configure them for their local situation, and assess them for their costs, energy usage, and resilience benefits versus relevant Design Basis Threats. This allows them to compare multiple architectures or different configurations of the same architecture (using different types or grades of equipment, for example).

The process begins with the user's description of goals, site constraints, and available resources shown in Figure 2-6. These criteria can be used to help the user select (filter out irrelevant choices and/or recommend especially relevant choices) and evaluate (tracking status of a design versus goals and/or constraints) architectures.

Next, the planner can proceed to architecture selection from a database of architectures. This selection can be guided based on site criteria. For example, if users specify that they have electrical and heating loads only (i.e., no cooling load), only those architectures with heating and electrical supply will be made available for browsing. An architecture is a pre-constructed template for how certain types of technologies are typically connected together. The architecture, once selected, must also be configured to match the user's unique situation. Configuration involves adjusting the selected architecture to better represent the desired situation by choosing specific equipment, specifying multiples, etc. Potential component technologies that fit with the architecture are looked up in a database of technologies. This results in the creation of an input file to be used by the resilience tool "engine."

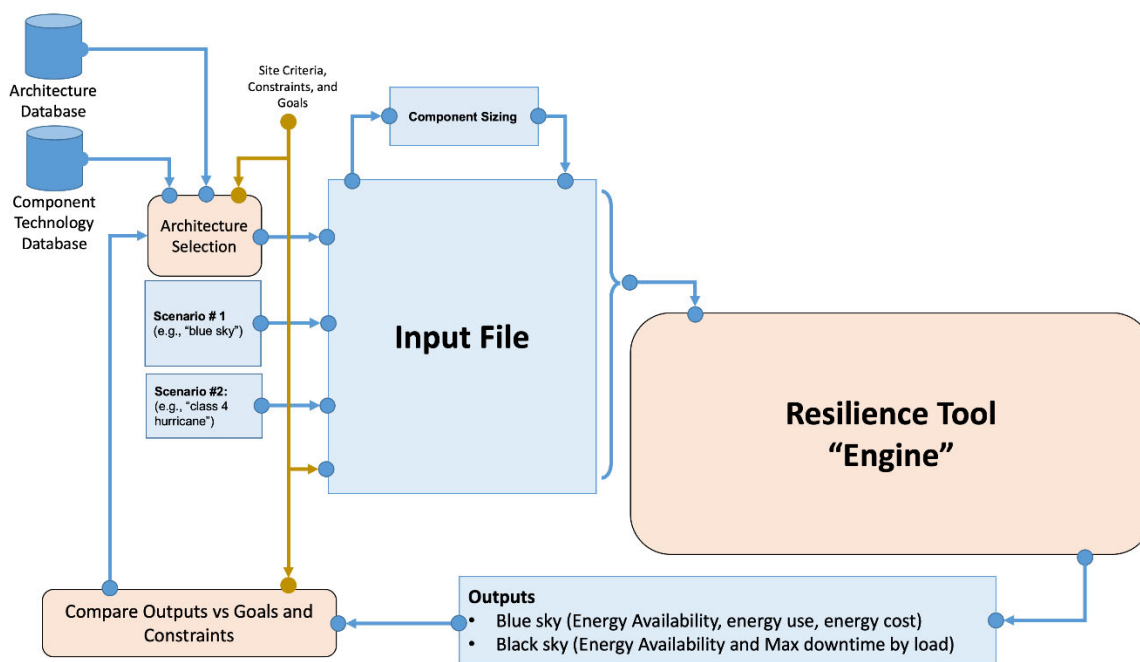


Figure 2-6. Overall energy and resilience assessment process.

Additional data needs include building load profiles for blue-sky and black-sky scenarios, along with the scenario descriptions themselves. Blue sky and black sky are categories of scenarios. A blue-sky scenario represents normal operating assumptions. In contrast, a black-sky scenario involves consideration of Design Basis Threats. Load profiles represent the loads on the network over time for electrical, heating, and/or cooling needs. Load profiles correspond to a given building load or cluster of buildings under a given scenario.

Scenarios have an occurrence distribution, a duration, an optional maximum number of occurrences during the simulation, and, optionally, various Design Basis Threats intensities. Design Basis Threats intensities specify things like the wind speed during a hurricane, the inundation depth during a flood, and the Richter scale during an earthquake. A scenario can also

specify whether normal reliability (failure and repair under typical conditions) should (or should not) be considered. Probability of occurrence can be based on actual data for an event.

A component technology database stores information about actual components that can be used by the tool. Components represent equipment on the network: chillers, boilers, backup generators, UPS systems, TES tanks, fuel drums, etc. If the user has specific information about a given component, they can specify it. Otherwise, the information can be queried from the component technology database.

Once the architecture selection, configuration, and any sizing have been conducted, an input file can be written for the resilience tool “engine.” The input file is parsed by the resilience tool “engine” and a simulation is initiated.

A model may be built using the ERIN tool in two ways. The first method involves manual construction of an input file in which the user creates an input file using the TOML format. The TOML file is split up into different sections: buildings and their load files, simulation details, components, energy sources, the fuel system, distributions, failure modes, networks, and scenarios. Although manual creation of an ERIN input file is simple enough for very small networks (Figures 2-7 and 2-8), it quickly becomes infeasible when working with hundreds of buildings and complex networks. Case Study 1 (section 3.1) demonstrated this version of the tool.

```
[simulation_info]
rate_unit = "kW"
quantity_unit = "kJ"
time_unit = "years"
max_time = 100

[streams.electricity]
type = "electricity"
[streams.steam]
type = "steam"
[streams.natural_gas]
type = "natural_gas"
[streams.biomethane]
type = "biomethane"

[loads.normal_electric_mission_critical_consumer]
csv_file = "ex07-normal-electric-mcc.csv"
[loads.normal_electric_other_consumer]
csv_file = "ex07-normal-electric-oc.csv"
[loads.normal_steam_mission_critical_consumer]
csv_file = "ex07-normal-steam-mcc.csv"
[loads.normal_steam_other_consumer]
csv_file = "ex07-normal-steam-oc.csv"
[loads.normal_heating_mission_critical_consumer]
csv_file = "ex07-normal-heating-mcc.csv"
[loads.normal_heating_other_consumer]
csv_file = "ex07-normal-heating-oc.csv"
[loads.emergency_electric_mission_critical_consumer]
csv_file = "ex07-emergency-electric-mcc.csv"
[loads.emergency_electric_other_consumer]
csv_file = "ex07-emergency-electric-oc.csv"

[fragility.somewhat_vulnerable_to_flooding]
vulnerable_to = "inundation_depth_ft"
type = "linear"
lower_bound = 6.0
upper_bound = 14.0
[fragility.highly_vulnerable_to_flooding]
vulnerable_to = "inundation_depth_ft"
type = "linear"
lower_bound = 2.0
upper_bound = 6.0
[fragility.highly_vulnerable_to_wind]
vulnerable_to = "wind_speed_mph"
type = "linear"
lower_bound = 80.0
upper_bound = 180.0

[components.electric_utility]
type = "source"
outflow = "electricity"
[fragilities] = ["highly_vulnerable_to_wind", "highly_vulnerable_to_flooding"]
[components.natural_gas_utility]
type = "source"
outflow = "natural_gas"
[fragilities] = ["somewhat_vulnerable_to_flooding"]
[components.biomethane_source]
type = "source"
outflow = "natural_gas"
[fragilities] = ["somewhat_vulnerable_to_flooding"]
[components.biomass_source]
type = "source"
outflow = "biomass"
[fragilities] = ["highly_vulnerable_to_flooding"]
[components.chp_inputs]
type = "mixer"
stream = "natural_gas"
sum_inflows = 2
sum_outflows = 1
inflow_dispatch_strategy = "in_order"
outflow_dispatch_strategy = "in_order"
[fragilities] = ["somewhat_vulnerable_to_flooding"]

[networks.nw_1]
connections = [
# Natural Gas and Biomethane Network
["natural_gas_utility", "outflow", "0", "natural_gas_manifold", "inflow", "0"],
["biomethane_source", "outflow", "0", "chp_inputs", "inflow", "0"],
["natural_gas_manifold", "outflow", "0", "chp_inputs", "inflow", "1"],
["chp_inputs", "outflow", "0", "chp_electricity", "inflow", "0"],
["natural_gas_manifold", "outflow", "1", "natural_gas_boiler", "inflow", "0"],
# Biomass Network
["biomass_source", "outflow", "0", "biomass_boiler_steam", "inflow", "0"],
]

[scenarios.category_4_hurricane]
time_unit = "hours"
occurrence_distribution = {type = "fixed", time_unit="years", value = 30}
duration = 336
max_occurrences = -1
network = "nw_1"
intensity.wind_speed_mph = 156
intensity.inundation_depth_ft = 8
```

Figure 2-7. An example of a TOML file that the ERIN tool uses as an input in a standalone application.

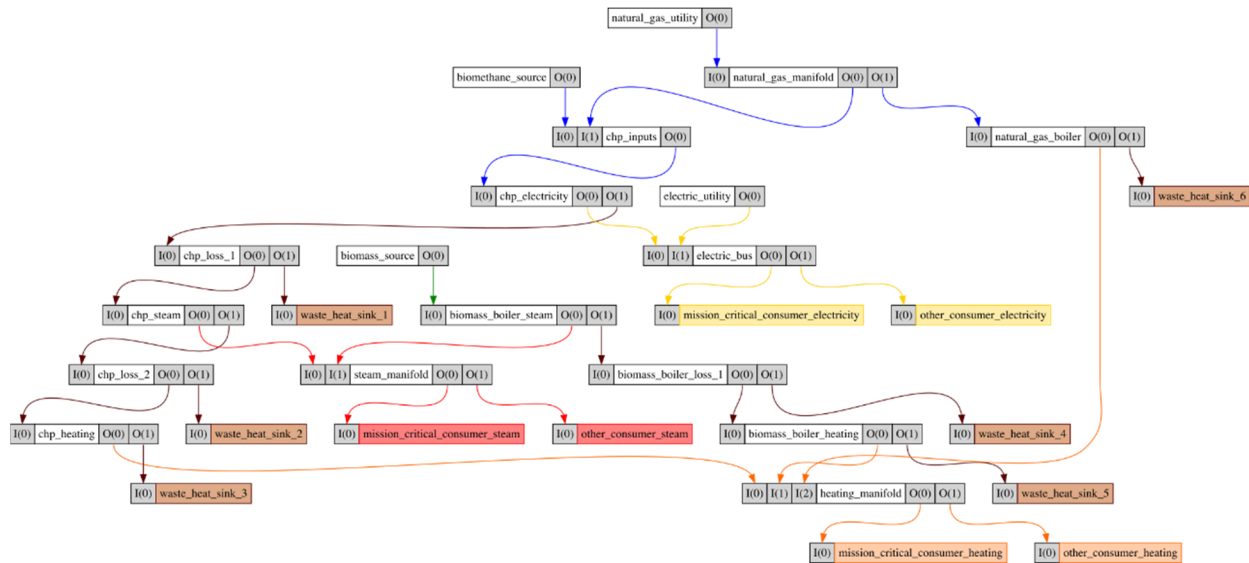


Figure 2-8. The Energy Resilience Simulation Tool can generate customized maps of interconnection points.

The second method involves creating the model via the SMPL user interface. This interface simplifies the process by creating a user-friendly workflow for the construction of the TOML file. The TOML file creation is hidden from the user, as are most of the inner workings of ERIN. This increases the usability of the program, as building the TOML file requires specialized expertise and can be both tedious and error prone. The user interface (UI) first prompts the user to create a model, initialize a Blue Sky Scenario, and create a network. Blue Sky Scenarios are used as a Baseline for comparison with other scenarios; they allow the user to perform an initial assessment of whether the goal requirement metrics are achieved. The UI enables the user to place model components (electrical and thermal loads, equipment, and sources, defined below) on a map. The user then connects the components in interacting networks of energy streams, from source, through equipment, to loads. For example, coal flows through a transportation network to a coal pile, where it is then converted to steam. The steam network flows to turbine generators, where it is converted to electricity and distributed through an electrical network. The steam also flows to building loads through a steam network and is then used to provide heat to buildings. The user may also define failure modes representing a stochastic model of reliability and fragility modes that represent components' vulnerability to natural and manmade events. SMPL creates an ERIN input file, runs the simulations, then extracts and displays results. Results include metrics such as MaxSED, energy availability (EA), and energy robustness (ER), all described in more detail below. This version of the tool is demonstrated in Case Study 2 (section 0).

2.8.2 Model elements

As described above, components are classified as sources, equipment, and loads. Once all components are created, they can be connected to form a network, and assigned scenarios, failure modes, and fragilities. Network connections associate the output of one or more components with the input of one or more other components. Connections represent the flow of an energy

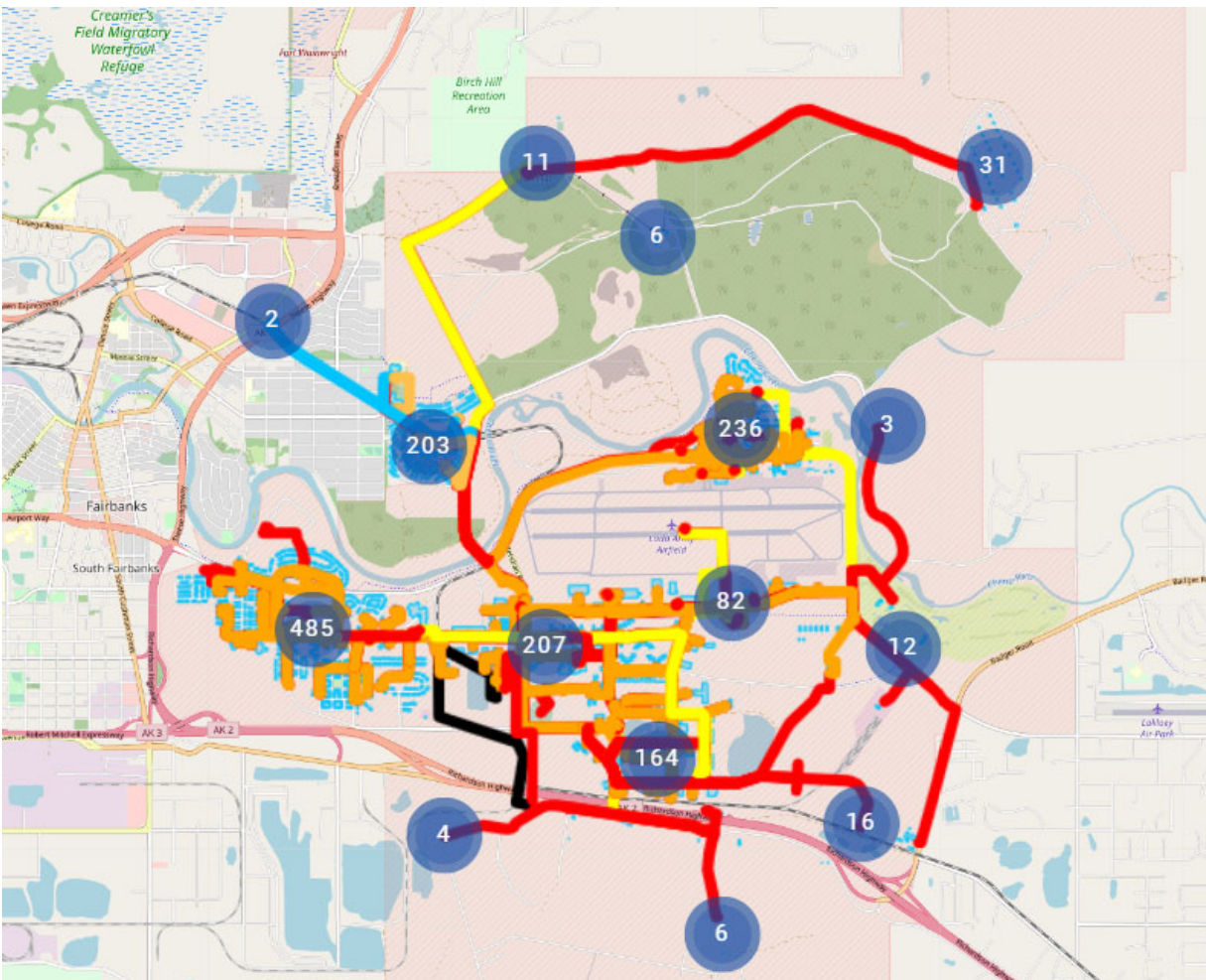
“stream,” which is a generalization of a specific flow of energy (e.g., electricity, steam, hot water, natural gas, etc.). Some short definitions of each element follow:

- *Source*: The origin of an energy stream, such as a coal mine, electric utility, natural gas utility, or fuel depot. Sources also represent renewable resources, such as wind and solar energy.
- *Equipment*: The equipment element can be further broken down into the subtypes of *pass-through*, *converter*, and “*muxer*.”
 - *Pass-through*: This allows a stream to flow through without making changes to it. It has one inlet and one outlet. Used for assigning capacities to an energy stream
 - *Converter*: Changes the stream from one type to another. An example would be a boiler, which converts a stream of coal into steam
 - “*Muxer*”: Used for splitting or combining streams. Has multiple inlets and outlets depending on the desired output
- *Loads*: A representation of the energy a facility or group of facilities requests from the network. Loads may be defined by EnergyPlus™ simulations run in SMPL and then imported into ERIN.
- *Scenario*: An instance of the model for a particular set of circumstances where fragilities are assigned. The user sets parameters for duration, probability of occurrence, and intensities (e.g., maximum wind speed).
- *Failure Modes*: Used to represent the reliability of a component. They consist of a failure distribution and a repair distribution (discussed in more detail in a later section).
- *Fragilities*: Used to establish vulnerability to a specific event outside of usual wear on a component. When exceeded, a component can no longer withstand the event and will fail.

After basic components are defined, energy flows can be drawn in by hand through the UI. Each flow is color-coded to allow for a clear distinction between the flows that form an energy network. Figure 2-9 shows an example of what these networks look like within the UI, in which:

- Red lines represent electric flow.
- Black lines represent coal flow.
- Orange lines represent steam flow.
- Yellow lines represent diesel flow.
- Blue pins represent sources, loads, and equipment.

Within a single model, it is possible to either use the throughput of the same network or to assign different networks by scenario. For example, a scenario that models an emergency might switch to a secondary network that supplies only a select few buildings. While only one network was used in the Fort Wainwrights model, this proves a useful feature for future investigation.



Note: Circles containing a number represent a group of loads to be broken out when “zoomed in” on.

Figure 2-9. An example set of networks within ERIN.

2.8.3 Defining and assigning reliabilities

Reliabilities were developed for pieces of equipment by assigning a “Failure Distribution” and a “Repair Distribution.” These distributions represent a Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) for model components. Various types of distributions were used including:

- *Weibull* – A type of continuous probability distribution
- *Fixed* – A fixed value, which will always return the same number
- *Normal* – A symmetric probability distribution around a mean value (e.g., Bell curve).

Weibull distributions were developed for failure distributions to predict when each piece of equipment might fail due to normal wear and tear. Equipment age had to be accounted for while developing Weibull distributions for reliabilities. Without setting an appropriate offset, all equipment is assumed to be starting from an age of zero and is likely to experience failures at the same time as similar equipment. Consider the arbitrary example failure distribution shown in Figure 2-10.

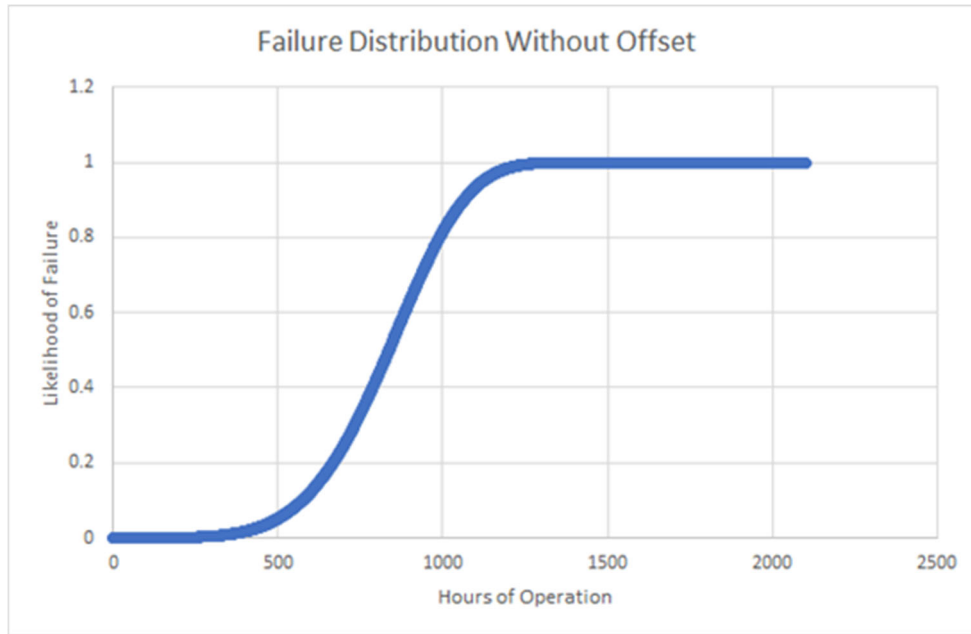


Figure 2-10. Failure distribution without offset.

Because all equipment of the same type uses the same MTBF to determine the scale of the failure distribution, they all reach a near-certain probability of failure in this example around 1200 hours of operation. However, if we now consider a piece of equipment at the same time that began operating 500 hours sooner, we see that it will now reach a near-certain probability of failure at around 700 hours from the time of simulation initiation because its age has been considered (Figure 2-11). This provides a more accurate picture of expected equipment failure.

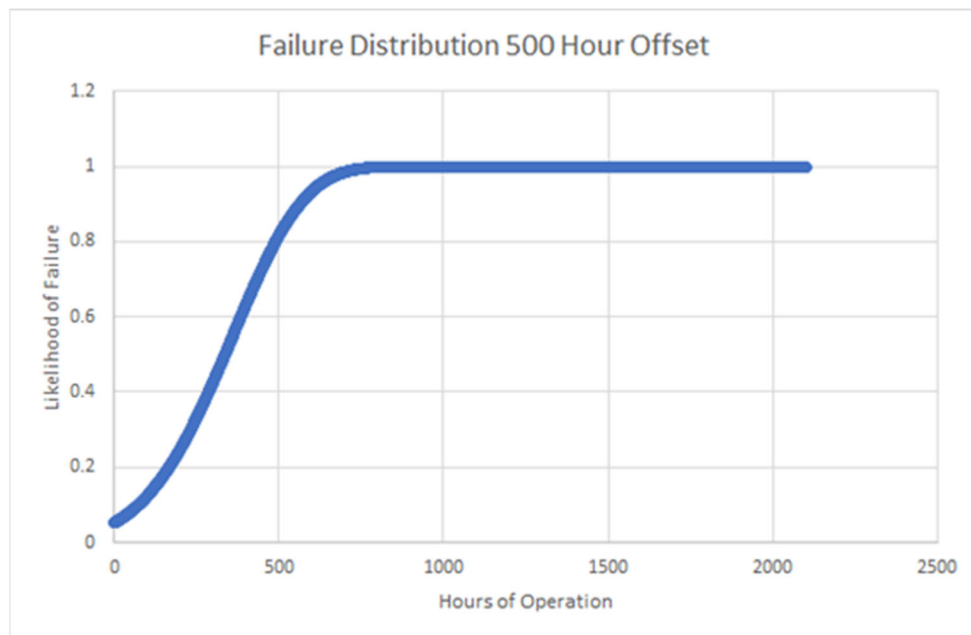


Figure 2-11. Failure distribution 500-hour offset.

The logged lifetime hours of equipment were used as a starting point to determine offset. MTBF was determined using U.S. Army Technical Manual (TM) 5-698-1, *Reliability/Availability Of Electrical And Mechanical Systems For Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) Facilities* (HQDA 2007) as reference.

When Weibull distributions were not appropriate, normal or fixed distributions were used for both reliabilities and repair distributions. For a fixed distribution, equipment was always repaired at the same interval. That is, if the distribution was set to 48, the repair always occurred after 48 hours. For the normal distribution, repairs or failure often occurred around the mean, with a standard deviation set for a variance on either side of the mean.

2.8.4 Threats

When analyzing resilience, one must understand the specific threats that require increased resilience. At a base level, three types of threats exist: natural; unintentional and technological; and manmade threats. Those threats most applicable to a particular site will vary based on environment, mission, etc. Design basis threats, which can be singular or multiple compound threats, therefore provide the most useful data when resilience modeling.

To avoid running many threat scenarios, it is helpful to consider the effect of each threat on the thermal and electric distribution systems. Such threats as a wildfire may disrupt the connection to the grid and leave the installation with only onsite generation capabilities. However, the same effect may be caused by earthquakes, floods, or any number of threats. Thus, it may be unnecessary to model each threat individually since all modeled threats create a similar response. Table 2-5 lists various example threats categorized by their effects on installation operations.

Table 2-5. Threats by operations outcome.

Off-Base Power Loss	On Base Power Loss	Steam Loss	Transportation Disruption
• Earthquake • Wildfire • Flood	• Earthquake • Wildfire • Cyber-Attack	• Earthquake • Wildfire • Cyber-Attack	• Earthquake • Wildfire • Flood • Fuel shortage

2.8.5 Creating scenarios and fragilities

The categories presented as examples in Table 2-5 (column headings) serve as the basis for the scenarios used during the study. While this manner of threat modeling simplifies the process, it is important to not discount individual threats entirely. Especially unique threats may require unique repair and failure distributions or fragilities that warrant a unique modeled scenario.

As mentioned, when creating scenarios, the user must assign the duration, probability of occurrence, and intensities. The probability of occurrence is governed by the occurrence distribution. In the example scenario created in the standalone application (Figure 2-12) and in the integrated application (Figure 2-13), this is set to “immediately” so the event will occur at the beginning of the simulation. The user may also choose to not have reliabilities calculated for every scenario. The example shown in Figure 2-13 has the reliability option toggled “on,” so that normal equipment failure may still occur during the scenario. Finally, the user must define the

intensity of the scenario. This may include how fast wind blows during a storm or how high-water levels rise during a flood. For the scenario described in Figures 2-12 and 2-13, which models a cyber-attack, the intensity is set as “cyber_attack_sophistication.”

```
# Scenarios
[scenarios.blue_sky]
id = 1
time_unit = "hours"
occurrence_distribution = "immediately"
duration = 8760
max_occurrences = 1
calculate_reliability = true
network = "normal_operations"

[scenarios.cyber_attack]
id = 2
time_unit = "hours"
occurrence_distribution = "immediately"
duration = 300
max_occurrences = 1
calculate_reliability = true
network = "normal_operations"
intensity.cyber_attack_sophistication = 70.0
```

Figure 2-12. Defining a scenario for ERIN as a standalone application.

Edit Scenario

Name	Model
Cyber Attack	CHP Model
Occurrence Distribution	Network
Immediately	Normal Operations
Time Unit	Duration
hours	300
Max Occurrences	Calculate Reliability
1	☒
Description	
Intensities	
☒ Cyber Attack Sophistication	70

Figure 2-13. Creating a scenario in ERIN user interface.

Once these parameters are set, fragilities must be established by setting repair distribution, vulnerability, and upper and lower bounds. Intensities of scenarios can then be compared to these upper and lower bounds to determine the chance that a particular piece of equipment will fail.

In the example shown in Figures 2-14 and 2-15, a cyber-attack with a sophistication of less than 50 would not be enough to cause a disruption. Any attack with a sophistication between 50 and 65 will have an increased probability of causing failure as the sophistication increases. The previously defined cyber-attack has a sophistication of 70. Sophistication is based on an arbitrary scale based on the best estimate of cybersecurity subject matter experts. Because this exceeds the upper bound of the fragility, any pieces of equipment assigned this fragility have a certain chance of failure.

```
# Fragility Modes
[fragility_mode.cyber_attack]
id = 1
fragility_curve = "cyber_attack"
repair_dist = "cyber_repair"

# Fragility Curves
[fragility_curve.cyber_attack]
id = 1
vulnerable_to = "cyber_attack_sophistication"
type = "linear"
lower_bound = 50.0
upper_bound = 65.0
```

Figure 2-14. Defining a fragility for ERIN as a standalone application

Name	Model
Cyber Attack	CHP Model
Repair Distribution	Vulnerable To
Cyber Repair	Cyber Attack Sophistication
Lower Bound	Upper Bound
50	65
Description	

CANCEL UPDATE

Figure 2-15. Creating a fragility mode ERIN user interface.

2.9 Multicriteria Analysis of Alternatives and Scenario Selection

Analysis of the Base Case and alternatives produces quantitative results that allow a determination of how close the users were able to come to achieving their goals and objectives, and a comparison of the Baseline, Base Case, and alternatives using defined criteria. There may be additional conflicting qualitative and quantitative criteria (e.g., risk, safety, comfort, fuel availability, etc.) that can support decisions in defining the roadmap to achieving ultimate framing goals.

The decision criteria are not usually equally important. To support the installation's decision process, users must elicit relative weights for the different criteria from decision-makers. This is not always an easy process, but it does encourage decision-makers to carefully consider how they make their decisions.

Multicriteria Decision Analysis (MCDA) can be used to create weighted decision models and support traceable decision processes that integrate quantitative and qualitative factors. MCDA allows for the selection of a reduced set of good, non-dominating alternatives to be presented to decision-makers for final selection.

2.10 Implementation of Energy Master Plan

The scope of the EMP can be broad. It may include new construction, demolition, and consolidation projects; energy supply; and energy distribution and energy storage components, including creative methods to build innovative site-to-grid arrangements that may provide grid stability or site resilience (Figure 2-16). An EMP is not limited to energy-related projects; it may include a spectrum of non-energy-related projects, including new building construction and demolition, and utility modernization projects and non-energy-related measures to enhance the resilience of energy systems to Design-Based Threats, such as the elevation of energy equipment, construction of flood walls, or burying of cables.

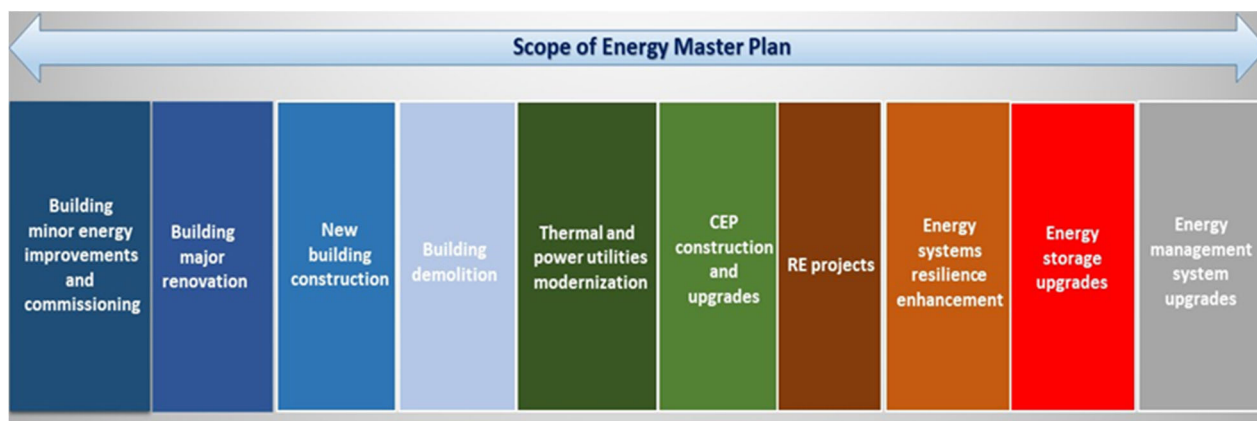


Figure 2-16. Scope of the Energy Master Plan.

In most cases, an EMP covers multiple interrelated projects (Figure 2-17) where the outcome of one project or a group of projects influences one or more other projects (e.g., building efficiency improvements impact the size of required energy generation capacity; thermal energy supply to a new building requires installation of a pipe connection to existing district system; connection of additional buildings to a hot water district system allows for an increase of CHP base load). Therefore, selection of alternatives for an EMP shall be based on the cost effectiveness of the entire EMP instead of on the cost effectiveness of individual projects that comprise the EMP. It is possible that some individual projects will not be cost effective when considered separately.

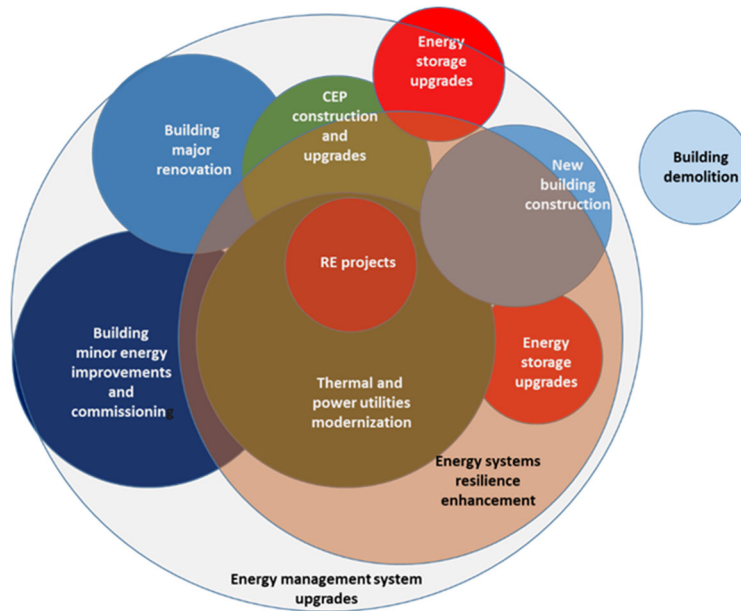


Figure 2-17. Interrelation of projects under EMP.

2.10.1 Life cycle cost analysis (LCCA)

One of the EMP alternatives, the Base Case, serves as a benchmark for LCCA of other alternatives. These alternatives might have different initial investment costs as well as different overall future cost savings, which could result in achieving better performance (e.g., greater energy use reduction, better environmental quality, and/or higher resilience of energy systems). LCCs typically include the following two cost categories: investment-related costs and capital expenditures (CAPEX) and operating expenditures (OPEX).

Investment costs describe total expenses of the investment into (1) buildings and (2) energy supply and distribution systems. These costs include the planning, modeling, design, and implementation of new materials; and the replacement and disposal costs of replaced materials, including both material and labor costs. The number and timing of capital replacements or future investments depend on the estimated life of a system and length of the service period. Sources for cost estimates for initial investments can be used to obtain estimates of replacement costs and expected service lives. A good starting point for estimating future replacement costs is to use initial investment costs along with price escalation factors related to comparable building construction and energy supply investment cost indices.

2.10.1.1 Synergetic impacts

The determination of the investment costs must consider synergetic impacts that can be obtained from a holistic EMP approach. For example, one approach could be to combine demand reduction on building and energy supply level measures, which would in turn allow supply to be reduced as a result of the reduction in demand on the building level. Another approach could be to organize piping and cable configurations for thermal and electrical grids located in infrastructure trenches to reduce trenching costs, which, depending on underground conditions, can comprise over 50% of the total grid costs.

While a standard building LCCA broadly considers many operational costs, most cost-effectiveness calculations either on the building or the community level consider only energy cost benefits. However, ambitious energy investments often produce benefits beyond reduced energy consumption and peak demand shaving. Many of these additional benefits contribute to the objectives of organizations that implemented the projects and can have significant added value for those making investment decisions. Prior research (Lohse and Zhivov 2019, Zhivov 2020) has investigated such benefits as the impact of increased thermal comfort on the productivity of the building occupants, or the willingness to pay increased sales prices or rental rates for higher-performing buildings. Nevertheless, the monetization of non-energy benefits (“co-benefits”) is still not broadly used on the building or building cluster level.

2.10.1.2 How to calculate risk and resilience costs and benefits

A long-duration power interruption and loss of thermal energy, especially in extreme climates, may significantly degrade regional and even national security (e.g., due to the loss of critical infrastructures or degrade critical missions at military bases). It can also affect the health and safety of a community and even result in a loss of human life (Viscusi and Aldy 2003).

While the cost of a given resilience measure is well understood (e.g., the costs of labor and materials to locate power lines underground), the resulting benefits are more difficult to assess, particularly because of a lack of supporting data (LaCommare et al. 2017). Although resilience has been acknowledged as a distinct benefit, it has not typically been quantified or valued.

National Renewable Energy Laboratory (NREL) authors Murphy et al. (2020) argue that the types of data that would support the benefits associated with resilience measures are difficult to collect because of the time and types of events needed to demonstrate the value of resilience investments (e.g., 100-year flood events happen so infrequently that the benefits of mitigation measures associated with those events are difficult to quantify in a realistic time frame). Moreover, even if the health, safety, and economic impacts of a threat could be quantified, it is very challenging to translate those impacts into financial consequences that will ultimately indicate to a given stakeholder whether a change in investment or operations is warranted.

This Guide (Annex 73 2021b) describes LCCA approaches to compare systems with different levels of energy systems’ resilience when benefits of resilience can and cannot be assigned.

2.10.1.3 Key risk factors

The decision-making process leading to EMP implementation is comparable to any other investment decision that requires variation analysis. The process assumes certain price, tax, and benefit value deviations. An analysis of a survey of project facilitators, Energy Service Companies (ESCOs), financiers, and insurance companies identified the following key risk factors: Capital costs, energy, maintenance and other life-cycle costs, and energy savings. This Guide discusses how the design and execution of de-risking measures during different stages of the EMP development are crucial for the success of the EMP from the economic point of view. The de-risking measures detailed in the following paragraphs focus on the key risk factors (investment and energy cost).

2.10.1.4 Business models

Table 2-6 lists the scopes of different business models. For many public agencies and communities, it is important to reduce the number of parties involved to minimize both the effort required to manage these parties and the intersections between the different scopes that each party is willing to cover. Table 2-6 also lists the number of different parties involved in the process to illustrate the full spectrum of all six stages. Further explanation is provided in the respective descriptions of the different business models.

Table 2-6. Selection aide for business models in communities – Comparison of EMP business models.

Business Model	Description	Pros	Cons
Appropriated Funds	Funds appropriated by the governing agency as part of the yearly budgetary process, execution supervised by agency and subcontracting parties	• Straight forward - follows the normal processes for capital improvement program • Can be done incrementally for several years • Manage resources to the highest priority areas	• Subject to normal budget priorities • Must be managed internally • Follows normal design-build processes - no extended guarantees • No energy performance guarantees • No budget limitation guarantee
Fixed Payment	Funded by a utility. Paid back via fixed payments on the utility bill or on the property tax bill	• Easily implemented • Usually low-interest rates • The payment stays with the property in the case property is sold	• No energy guarantee • Usually limited to small projects • EMP implemented in pieces
ESPC	Energy Savings Performance Contract	• Budget Neutral • Energy/Operations savings pay for the upgraded systems • The third-party manages the contract • Energy savings are guaranteed - resulting in lowered financing rates • Multiple technical updates can be built-in	• Not readily understood by many municipal officials • Typically need a 3rd party expert to advocate for the customer • Long approval cycles on final project/financing by customer • Concerns by some decision-makers on long-term debt
Utility Energy Service Contract (UESC)	Utility Energy Savings Contract	• Budget Neutral • Energy/Operations savings pay for the upgraded systems • Third Party manages the contract • Customer contracts with their utility - people they know • Customer decides level of energy guarantee	• Not readily understood by many municipal officials • Typically need a 3rd party expert to advocate for the customer • Long approval cycles on final project/financing • Concerns by some decision make on long-term debt • Not all utilities offer this service
Blended Funding	Combining appropriated funding with ESPC/UESC	• Same as ESPC/UESC • Shorten financing term by injecting one time or multiple cash payments • Can get more energy conservation measures (ECMs) in the project	• Same as ESPC/UESC • Ensuring that the cash payments are available in the budget
PPA	Power Purchase Agreement - buy power from a non-utility partner or developer	• Developer pays all costs • Customer buys power at a price • At the end of the contract period, customer can buy the equipment for fair market value or have it removed • Developer may pay a lease payment to use customer land • Consistency of long-term budget planning	• Long-term procurement contract for customer - typically 20 years • Energy prices may be fixed or escalated • Locked in prices result in not being able to take advantage of potential future lower pricing
EUL	Enhanced Use Lease - customer leases underutilized land to a 3rd party in exchange for resiliency	• Developer pays all costs • Lease payment is often "In-Kind Consideration," which is often required or needed customer infrastructure updates • If utility power is lost, the power being produced on the leased land is sent to the customer	• Lease is 30-40 years • Power from the leased land is sold to the utility grid or may be bought by the customer • Land is unavailable for future customer expansion

2.10.2 Major barriers for EMP implementation using ESPC and Utility Energy Savings Contract (UESC)

2.10.2.1 Operations and maintenance

Some savings opportunities can support many resilience projects without capturing operations and maintenance (O&M) savings; many others are only possible if they can capture those truly avoided costs that help finance a project. For example, many U.S. Department of Defense (DoD) installations have several hundred backup generators, which are often inefficient, oversized, and expensive to maintain. Installing a microgrid that eliminates all standalone generators, or that maintains only a few configured into the microgrid can produce significant O&M savings.

DoD's current approach to the funding of standalone generators represents another major barrier to the implementation of microgrids. Although our cost analysis shows that microgrids can generate sufficient savings and revenue to make them attractive to Energy Savings Performing Contract (ESPC) and UESC vendors, the Services report that their proposed microgrid projects do not "pencil out" for private vendors. The difference relies on an accounting distinction: whereas our calculation considered all of the costs that standalone generators impose on a hypothetical base (capital, O&M, etc.), DoD's accounting system provides no such recognition; the costs of standalone generators on a base are paid out of multiple budget activities and by dozens of tenants. For third-party financing to "pencil out," DoD needs to recognize the costs that it already pays for energy security (Marqusee et al. 2017).

2.10.2.2 Military construction projects

Per the U.S. Energy Independence and Security Act of 2007 (EISA), a significant majority of ESPC projects combine appropriations with private financing, which provides funding options. In conducting a contract under this subchapter, a Federal agency may use any combination of appropriated funds and private financing under an energy savings performance contract.

UESCs may be fully funded or may include any combination of appropriations and financing. DoD has determined that it is prohibited from using Military Construction (MILCON) funds in conjunction with an ESPC or UESC. Even ERCIP (Energy Resilience and Conservation Investment Program) funds are off-limits because MILCON is the source of ERCIP funds. Where MILCON or ERCIP funds are available for resilience projects, more comprehensive, coordinated projects could be done more quickly and more seamlessly if those funds could be combined with ESPC or UESC. Additionally, such a funding combination could guarantee or assure more savings and those savings could be leveraged for even more investment than the total investment of separate projects—some privately financed and others funded with appropriations.

2.10.2.3 Utilities privatization in DoD

In resilience planning, consideration should be given to the status of utilities at a given DoD installation. In particular, where utilities privatization has occurred, there will be a need to coordinate with the utilities privatization contractor to ensure that resilience capabilities are at the ready. According to the Office of the Assistant Secretary of Defense for Sustainment (OASD 2019), maintaining access to reliable, resilient, and cyber-secure energy resources, generation assets, distribution infrastructure, and facility-related controls and data is critical to the execution

of DoD missions. Alternative Financing Mechanisms (AFMs) leverage commercial sources of capital to finance near-term enhancements to DoD utility infrastructure.

As part of a comprehensive Installation Energy Plan (IEP), AFMs can provide material benefits to DoD Components by providing cost-effective access to capital that might not otherwise have been obtainable through traditional methods. AFMs require DoD Components, however, to also use contractual mechanisms to ensure compliance with energy security, energy resilience, and cybersecurity requirements. Utilities privatization is one of several AFMs that a Military Department may use to finance utility improvements in support of the DoD's energy reliability, energy resilience, and cybersecurity goals. In the privatization process, military installations shift from the role of owner/operators to that of smart utility service customers. Privatized systems continue, however, to function as Defense Critical Infrastructure (DCI) such that a DoD Component's decision to pursue utilities privatization must be consistent with prioritized mission assurance requirements (10 U.S.C. 2688), with applicable DoD instructions and guidance, and with the affected installation's IEP.

2.11 Guides

2.11.1 Energy Master Planning toward Net-Zero Energy Resilient Public Communities Guide

This project contributed to the development of the *Energy Master Planning toward Net-Zero Energy Resilient Public Communities Guide* (IEA EBC 2022) (Figure 2-18) which provides a deeper understanding of the EMP process through the lens of best practices and lessons learned from case studies from across the globe. It helps to establish objectives and constraints for energy planning and to give a better understanding of available technologies and energy system architectures that combine to comprise a diverse set of local energy supply and demand considerations. The Guide introduces concepts and metrics of energy system resilience methodologies and discusses business and financial models for Energy Master Plans implementation.

Based on the architectures and an extensive technology database that includes prime movers, network distribution components, and auxiliary equipment needed in a system, a tool has been developed to help inform energy planners, energy engineers, system and building developers, political leaders, building owners, and city planners to better analyze and address their own local circumstances. The tool conducts a multicriteria analysis of alternatives and scenario selection that integrates economic, energy, and resiliency targets.

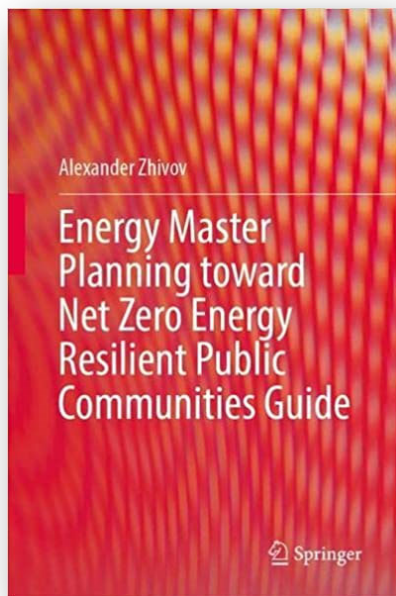


Figure 2-18. Cover of the *Energy Master Planning toward Net-Zero Energy Resilient Public Communities Guide*, published by Springer in 2022.

The Guide is organized into the following chapters and appendixes:

Chapter 1 is an introduction to the Guide.

Chapter 2 focuses on the integration of energy planning into community planning.

Chapter 3 details the methodology of Energy Master Planning and the process of integration of Energy Systems Resilience Analysis into the Energy Master Plan.

Chapter 4 is devoted to establishing energy goals and constraints.

Chapter 5 provides an understanding of the data required for Energy Master Planning and resilience analysis.

Chapter 6 focuses on defining, measuring, and assigning resilience requirements.

Chapter 7 provides a methodology for the selection of energy system architecture and technologies.

Chapter 8 describes a tool that supports analysis of the Baseline and different energy alternatives.

Chapter 9 delves into the multicriteria analysis of alternatives and scenario selection: Integrating economic, energy, and resiliency targets.

Chapter 10 describes economic and business aspects of Energy Master Planning.

2.11.2 *Guide for Resilient Energy Systems Design in Cold and Arctic Climates*

This Guide (Figure 2-19) was developed as a spin-off from the Guide described in section 2.11.1. It is the first attempt to address requirements for thermal energy systems resilience, which is

especially important in extreme climates. Arctic climates provide unique challenges to designers of HVAC, plumbing, and thermal energy systems. The importance of considering facility operation in the context of outside air temperatures, system reliability, and building resiliency cannot be understated. This Guide describes best practice examples of robust and reliable systems that emphasize redundancy, durability, and functionality. It helps to identify the maximum allowable time available to correct any problems with heat supply to mission-critical facilities for different facility archetypes (building mass, and insulation characteristics) and air leakage rates before the indoor air temperature reaches habitability or sustainability thresholds. This effort went beyond the traditional approach to establish requirements for building envelope characteristics based on economic and environmental considerations to introduce the consideration of thermal energy system resilience as another parameter in the optimization process.

The Guide is organized into the following chapters:

Chapter 1. Introduction

Chapter 2. Requirements for Building Thermal Conditions under Normal and Emergency Operations in Cold and Arctic Climates

Chapter 3. Parameters for Thermal Energy System Resilience

Chapter 4. Building Envelope

Chapter 5. Considerations for Foundation Construction on Permafrost

Chapter 6. Best Practices for HVAC and Heat Supply

Chapter 7. District Heating Systems

Chapter 8. Evaluation of Maximum Time to Repair.

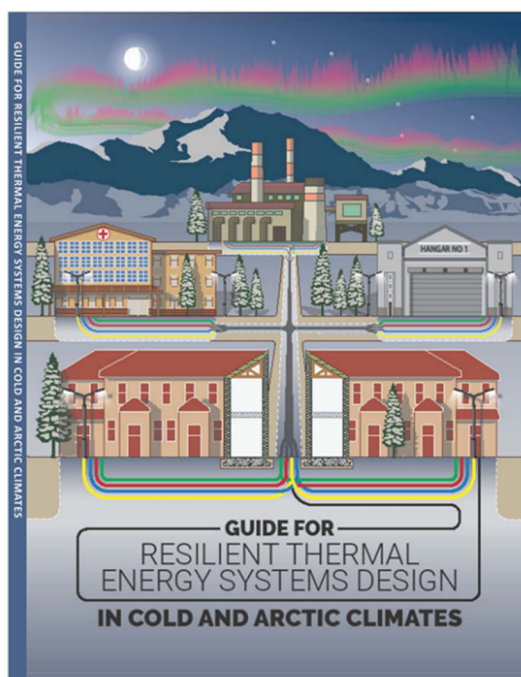


Figure 2-19. Cover of the *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates*, published by ASHRAE in 2021.

2.11.3 Guide for Resilient Energy Systems Design in Hot and Humid Climates

This Guide (Figure 2-20) is another spin-off from the Guide described in section 2.11.1. Hot and humid climates present some of the most complex challenges for sustainable building design and operation to maintain high indoor air quality (IAQ) efficiently. Additionally, high temperatures, coupled with high humidity, create extreme comfort issues and exacerbate the potential for condensation, mold, and mildew.

Buildings in humid climates, especially in coastal locations, are also subject to rust and decay of materials much more quickly than in other environments. In extreme situations, e.g., at Kwajalein or Okinawa, concrete elements of the building envelope break down and condenser units installed outside of the building envelope must be replaced within 2-3 years due to premature corrosion caused by a salt-laden ambient air. Additionally, many coastal areas located in hot and humid climates are frequented by tropical storms and hurricanes with heavy winds, which can force water into the building and damage the building envelope.

Hot and humid climates provide unique challenges to designers of HVAC, plumbing, and thermal energy systems. The importance of considering facility operation in the context of high outside air (OA) temperatures and humidity, system reliability, and building resiliency cannot be understated. This Guide describes best practice examples of robust and reliable systems that emphasize redundancy, durability, and functionality.

The Guide is organized into the following chapters:

Chapter 1. Introduction

Chapter 2. Requirements for Building Thermal Conditions under Normal and Emergency Operations in Hot and Humid Climates

Chapter 3. Parameters for Thermal Energy System Resilience

Chapter 4. Building Enclosure

Chapter 5. Heating, Ventilation, and Air-Conditioning (HVAC) Considerations for Hot and Humid Climates

Chapter 6. District Cooling Systems

Chapter 8. Evaluation of Maximum Time to repair.

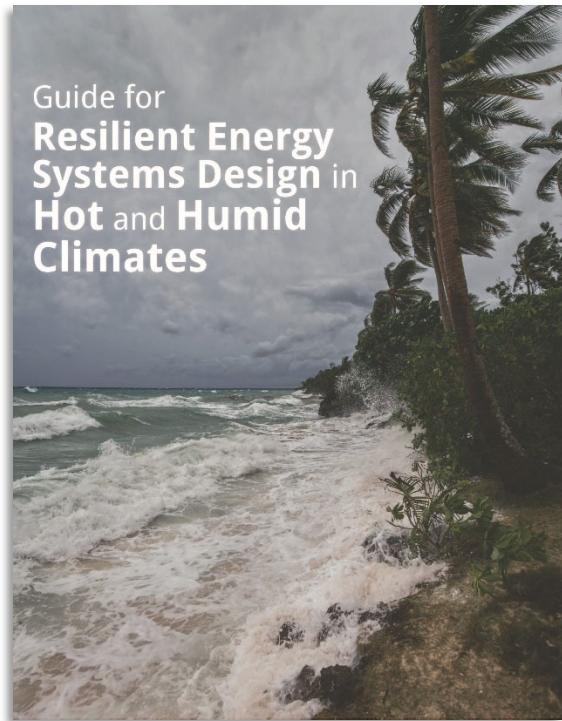


Figure 2-20. Cover of the draft *Guide for Resilient Thermal Energy Systems Design in Hot and Humid Climates*.

3.0 TECHNOLOGY DEMONSTRATION

The two pilot studies described in this chapter were conducted to demonstrate the Energy Resilience of Interacting Networks (ERIN) modeling tool. The studies demonstrated the tool's ability to function in a standalone application (Study 1) or to be integrated into other software platforms (Study 2). The first pilot study used the ERIN tool as a standalone application and simulated different energy resilience approaches, primarily focusing on electricity. The second pilot study used ERIN as a function of the System Master PLanner (SMPL) tool, which adds a graphical user interface, Simulation Server, and statistical post-processing, which together simplify the development and interpretation of models. Installation building and infrastructure data were used to simulate thermal and electrical networks representative of military installations in cold and moderate climates. Results were then compared to typical resilience metric goals to determine requirements and inform strategies for mitigation.

3.1 Case Study 1. Fort Leonard Wood Energy Resilience

3.1.1 Introduction

The case study at Fort Leonard Wood, MO (Figure 3-1) demonstrates an integrated approach to energy master planning at a military installation the size of a small city. Aging infrastructure, as well as natural and manmade events, are an increasing threat to cities, university campuses, and military installations. Resilient energy and thermal systems for mission-critical facilities and operations have primarily focused on generators as a backup source in case of a black sky (worst case scenario) event. The purpose of this study was to evaluate a holistic system – integrating resilience, efficiency, and sustainability factors – to determine scenarios that support installation master planning at Fort Leonard Wood.

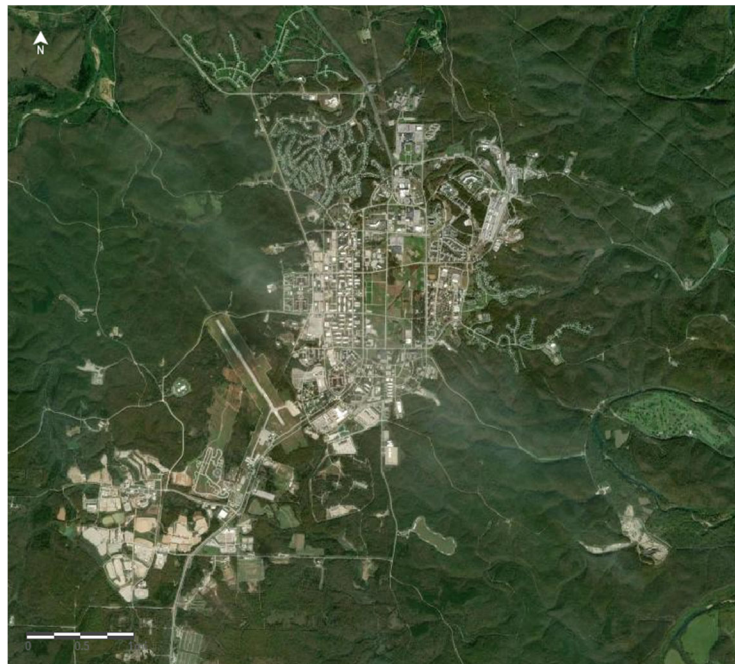


Figure 3-1. Aerial view of Fort Leonard Wood, MO (ESRI map 2021).

The ERIN modeling tool simulates energy flows through a district energy system composed of an interacting network of components. This tool provides increased resilience analysis to the System Master Planning Tool (SMPL), which on its own would only forecast present and future energy usage. With the additional resilience capabilities of ERIN, equipment reliabilities and threat vulnerabilities are factors that provide a broader determination of site resilience. After the initial analysis was conducted, this case study primarily used ERIN to determine the most economically feasible approach to resilience.

3.1.2 Key characteristics and threats

The installation studied is in the Missouri Ozarks, south of the City of Saint Robert, where dramatic shifts in weather are considered the norm. Hot, humid, rainy summers follow very cold, sometimes snowy winters. The temperature typically varies between -3 °C and 32 °C (26 °F and 89 °F) throughout the year and is cloudy most of the time. Major natural threats to Fort Leonard Wood include severe weather events throughout the year, and the primary driver for infrastructure outages across the area is severe weather (storms). The National Oceanic and Atmospheric Administration (NOAA) tracks storm events by county (Table 3-1). In combination with data collected by NOAA, the leading cause of power outages is thunderstorms (hail, wind, tornadoes, and lightning). Winter weather can cause transportation issues and severe ice storms can result in significant damage to electric distribution (broken and fallen power lines). Other hazards of concern include potential flooding along with low-lying areas; extreme temperatures that cause high demand on electric or gas systems, which can potentially strain the infrastructure; and earthquakes. Although there is a small possibility of earthquakes, a major earthquake on the New Madrid fault (up to 8.6 magnitude) could cause moderate damage to well-built buildings at Fort Leonard Wood.

Table 3-1. Pulaski County, MO total natural hazard events since 1996 (NOAA Storm Events Database).

Hazard Type	Pulaski County No. of Occurrences
High Winds	118
Hail	148
Flooding	89
Winter Weather	31
Extreme Temperatures	17
Earthquakes	0

Manmade risks include bombings, active shooters, and threats to cybersecurity. Threats could lead to power and communication outages, weakened or blocked supply systems, and mass casualty events. These threats could also compromise the availability of locational resources (e.g., district chilled and hot water, steam, water, electricity grid, natural gas pipeline, liquid fuel) or cause a loss of energy supply (e.g., power and gas supply, renewable sources, energy alternatives).

3.1.3 Total installation load profiles

Fort Leonard Wood has a total of 17 mission-critical facilities and several thousand facilities listed as non-critical that are used for support functions. The Fort Leonard Wood 2020 Installation Energy and Water Plan (IEWP)* assessed the Baseline for the operating conditions of both energy and water systems for the entire installation with an emphasis on mission-critical facilities. The Baseline is defined as the current energy (and water) consumption profile. It includes cooling, heating, electrical energy usage, and operating costs.

Overall, the IEWP assessed three main cantonment areas: Specker Central Plant-connected facilities, South Plant-connected facilities, and all remaining facilities (Table 3-2). This information was obtained through actual usage based on utility bills and consumption reports and was verified through available metered data.

Table 3-2. Generated output from SMPL of three main cantonment areas (Fort Leonard Wood 2020 IEWP).

Group Name	Specker	South Plant	Remaining Buildings
Number of facilities	45	20	2,313
Number of mission-critical facilities	0	0	17
Conditioned area	684,450	695,156	14,750,441
Ground coverage (sq ft [m ²])	2,917,875 [27,1079]	5,885,484 [546779]	1,497,480,576 [139120497]
Total electrical load (kWh/year [MMBtu/hr])	8,102,292 [27,646]	7,481,180 [25,526]	150,946,624 [515,051]
Total space heating load (kWh/year)	7,096,755	7,362,242	113,407,544
Total domestic hot water (DHW) load (kWh/year)	2,633,544	1,637,438	25,506,904
Total cooling load (kWh/year)	4,872,712	3,305,807	68,687,800
Total electrical peak (kW [Btu/hr])	1,493 [5,094]	1,567 [5,346]	32,693 [111,553]
Total cooling peak (kW)	6,067	5,079	102,516
Total space heating peak (kW)	7,275	10,403	177,760

The data in Table 3-2 define the three areas of interest based on buildings currently connected to two separate central plants. When the IEWP team calculated the three areas of cantonment, two locations – Specker and South Plant -- included two of the central plants. The IEWP did not break down other areas of the cantonment or proximity to mission-critical facilities. There are mission-critical facilities near to the Specker area and South Plant, but the mission-critical facilities are not currently connected to those two plants, and were thus considered separately. There are also mission-critical facilities that are not near any current central plant.

*ERDC-CERL (Engineer Research and Development Center, Construction Engineering Research Laboratory). 2020. *Fort Leonard Wood 2020 Installation Energy and Water Plan*. Draft Technical Report. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL).

There are currently five government-owned central energy plants located at Fort Leonard Wood. These include two high temperature hot water (HTHW) plus chilled water plants (Specker and South Plant) serving approximately 65 buildings. There is a steam and chiller plant serving the hospital, a central chiller plant serving 15 facilities on the west side of cantonment, and lastly a four-building complex on the north side of cantonment that is served by a steam and chilled water plant. There is no other onsite generation.

3.1.4 Establishing the baseline

Of all energy resources currently used at Fort Leonard Wood, the top four consumption types were identified in the IEWP: heating consumption (42%), interior equipment (22%), cooling (13%) and, interior lighting (11%). In 2020, Fort Leonard Wood consumed a total of 35,177 MWh of electricity and 797,695 MMBtu of natural gas. There are two current suppliers of electricity and natural gas, Sho-ME Power and Omega Gas. Table 3-3 lists the average cost for electricity at Fort Leonard Wood. Figure 3-2 shows the highest consumption of electricity occurring in the summer months at this particular installation. The maximum peak demand for natural gas is 6,000 MCFD, with one entry point for delivery. The rate structure is tiered with an average of \$2.66 per dekatherm.

Table 3-3. Average cost per kilowatt hour of electricity at Fort Leonard Wood.

		2016-2017	2017-2018	2018-2019
Energy	Base	\$0.08/kWh	\$0.04527/kWh	\$0.04527/kWh
	Peak	\$4.25/kWh	\$6.00/kWh	\$7.50/kWh

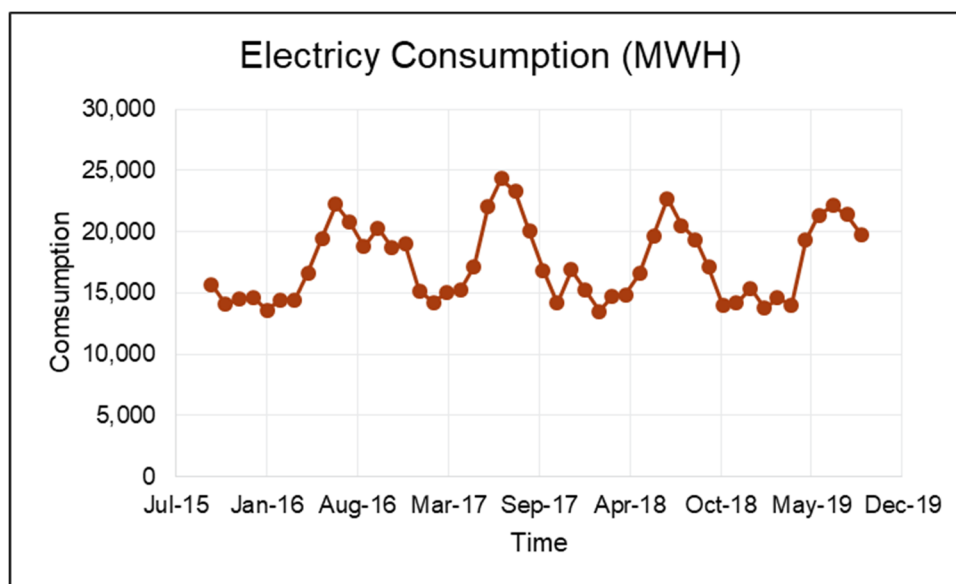


Figure 3-2. Army Energy and Water Reporting System (AEWRS) data from Fort Leonard Wood, 2015 to 2019.

Out of the 17 mission-critical facilities at Fort Leonard Wood, 13 use generators for backup power. These generators range from 8 to 36 years in age. Most are diesel generators, and two are natural gas. In 2020, fuel oil consumption was at 7,000 gallons used for backup generation,

backup for central plant boiler fuel, and other purposes. There is also a propane air injection system used for backup. This is supplied locally as needed in the form of 13 tanks (30,000 gallons in size). The propane is consumed at the building level and is piped directly from those storage tanks, which are located near the buildings they serve. Propane consumption in 2020 was 1.06 million gallons for general heating, water heating, and backup generation for buildings within the cantonment area not connected to natural gas distribution lines and for buildings located further away on the training ranges.

Besides 90kW (307 Btu) of solar power, no large-scale renewable energy resources are currently used at Fort Leonard Wood, but when evaluating the consumption of energy and thermal systems, alternative solutions may include the following benefits:

- Increased energy supply security
- Reduced economic disruptions caused by volatile energy prices
- Realization of local economic advantages by capitalizing on local/regional investments in energy conservation or renewables
- Improvement and modernization of local infrastructure.

After considering the energy resources currently used (Baseline) the next step in the determination of resilience is to evaluate the systems for black sky (emergency) situations. After determining the total energy usage and priority load of each mission-critical facility, as well as the HVAC and electrical systems serving each, the non-critical facilities in nearby locations should also be assessed. Furthermore, maximum down time for mission-critical facilities and the associated thermal and electric energy quality must be determined.

3.1.5 Establishing the base case

According to IEA Annex 73, a seven-step process should be considered when assessing resilience (including robustness, recovery, time, availability, and quality). The Base Case or “business as usual” alternative includes all existing and already planned facilities. Facilities planned for demolition in the Baseline are not included. The Baseline models of buildings and energy systems are adjusted to reflect all planned construction or modifications. The Base Case also includes primary energy usage and energy costs with categories similar to the Baseline (IEA EBC 2022). Planned facilities at Fort Leonard Wood include a new hospital, a blood processing center, a fire station, and a school for up to 10,000 students.

When establishing the Base Case, four major areas were identified within the Fort Leonard Wood cantonment. Determining these Base Case areas included detailed discussions with installation stakeholders to ensure that the outcomes would align with the installation’s vision, goals, and mission. Some of the mission-critical facilities were out of range of the cantonment or were not near enough to other facilities that would benefit from resource enhancement (Table 3-4 and Figure 3-3). To achieve the optimum balance for the entire energy system, based on energy delivered and lost, four elements were considered: energy generation, energy distribution, energy storage, and energy demand. Distribution strategies under consideration included 100% centralized energy supply solutions, completely decentralized solutions, or a combination of clusters of buildings connected to nearby central energy plants and buildings having individual decentralized energy systems (none currently at Fort Leonard Wood).

The IEWP noted that there is no dedicated supply of fuel for backup generators at Fort Leonard Wood. Generators at mission-critical facilities receive fuel from the main diesel storage area. Installation personnel indicated that it was difficult to ensure backup fuel supply since they must share diesel with other consumers, including large trucks. Flooding also poses a threat to fueling since flooding could limit access to distribution. The IEWP estimated that most of the backup generators could run 2 to 5 days at half a load with internal storage tanks. Approximately 133,000 gallons of fuel would be needed to run at full capacity for 14 days and approximately 69,500 gallons at half capacity for 14 days.

Table 3-4. Mission-critical facilities at Fort Leonard Wood listing location (cluster or out of range of cluster), type of mission-critical facility, and characterization of emergency backup generation/storage.

Mission Critical Facility #	Cluster Area or Out of Range (OR)	Operations (O) or Life & Safety (LS)	Onsite Backup Generation & Energy Storage Equipment Characterization
1	1	LS	Diesel generator x4, 920 kW (2,760 Btu/hr) each 1983 install date
2	OR	LS	Diesel generator x1, 40 kW (120 Btu/hr) 112-gal (424 L) tank 1984 install date
3	3	O	Diesel generator x2, 45 kW (135 Btu/hr) each 306-gal (1158 L) tank 2004 install date
4	OR	O	Diesel generator x1, 750 kW (2,250 Btu/hr) each 1390-gal (5262 L) tank 2017 install date
5	OR	LS	Diesel generator x1, 750 kW (2,250 Btu/hr) each 1390-gal (5262 L) tank 2017 install date
6	1	O	Diesel generator x2, 880 kW (2,640 Btu/hr) each 2006-gal (7594 L) tank 2013 install date
7	1	O	Shares with Facility # 6
8	1	O	Diesel generator x1, 600 kW (1,800 Btu/hr) each 1206-gal (4565 L) tank 1998 install date
9	2	O	None
10	2	O	Natural Gas generator x 2, 2080 kW (6,240 Btu/hr) each UPS for mission-critical equipment 2012 install date
11	2	O	Shares with Facility # 10
12	OR	O	None
13	2	LS	Diesel generator x 1, 100 kW (300 Btu/hr) each 349-gal (1321 L) tank UPS for mission-critical equipment 2000 install date

Mission Critical Facility #	Cluster Area or Out of Range (OR)	Operations (O) or Life & Safety (LS)	Onsite Backup Generation & Energy Storage Equipment Characterization
14	OR	LS	Diesel generator x1, 350 kW (1,050 Btu/hr) each 1887-gal (7143 L) tank 2003 install date
15	OR	LS	None
16	OR	LS	None
17	2	LS	Diesel generator x1, 18 kW (54 Btu/hr) each 171-gal (647 L) tank 2000 install date

3.1.6 Alternative scenarios and economic analysis

The research team for this integrated analysis considered four primary clusters within Fort Leonard Wood's cantonment rather than the three segregations determined by the IEWP. This restructured analysis considered currently used mission-critical facilities in proximity to other high-traffic facilities, and also potential strategic locations for future planned buildings. It also considered energy conservation, i.e., the potential to reduce energy consumption and increase thermal storage. Four major energy system elements were considered: energy generation, energy distribution, energy storage, and energy demand (Güssing 2011). Ultimately, based on several factors specific to Fort Leonard Wood's location, mission, primary threats, and other factors, a CHP system and thermal storage were prioritized. The four clusters analyzed include

- North Cluster (Area 1): 4 mission-critical facilities
- West Cluster (Area 2): 4 mission-critical facilities
- South Cluster (Area 3): 1 mission-critical facility
- Combined West and South Cluster (Areas 2 and 3): 5 mission-critical facilities.

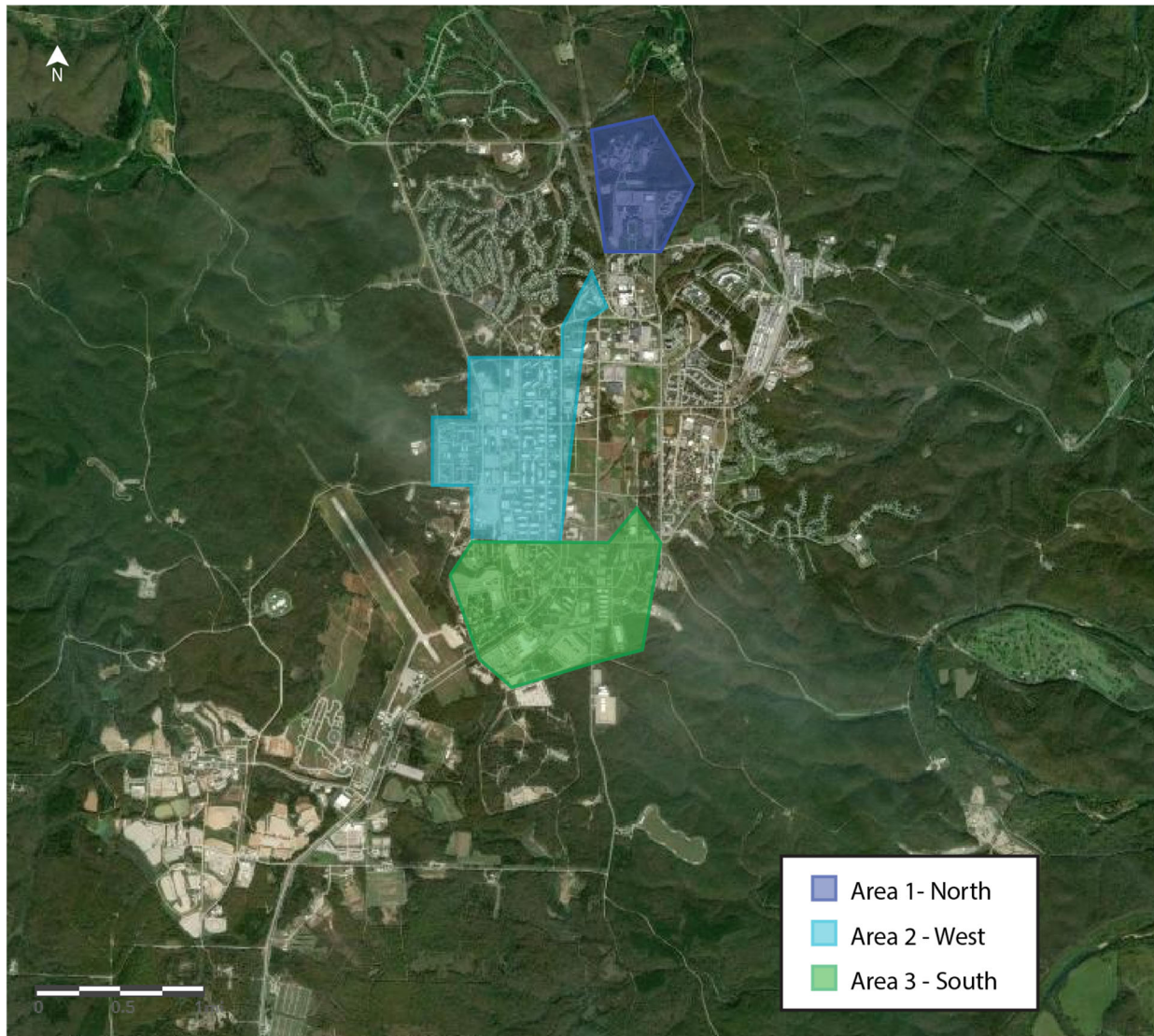


Figure 3-3. Cantonment areas at Fort Leonard Wood analyzed by cluster and proximity to mission-critical facilities.

3.1.7 North Cluster (Area 1)

Analysis of the first area considered 27 total buildings, including instructional and hotel buildings, and four mission-critical facilities. There is ongoing construction in the cluster that includes a new hospital. The down-selection analyzed the economic viability of the mission-critical facilities-only, swapping out the old hospital with the new (including upgrades). The second alternative included those same mission-critical facilities with nearby instructional and hotel buildings. Figure 3-4 shows the cluster and the proximity of buildings and Table 3-5 lists the load profile of selected buildings.

The CHP would be collocated so it would serve all mission-critical facilities, not only the hospital. It would offer supplemental backup electricity and use the district hot water heating system, including thermal storage, to supply heat. Table 3-6 lists the ROI parameters and results of calculations for the North Cluster, Alternative 1.

Table 3-6. ROI for North Cluster, Alternative 1.

Parameter	Measure
Electrical Generation Capacity	0.25 MW
Thermal Generation Capacity	0.375 MW
Initial Investment	\$1,457,030
Recurring Costs	\$101,971/year
Electrical Energy Savings	\$137,794/year
Thermal Energy Savings	\$35,072/year
Cost Savings	\$70,895/year
ROI	20.55 years

3.1.7.2 ROI for North Cluster, Alternative 2

The second alternative for the North Cluster considered not only the mission-critical facilities as described in the first alternative, but also nearby support buildings such as the hotels and instructional buildings. In this alternative, the CHP and thermal storage would have a much larger capacity and increased investment, but the payback time is similar (Table 3-7).

Table 3-7. ROI for North Cluster, Alternative 2.

Parameter	Measure
Electrical Generation Capacity	1 MW
Thermal Generation Capacity	1.5 MW
Initial Investment	\$7,228,498
Recurring Costs	\$313,347/year
Electrical Energy Savings	\$551,178/year
Thermal Energy Savings	\$140,288/year
Cost Savings	\$378,119/year
ROI	19.11 years

3.1.8 West Cluster (Area 2)

Analysis of the second area considered the proximity between the mission-critical facilities and other types of buildings, primarily newly constructed and/or planned dorm-style military barracks (Figure 3-5 and Table 3-8). This scenario considered the need for an expanded distribution system to the newer barracks, or alternatively, continued use of the current electrical and thermal connections to the older, already established buildings.

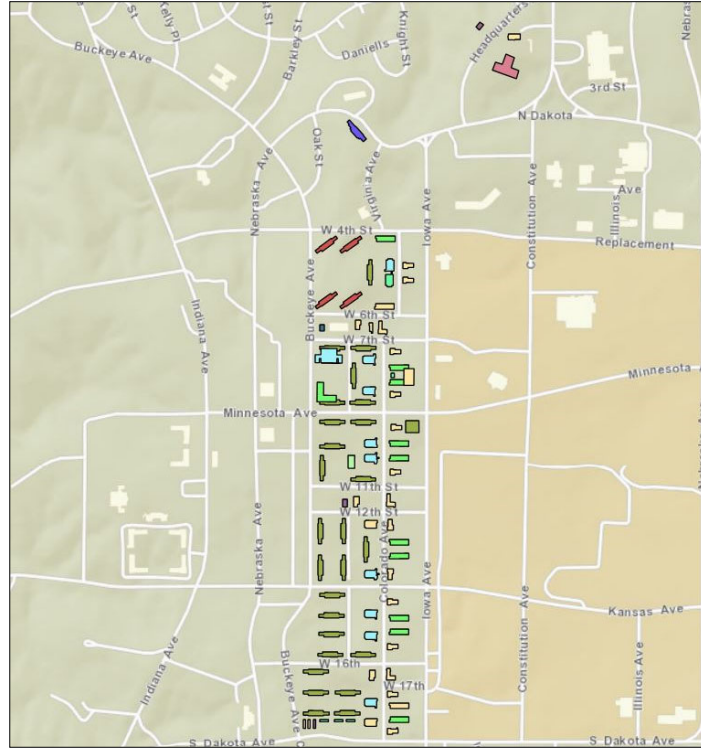


Figure 3-5. Conceptual representation of West Cluster of buildings.

Table 3-8. West Cluster building load profile.

Parameter	Measure
Number of Facilities	92
Number of MC Facilities	5
Conditioned Area (sq ft [m ²])	12,564,201 [1,167,252]
Ground Coverage (sq ft [m ²])	26,167,432 [2,431,033]
Total Electrical Load (kWh/year [MMBtu/yr])	21,870,402 [74,625]
Total Space Heating Load (kWh/year)	7,792,985
Total DHW Load (kWh/year)	14,541,565
Total Heating Load (kWh/year/sq ft)	2.36
Total Cooling Load (kWh/year/sq ft)	1.16
Total Electrical Peak (kW [MMBtu/hr])	4,868 [16.6]
Total Cooling Peak (kW)	19,753
Total Space Heating Peak (kW)	22,484

3.1.8.1 ROI for West Cluster, Alternative 1

The first alternative analyzed costs associated with current infrastructure in place. The size of the CHP was limited by the amount of thermal energy requested during normal operations. In general, the larger the generator, the greater the energy efficiency and greater investment return. This assumes that the CHP is loaded at its optimal capacity throughout the course of the year. When factoring in storage, the optimal energy production can be sized to meet the average load (Table 3-9).

Table 3-9. ROI for West Cluster, Alternative 2.

Parameter	Measure
Electrical Generation Capacity	3 MW
Thermal Generation Capacity	4.5 MW
Initial Investment	\$18,411,750
Recurring Costs	\$940,042/year
Electrical Energy Savings	\$1,653,536/year
Thermal Energy Savings	\$420,866/year
Cost Savings	\$1,134,360/year
ROI	16.25 years

The second alternative analyzed the potential to increase the load served by expanding distribution to a potential new barracks complex. This would increase the average load enough to increase the size of the CHP, thereby increasing gross return. However, due to the costs associated with the additional thermal distribution, this increased CHP size reduced the ROI by less than a year (Table 3-10).

Table 3-10. ROI for West Cluster, Alternative 2, including expanded distribution to a potential new barracks complex.

Parameter	Measure
Electrical Generation Capacity	4 MW
Thermal Generation Capacity	6 MW
Initial Investment	\$23,727,200
Recurring Costs	\$1,253,388/year
Electrical Energy Savings	\$2,204,714/year
Thermal Energy Savings	\$561,155/year
Cost Savings	\$1,512,481/year
ROI	15.69 years

3.1.9 South Cluster (Area 3)

The South Cluster contained 21 buildings in total, including one mission-critical facility (Figure 3-6 and Table 3-11). Some of the buildings were dorm-style military barracks and maintenance facilities.



Figure 3-6. Conceptual representation of South Cluster of buildings.

Table 3-11. South Cluster building load profile.

Parameter	Measure
Number of Facilities	21
Number of MC Facilities	1
Conditioned Area (sq ft [m ²])	768,504 [71,396]
Ground Coverage (sq ft [m ²])	6,447,796 [599,019]
Total Electrical Load (kWh/year [MMBtu/yr])	8,504,804 [29.020]
Total Space Heating Load (kWh/year)	7,518,787
Total DHW Load (kWh/year)	1,688,778
Total Heating Load (kWh/year/sq ft)	3,680,623
Total Cooling Load (kWh/year/sq ft)	1.43
Total Electrical Peak (kW [Btu/hr])	0.57 [1.9]
Total Cooling Peak (kW)	1,826
Total Space Heating Peak (kW)	5,554

3.1.9.1 ROI for South Cluster, Alternative 1

The first alternative considered a relatively small CHP consolidated near the southern portion of campus. This presented a unique opportunity to capitalize on existing thermal distribution infrastructure. This resulted in a 13.85 year ROI (Table 3-12).

Table 3-12. ROI for South Cluster, Alternative 1.

Parameter	Measure
Electrical Generation Capacity	1 MW
Thermal Generation Capacity	1.5 MW
Initial Investment	\$5,237,987
Recurring Costs	\$313,347/year

Parameter	Measure
Electrical Energy Savings	\$551,178/year
Thermal Energy Savings	\$140,288/year
Cost Savings	\$378,119/year
ROI	13.85 years

3.1.9.2 ROI for South Cluster, Alternative 2

Alternative 2 considered an approach similar to that of Alternative 1, with a proposed expansion to a barracks complex. This justified an increase in CHP capacity, but also slightly increased distribution costs. While the distribution costs did increase, leveraging the existing thermal distribution infrastructure had significant impacts on the cost projections (Table 3-13).

Table 3-13. ROI for South Cluster, Alternative 2.

Parameter	Measure
Electrical Generation Capacity	2 MW
Thermal Generation Capacity	3 MW
Initial Investment	\$9,261,634
Recurring Costs	\$626,694/year
Electrical Energy Savings	\$1,102,357/year
Thermal Energy Savings	\$280,577/year
Cost Savings	\$756,240/year
ROI	12.25 years

3.1.10 Combined West and South Clusters (Areas 2 and 3)

Connecting all five mission-critical facilities with a total of 113 buildings (Figure 3-7 and Table 3-14) in the larger cluster of buildings in the combined West and South Clusters of the installation would improve energy supply to more remote mission-critical facilities and may prove cost effective during normal operations.



Figure 3-7. Conceptual representation of combined West and South Clusters of buildings.

Table 3-14. West and South Clusters building load profile.

Parameter	Measure
Number of Facilities	113
Number of MC Facilities	6
Conditioned Area (sq ft [m ²])	13,332,705 [1,238,648]
Ground Coverage (sq ft [m ²])	32,615,228 [3,030,053]
Total Electrical Load (kWh/year [MMBtu/yr])	30,375,206 [103,645]
Total Space Heating Load (kWh/year)	15,311,772
Total DHW Load (kWh/year)	16,230,343
Total Heating Load (kWh/year/sq ft)	3,680,625
Total Cooling Load (kWh/yr/sq ft)	3
Total Electrical Peak (kW [MMBtu/hr])	4,869 [16.6]
Total Cooling Peak (kW)	21,579
Total Space Heating Peak (kW)	28,038

3.1.10.1 ROI for Combined Cluster, Alternative (no other considered)

This alternative considers the combination of the West and South Clusters. Increasing the CHP and thermal storage size further reduces the ROI to 11.5 years (Table 3-15). This would both leverage existing infrastructure as well as the development of new infrastructure.

Table 3-15. ROI for Combined Cluster Alternative.

Parameter	Measure
Electrical Generation Capacity	6 MW
Thermal Generation Capacity	9 MW
Initial Investment	\$26,427,234
Recurring Costs	\$1,852,304/year
Electrical Energy Savings	\$3,310,000/year
Thermal Energy Savings	\$840,000/year
Cost Savings	\$2,297,696/year
ROI	11.5 years

3.1.11 Resilience analysis and comparison of alternatives to baseline and base case

Fort Leonard Wood serves as a good example of a small community with critical infrastructure susceptible to naturally occurring and manmade threats. The scope of this pilot study was to model the electrical resilience of four buildings while evaluating the costs/benefits of increasing power production capabilities to specific areas. There are several methods to quantifying resilience; this study focused primarily on the ER metric since the basis of the study focuses on increasing power production in localized areas. ER can be calculated by dividing the energy achieved by the energy requested over a specific period. For example, the desired result would be that all the energy requested is supplied, giving an EA of 1. If half of the energy that was requested were supplied, the EA would be 0.5. For the blue and black sky scenarios in this study, a period of 8760 hours (1 year) and 300 hours (12.5 days) were used, respectively.

3.1.11.1 Baseline comparison for North Cluster, Alternative 1 Scenario

The Baseline approach assessed only power supplied by the local utility company. For modeling purposes, the source was represented by the “Transmission” variable (Figure 3-8). This represented all energy transmission upstream from Fort Leonard Wood’s main substation or outside Fort Leonard Woods area of responsibility. The main substation represents the distribution from the source to the load, and each building (A, B, C, and D) represents the system load.

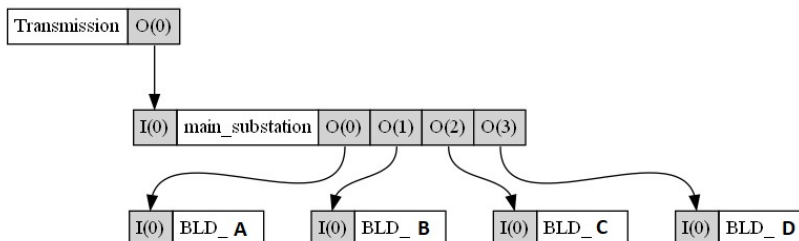


Figure 3-8. Network ports for Baseline resilience analysis.

While this model is not a holistic representation of Fort Leonard Woods electrical distribution system, it does allow for a simplified picture of the mission essential electrical grid in the community. The failure rates during the Blue Sky Scenario used a Weibull distribution, which considers life-cycle in determining the probability of failure. The MTTR for the electrical system was set as a fixed time of 24 hours, which would be similar to a real-life reliability target that a utility company would be compelled to achieve (Table 3-16). During the black sky scenario, a “severe” flood was modeled. While modeling severity is relative and somewhat subjective, it allows for different components of the overall system to be set to fail at specific levels of severity. For example, most of the electrical transmission for the state of Missouri is overhead distribution, which may be less susceptible to flooding events than a substation located near a river system or in a valley. This is not to say that flooding would not cause a transmission system to fail, but rather the time to repair transmission systems would generally be less than the time to repair a transformer at a substation.

Table 3-16. Baseline electric facilities not meeting requirements during blue sky conditions.

Building No.	Gen?	Acceptable MaxSED (hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
A	N	0.005	0.99999	24	0.997	0.994
B	N	0.25	0.9995	24	0.997	0.997
C	N	0.05	0.9999	24	0.997	0.996
D	N	0.05	0.9999	24	0.997	0.994

Under blue sky conditions with no redundancy in place, the loads were not served according to the minimum acceptable standards, resulting in a disruption to the mission. Under black sky scenarios these results would become much worse (Table 3-17).

Table 3-17. Baseline electric facilities not meeting requirements during black sky conditions.

Building No.	Gen?	Acceptable MaxSED (hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
A	N	0.005	0.99999	77	0.743	0.726
B	N	0.25	0.9995	77	0.743	0.729
C	N	0.05	0.9999	77	0.743	0.788
D	N	0.05	0.9999	77	0.743	0.712

The biggest risk with the Baseline approach is that the loads will be subjected to a single point of failure. Despite the transmission (source) being modeled as more resilient to flooding events than the substation, the load was without power for as long as the substation was out of commission. To avoid this single point of failure, a simple approach is to supply backup generators to individual facilities. This approach was evaluated for the Base Case scenario.

3.1.11.2 Base Case comparison for North Cluster, Alternative 1 Scenario

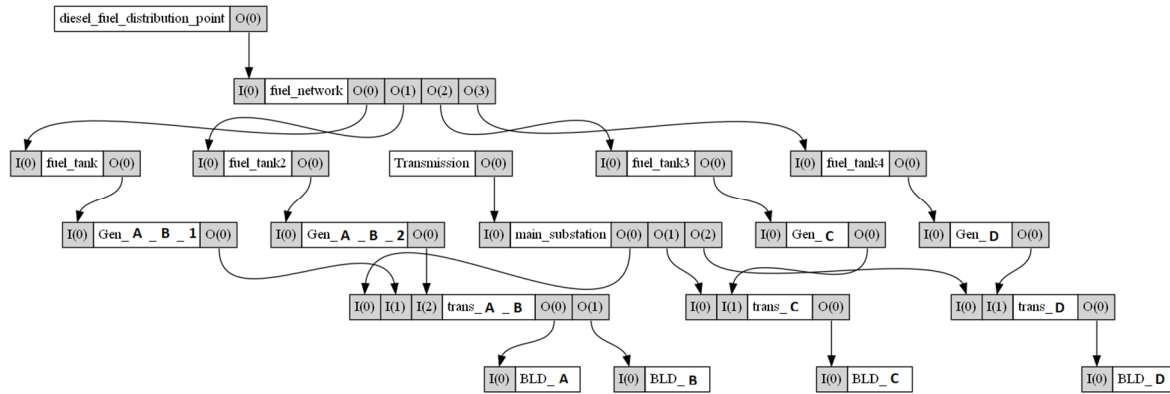


Figure 3-9. Network ports for Base Case resilience analysis.

The Base Case implemented a simple approach to improving resilience by placing backup generators at each individual building (Figure 3-9.). With Buildings A and B being the exception, these generators were sized to meet the specific peak demand of their respective buildings and did not share power between buildings. Buildings A and B are collocated with each other and share two generators. This provides an additional layer of resilience for these two buildings by providing redundancy in that, if one of the generators fails, the other can supply both loads outside of peak demand times.

The failure rates were modeled as the same as the Baseline approach, with an MTTR of 24 hours during blue sky scenarios and a “severe” flooding event during the black sky scenario (Table 3-18). Similar to the utility power source, the backup generators were susceptible to regular outages and were assigned specific failure thresholds for flooding events. Generator C was rated for a severe flooding event, while Generators A and B were not. The susceptibility for generator D was set such that the probability of failure increased during a “severe” flooding event but was not certain. The reasoning behind this was to account for differences in elevation and proximity to water sources, with respect to generator placement.

Table 3-18. Base case electric facilities not meeting requirements during black sky conditions.

Building No.	Gen?	Acceptable MaxSEDT (hours)	Acceptable EA	Model MaxSEDT (Hours)	Model EA	Model ER
A	Y	0.005	0.99999	7.97	0.973	0.990
B	Y	0.25	0.9995	7.97	0.973	0.979
C	Y	0.05	0.9999	0	1	1
D	Y	0.05	0.9999	9.73	0.968	1

The results from the Base Case scenario demonstrate the value, in terms of improved resilience, that backup generators provide. While the source and distribution still experienced outages during blue sky scenarios (Table 3-19), the backup generators were able to supply the load during the outage. Despite the fact that the backup generators themselves will experience specific downtimes (maintenance, failures, etc.), it is very unlikely that these occurrences will coincide with a utility power outage, meaning that, during normal conditions, the loads are served 100% of the time.

Table 3-19. Base case electric facilities not meeting requirements during blue sky conditions.

Building Number	Gen?	Acceptable MaxSEDT (hours)	Acceptable EA	Model MaxSEDT (Hours)	Model EA	Model ER
A	Y	0.005	0.99999	0	1	1
B	Y	0.25	0.9995	0	1	1
C	Y	0.05	0.9999	0	1	1
D	Y	0.05	0.9999	0	1	1

During black sky conditions, these systems may be just as susceptible to failure as fixed utility infrastructure. The main difference is that failures on smaller energy infrastructure will have a shorter recovery time than failures on larger systems (Table 3-18). Furthermore, it is easier to take steps on a smaller/mobile infrastructure to remediate the sources of failures. Adding backup generators allowed the system to maintain loads at their desired state during the blue sky scenarios and reduce the single event downtime by nearly a factor of 10 during the black sky event. This can be further improved by developing a simplified microgrid for this specific cluster of buildings that would increase the overall power production of the cluster and use a control strategy to island these four buildings during a disaster event.

3.1.12 Future case for North Cluster, Alternative 1 Scenario

The third and final approach is to outline and analyze alternative/conceptual designs. While backup generators improve resilience sufficiently during blue sky conditions, improvements should still be made during black sky events. Backup generators typically provide power only during emergency situations. This approach would integrate a larger, high efficiency CHP plant that would deliver power to the grid, reducing the ROI during normal operations (Figure 3-10). During emergency situations, this generator could island itself from the main grid and deliver power directly to mission essential buildings, thereby adding another layer of resilience.

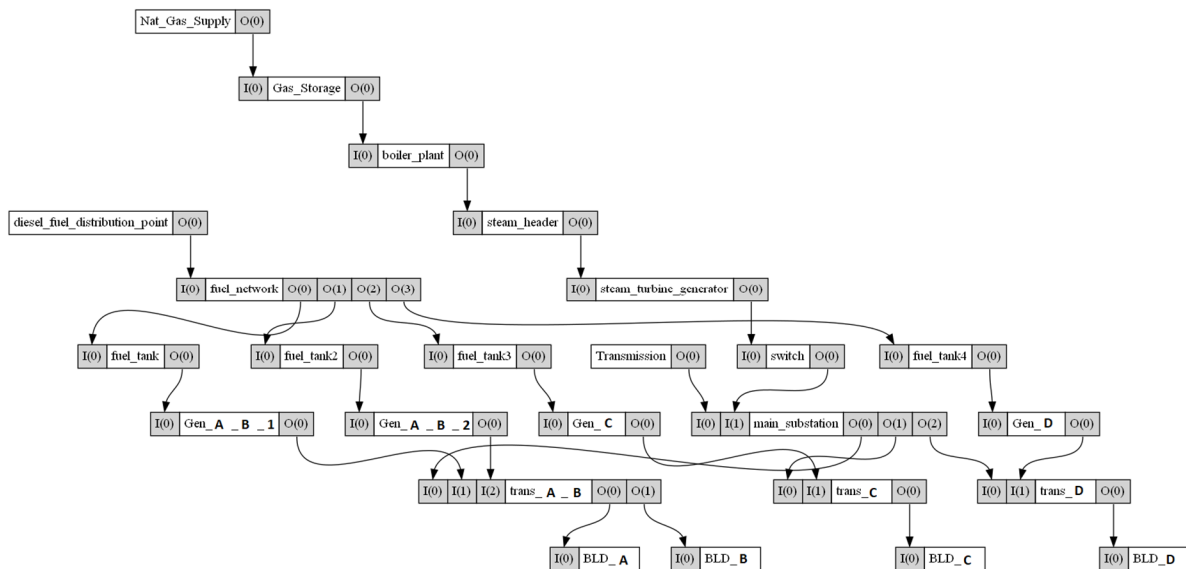


Figure 3-10. Network ports for a future case resilience analysis.

The failure rates and black sky event were identical to the Baseline and Base Case approach. This assumed that, since the CHP plant would require a significant investment into energy infrastructure, it would be placed, designed, and rated for natural disaster events, and would be rated for the modeled flooding severity.

Since the CHP and distribution systems were rated for the simulated natural disaster event, none of the loads lost power during either the blue sky or black sky events (Tables 3-20 and 3-21). This provided the small cluster of buildings with an additional layer of resilience during emergency scenarios. During normal operations, the CHP can produce power as a peaking generator, reducing the ROI for resilient energy systems.

Table 3-20. Base case electric facilities not meeting requirements during blue sky conditions.

Building No.	Gen?	Acceptable MaxSED (hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
A	Y	0.005	0.99999	0	1	1
B	Y	0.25	0.9995	0	1	1
C	Y	0.05	0.9999	0	1	1
D	Y	0.05	0.9999	0	1	1

Table 3-21. Base case electric facilities not meeting requirements during black sky conditions.

Building No.	Gen?	Acceptable MaxSED (hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
A	Y	0.005	0.99999	0	1	1
B	Y	0.25	0.9995	0	1	1
C	Y	0.05	0.9999	0	1	1
D	Y	0.05	0.9999	0	1	1

3.1.13 Implementation of design recommendations

3.1.14 Conclusion

To simplify the Fort Leonard Wood study and to test the durability of the ERIN resilience tool, only one cluster was deeply analyzed with ERIN. As mentioned, the total budget and installation goals from stakeholders must be considered. Recommended alternatives to the Baseline may vary by system architecture and components and may include energy conversion, storage options, or various distribution technologies for meeting long-term energy goals. Ultimately, the ideal solution will consider stakeholder needs, budgetary constraints, and a thorough threat analysis. This study sought to demonstrate that a thorough analysis at the installation master planning level can lead to an integrated approach that includes resilience, efficiency, and sustainability that support the entire community.

The actual implementation of design recommendations may be challenging due to the long-term nature of the project. At military installations, it is common for decision-makers such as installation commanders to have short-term assignments. Ideally, any project they are initiating

would see completion within 1 to 5 years. A way to meet both short- and long-term EMP goals is to ensure that all short-term projects fit into the long-term roadmap (e.g., achieving net-zero emissions by 2045 requires that all new buildings constructed after 2025 be net-zero). At this installation, the stakeholders did not wish to pursue the combination of the hospital with other nearby mission-critical facilities since contracts for the construction of the hospital were well underway and this change departed significantly from already established plans. Additionally, the goal to construct a new hospital as a standalone project that did not originally coordinate well with a full master plan that included longer-term installation energy resilience measures. As long as the hospital had sufficient building-level backup, this was considered sufficient to meet resilience goals for mission-critical facilities. This illustrates why it is crucial to consider the whole installation (or whole campus/community) rather than simply individual buildings (IEA EBC 2022). In the long run, this holistic approach could benefit multiple building types, including both mission-critical and support functions.

3.2 Case Study 2. Fort Wainwright

3.2.1 Introduction

The case study at Fort Wainwright, AK sought to demonstrate resilience modeling for a large-scale site in an arctic climate. This study used the integrated ERIN module within SMPL 2, which allowed the model to be developed using a graphical user interface (GUI). Fort Wainwright required a large scale study, including hundreds of individual buildings and building groups, so the GUI enabled a more manageable modeling experience. When models become large in scale, TOML files quickly become difficult to organize and debug. Furthermore, network maps such as that shown in Figure 3-10 become complex and hard to follow. The adaptability of ERIN as a standalone or integrated app allows users to adjust the tool to meet the needs of a particular study.

3.2.2 Locations and characteristics

Fort Wainwright is located in interior Alaska in the Tanana River Valley basin. The installation spans both sides of the Chena River near its confluence with the Tanana River. Wide seasonal temperature variations are common in this area with summer temperatures averaging between 10 °C and 21 °C (50 °F and 70 °F) and winter temperatures averaging between -26 °C and -43°C (-15 °F and -45 °F).

3.2.2.1 Building Overview

The study conducted at Fort Wainwright was a large-scale effort that modeled most onsite facilities. To present data efficiently, seven representative facilities were selected. These facilities were chosen due to their variety in construction (mass vs. frame), resilience goals, and standby generation capabilities.

3.2.2.2 Design Basis Threats

Threats can be organized by the effects they produce to facilitate modeling. This technique was used during the Fort Wainwright study to create four scenarios, a Baseline and three threat scenarios:

- Baseline (Blue Sky/Business as usual)
- Off Site Electrical Outage (Threat Scenario)
- Onsite Electrical Outage (Threat Scenario)
- Onsite Powerhouse Failure (Threat Scenario).

3.2.3 Baseline

This scenario lasted 1 year, or 8760 hours. Once the Baseline simulation is finished running, facilities must be evaluated for their resilience against the resilience goals for each facility. During the Baseline simulation period, almost all facilities met the required resilience metrics for electricity. Only one facility failed to meet the needed level of resilience (Table 3-22).

Table 3-22. Baseline electric facilities not meeting requirements.

Building No.	Gen?	Acceptable MaxSED (hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
IONL	N	0.25	0.9995	0.9	0.999897	0.999893
LMCN	Y	8.4	0.95	0	1	1
SVPF	Y	0.005	0.99999	0	1	1
CNXN	Y	25	0.95	0	1	1
GSQP	N	8.4	0.95	0.9	0.999897	0.999893
GGJN	N	0.25	0.9995	0	1	1
ALOT	N	50.4	0.9	0.9	0.999897	0.999893

While multiple facilities are affected by an electrical outage, Facility IONL is the only facility to fail the maximum acceptable downtime metric. Facilities GSPQ and ALOT both experienced outages of the same duration as IONL. However, these facilities have lower resilience requirements than IONL and are therefore able to meet the prescribed metrics for their facility type. The source of these downtimes was ascribed to several failures of a turbine at the central heating and power plant (CHPP). These failures involve the assigned reliability and maintenance of the turbine. Figure 3-11 shows a sample from within ERIN of the data produced for the turbine that may help the user visualize and compare the requested energy from a load or piece of equipment vs. what it is able to achieve. Figure 3-11 shows two of the previously mentioned outages. Before the first outage, only a solid line is seen, indicating that the amount of electricity requested from the turbine is being met as the solid “achieved” line is drawn over the dashed “requested” line. After June 12th, the solid line dips but the dashed line it overdrew remains the same, showing an outage of the turbine. This occurred again for a longer duration around June 22nd.

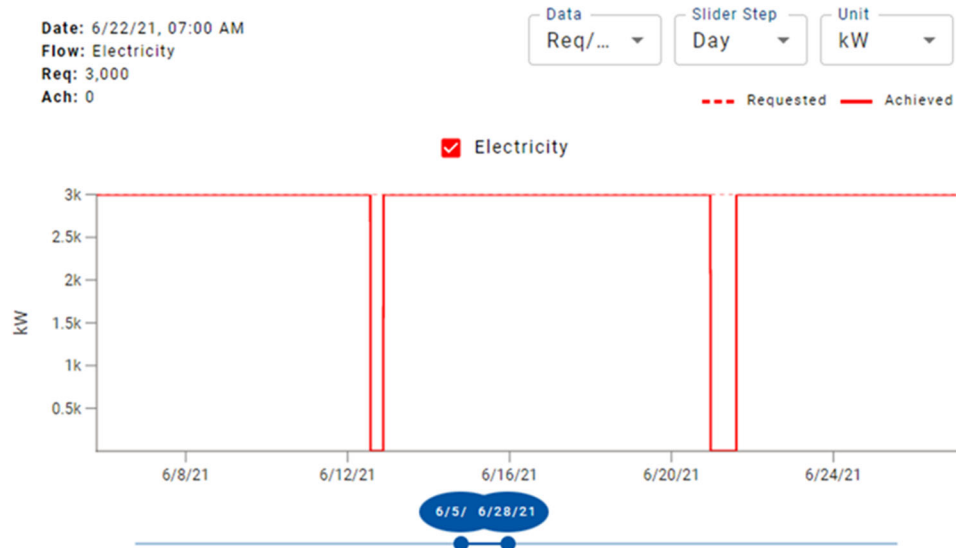


Figure 3-11. Sample turbine outages.

More outages occur during the Baseline, ranging in duration from 4 hours to as long as 13½ hours. During these times, the electrical provider is able to pick up the loads that the turbine no longer covers; this allows facilities to resume operation with minimal interruption. The longest outage, of 13.47-hour duration, occurred in early June. The installation can plan for this regular seasonal summer turbine maintenance to mitigate the effects of the outage during the lag between power supplied by the turbine and power supplied by the utility. However, since all facilities, with the exception of IONL, perform well, it appears Fort Wainwright would be resilient to this type of theoretical outage. If necessary, further mitigation for IONL may include the installation of a generator or quick connects so that mobile generation may be brought in. Some improvements may also be made with continued maintenance activities. Maintaining resilience is just as important as taking steps to reach a resilient state. For the Baseline, maintenance of resilience is both desired and appropriate. Maintenance of a resilient state includes regular preventive maintenance, testing of equipment, and consistent refresh of fuel in standby generators and tanks to avoid fuel spoilage.

The resiliency of the thermal portion of the Baseline depends on outdoor temperatures. The resilience metrics section above describes habitability and sustainability recovery times for different types of facilities at various temperatures. Facilities in the Fort Wainwright study were evaluated at the sustainability point (-40 °C [-40 °F]). These acceptable downtimes were then compared to those experienced by facilities during simulation. When one of these downtimes is exceeded by the downtime experienced by the facility, it is flagged in red. Because both electricity and steam are provided by the same turbine, the origin of the outage can be traced back to the turbine once again. The same maximum downtime of 13.47 hours is seen across several facilities. Table 3-23 lists a sampling of the facilities experiencing outages.

Table 3-23. Baseline thermal facilities.

Facility ID	MaxSED Experienced (Hours)	MaxSED for Sustainability at ODB Temperature (Hours)				
		-40 °C (-40 °F)	-29 °C (-20 °F)	-18 °C (0 °F)	-7 °C (20 °F)	4 °C (40 °F)
IONL	13.4717	18	22	28	35	47
LMCN	13.4717	36	46	59	78	112
SVPF	13.4717	36	46	59	78	112
CNXN	13.4717	18	22	28	35	47
GSQP	13.4717	18	22	28	35	47
GGJN	13.4717	18	22	28	35	47
ALOT	13.4717	10	15	21	28	41

While facility ALOT is the only one within the sample to miss the resilience requirements, it represents how 36% of facilities performed. An outage of this duration means that many facilities like ALOT will not remain sustainable when outdoor temperatures drop to -40 °C (-40 °F) or lower. These include facilities with a lower mass or frame construction type. Because the outage of longest duration occurs in June when outdoor temperatures are unlikely to reach this level, the outage is less cause for concern.

Another outage of 11-hour duration occurred in late March. Once again, because outdoor temperatures are unlikely to reach -40 °C (-40 °F) or lower during this time of year, facilities will be able to endure such an outage. Two more outages of 11-hour duration are seen, one in September and the other in November. While temperature averages in these months do not typically fall as low as -40 °C (-40 °F), outages in typically cooler months may indicate some need for remediation. However, because more than one turbine is present onsite and failure is seen in only one, it may be possible to transfer steam generation while the necessary repairs are made. For times when multiple turbines are down or when a short outage would threaten the facility's sustainability, portable boilers may provide support to those facilities requiring it.

3.2.4 Off site electrical outage

This scenario models the loss of power from the utility provider, making the installation fully dependent on onsite generation to meet electric needs of facilities. The scenario lasted for 400 hours. Table 3-24 lists results for the sample building group. At the beginning of the scenario, the connection to the electric utility is severed.

Table 3-24. Offsite outage electrical results.

Facility ID	Gen?	Acceptable MaxSED (Hours)	Acceptable Energy Availability (EA)	Model MaxSED (Hours)	Model EA	Model ER
IONL	N	0.25	0.9995	14	0.65	0.65625
LMCN	Y	8.4	0.95	1	0.952217	0.992228
SVPF	Y	0.005	0.99999	0	1	1
CNXN	Y	25	0.95	0	1	1
GSQP	N	8.4	0.95	13	0.716147	0.729262
GGJN	N	0.25	0.9995	0	1	1
ALOT	N	50.4	0.9	7	0.728647	0.733173

Some buildings never experience any outage at all. These tend to be those buildings that either have a backup generator, such as SVPF and CNCX, or that have very small loads that are easily met by onsite generation capabilities. As the scenario progresses, buildings that have outages begin to either fully or partially meet the requested load as the larger turbine at the CHPP comes online and is able to supply more facilities. Even with the full generation capacity of the CHPP, not all loads can be satisfied for the duration of the utility provider outage. IONL, GSPQ, and ALOT all miss at least one resilience requirement. Figure 3-12, which shows the requested vs. achieved loads for Facility IONL, provides a good representation of how most buildings performed during this outage. While some power is received, there is simply not enough capacity to meet peaks, so that several outages occur.

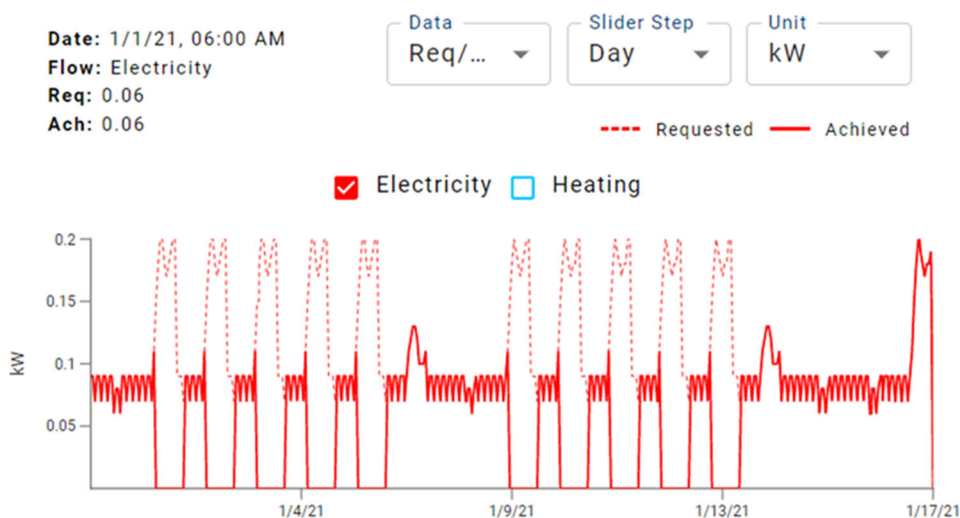


Figure 3-12. Facility IONL cannot meet loads during times of peak consumption.

Facilities IONL and GSPQ fail both the MaxSEDt and EA metrics while ALOT fails only the EA metric. This is because, while no single outage is long enough to cause a failure in the MaxSEDt category, the sum total of the multiple outages lowers the percentage of the mission time served to an unacceptable level.

Thermal results for this scenario proved unremarkable. There were no major thermal outages and all facilities met the required metrics for the duration of the event.

3.2.5 Onsite electrical outage

The onsite electrical outage scenario simulated a situation in which all capabilities to distribute electricity on site were lost. The scenario lasted 400 hours in total. Of note during this scenario is the failure of even those facilities to meet resilience requirements (Table 3-25). Facility SVPF is the only facility in the sample to maintain a fully powered state.

Table 3-25. Electric results for on base distribution outage.

Facility ID	Gen?	Acceptable MaxSEDt (Hours)	Acceptable EA	Model MaxSEDt (Hours)	Model EA	Model ER
IONL	N	0.25	0.9995	307	0.2325	0.240385
LMCN	Y	8.4	0.95	9	0.777217	0.973197

Facility ID	Gen?	Acceptable MaxSEDT (Hours)	Acceptable EA	Model MaxSEDT (Hours)	Model EA	Model ER
SVPF	Y	0.005	0.99999	0	1	1
CNXN	Y	25	0.95	307	0.2325	0.264149
GSQP	N	8.4	0.95	307	0.2325	0.240385
GGJN	N	0.25	0.9995	307	0.2325	0.240385
ALOT	N	50.4	0.9	307	0.2325	0.240385

When evaluating facility CNXN, it is apparent that, while the facility does receive support from its onsite generator for the duration of the event, the generator is only able to supply a small portion of what is requested (Figure 3-13). This causes the facility to be considered “down” since the requested load is never met before support from the CHPP and the electric utility is restored. In the previous scenario, support from the CHPP allows the generator to cover the peaks and satisfy the requested load, but the generator cannot supply the whole facility on its own. If more support is desired, the facility may require more permanent generation capacity or quick connects so that mobile generation can be brought in as needed in times of emergency.

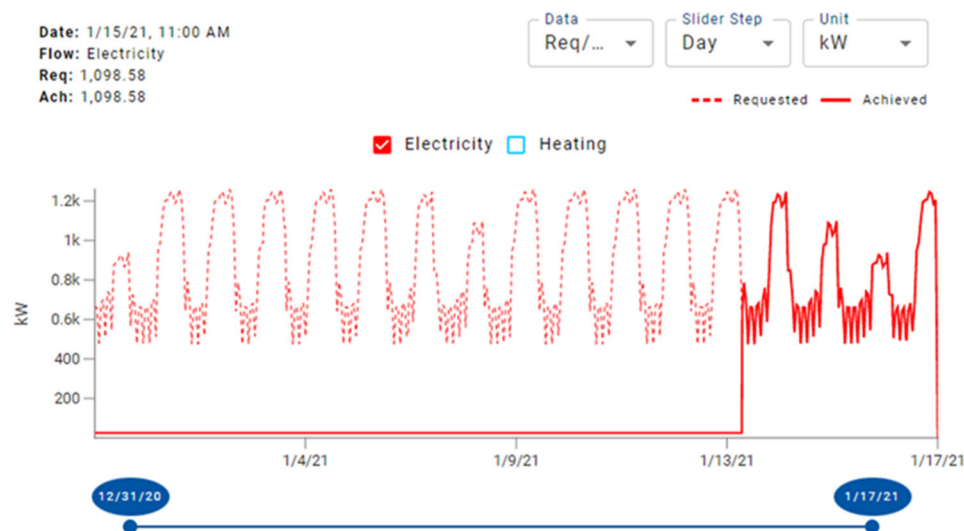


Figure 3-13. Facility CNXN requested vs. achieved.

Facility LMCN faces the same problem, however to a much lesser extent (Figure 3-14). Once again, if more support is desired, additional standby generation or mobile generation capabilities may prove useful for this facility.

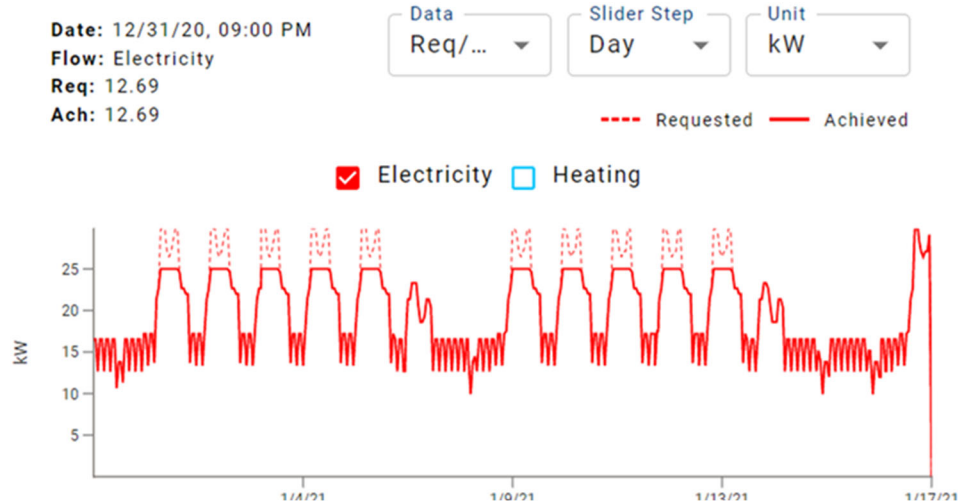


Figure 3-14. Facility LMCN cannot get enough power to cover peaks.

Because the outage is so widespread, it may be impractical to install enough quick connects and store enough mobile generators to support all onsite facilities and not just those with higher resilience requirements. Looped electrical systems or microgrids may help to mitigate this type of outage; however it is important to assess the benefits of these types of solutions vs. their cost. While such economic analysis did not play a major role in this study, it may prove an interesting subject for future study. Management of an outage of this magnitude is more important and relocation of missions and people may become necessary.

Thermal results for this scenario proved unremarkable (Table 3-26). There were no major thermal outages and all facilities met the required metrics or the duration of the scenario.

Table 3-26. Thermal results for the Off Site Electrical Outage scenario.

Facility ID	MaxSEDT Experienced (Hours)	MaxSEDT for Sustainability at ODB Temperature (Hours)				
		-40 °C (-40 °F)	-29 °C (-20 °F)	-18 °C (0 °F)	-7 °C (20 °F)	4 °C (40 °F)
IONL	0	18	22	28	35	47
LMCN	0	36	46	59	78	112
SVPF	0	36	46	59	78	112
CNXN	0	18	22	28	35	47
GSQP	0	18	22	28	35	47
GGJN	0	18	22	28	35	47
ALOT	0	10	15	21	28	41

3.2.6 Onsite powerhouse failure

The final scenario models a case in which the CHPP is taken offline. This removed the installation's capability to produce both power and steam on site. Electric distribution capabilities and connection with the electric utility provider were left intact (Table 3-27), thus facilities experienced little to no disruption in electricity as the utility was quickly able to increase supply to make up for what would have been produced on site.

Table 3-27. Power house outage electrical results.

Facility ID	Gen?	Acceptable MaxSED (Hours)	Acceptable EA	Model MaxSED (Hours)	Model EA	Model ER
IONL	N	0.25	0.9995	0	1	1
LMCN	Y	8.4	0.95	0	1	1
SVPF	Y	0.005	0.99999	0	1	1
CNXN	Y	25	0.95	0	1	1
GSQP	N	8.4	0.95	0	1	1
GGJN	N	0.25	0.9995	0	1	1
ALOT	N	50.4	0.9	0	1	1

During the steam outage, facilities are left without access to steam for periods of 278 hours. Outage times of this duration pose a threat to both facility habitability and sustainability. Sustainment of human life is essential in the event of this type of occurrence. All facilities with access to steam are affected by this outage, with those with more massive construction (higher thermal mass) able to maintain internal temperature for longer periods than other facilities with more lightweight construction (Table 3-28). Figure 3-15 provides a useful visual representation of the achieved vs. requested heating loads.

Relocation of inhabitants or portable boilers can provide potential ways to mitigate vulnerability. As previously stated, long thermal outages are of less concern during periods of mild weather, when outdoor air temperatures are warmer. Having designated cold shelters on site may also prove a valuable solution. These shelters may employ space heaters or other electric sources of heating to evacuate to so that the connection with GVEA or backup generators may be used to help sustain life while the CHPP is incapacitated.

Table 3-28. Power House outage thermal results.

Facility ID	MaxSED Experienced (Hours)	MaxSED for Sustainability at ODB Temperature (Hours)				
		-40 °C (-40 °F)	-29 °C (-20 °F)	-18 °C (0 °F)	-7 °C (20 °F)	4 °C (40 °F)
IONL	278	18	22	28	35	47
LMCN	278	36	46	59	78	112
SVPF	278	36	46	59	78	112
CNXN	278	18	22	28	35	47
GSQP	278	18	22	28	35	47
GGJN	278	18	22	28	35	47
ALOT	278	10	15	21	28	41

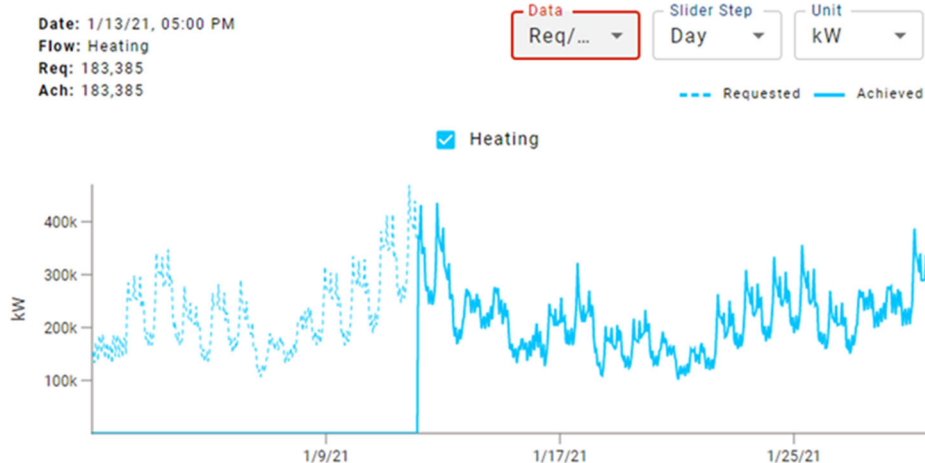


Figure 3-15. Boiler plant loads requested vs. achieved.

3.2.7 Planning for alternatives

Once a site’s vulnerabilities are identified, mitigation strategies can be tested to help gauge their effectiveness with respect to a particular vulnerability. In general, ERIN allows multiple strategies to be explored quickly to aid in decision-making.

The onsite powerhouse failure caused a widespread outage of heat; all facilities in the analysis sample lost both thermal habitability and sustainability while access to electricity remained largely unaffected. To combat the loss of heating, a diesel portable boiler was added to the model. Because backup generators already run with diesel, it should be relatively easy to integrate a diesel boiler into refueling schedules during a long event duration.

With the addition of a portable boiler, the electric results remain unchanged. This is expected since the utility is able to provide increased support and redundancy even when onsite generation is not possible. However, the additional boiler provides a considerable benefit in terms of improving the facility’s thermal resilience (Table 3-29).

Table 3-29. After Adding a portable boiler, facilities are able to maintain a habitable environment.

Facility ID	MaxSED Experienced (hours)	MaxSED for Sustainability at ODB Temperature (Hours)				
		-40 °C (-40 °F)	-29 °C (-20 °F)	-18 °C (0 °F)	-7 °C (20 °F)	4 °C (40 °F)
IONL	0	18	22	28	35	47
LMCN	0	36	46	59	78	112
SVPF	0	36	46	59	78	112
CNXN	0	18	22	28	35	47
GSQP	0	18	22	28	35	47
GGJN	0	18	22	28	35	47
ALOT	0	10	15	21	28	41

Previously, all facilities listed in Table 3-29 experienced outages of 278 hours. However, with the redundancy of a portable diesel boiler, facilities can now avoid losing heat so they meet resilience goals. Figures 3-16 and 3-17 show this redundancy.

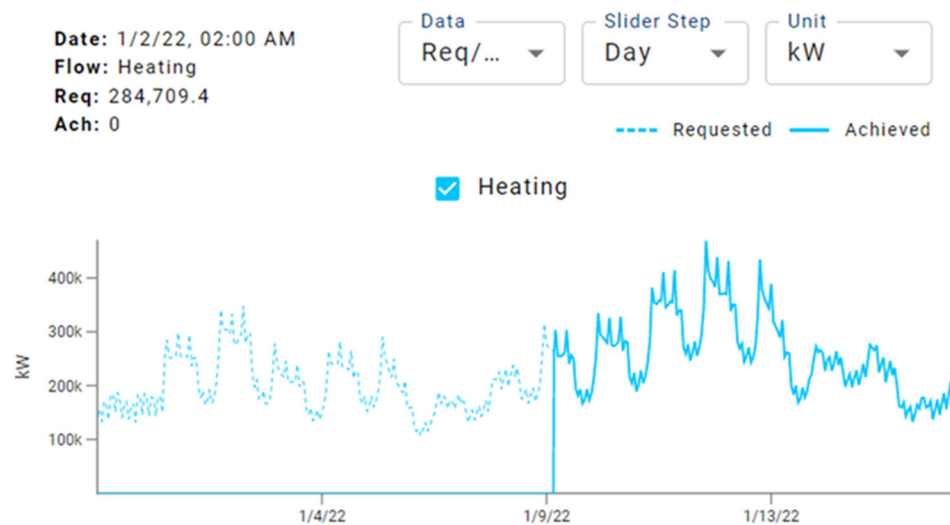


Figure 3-16. Boiler plant still undergoes outage.

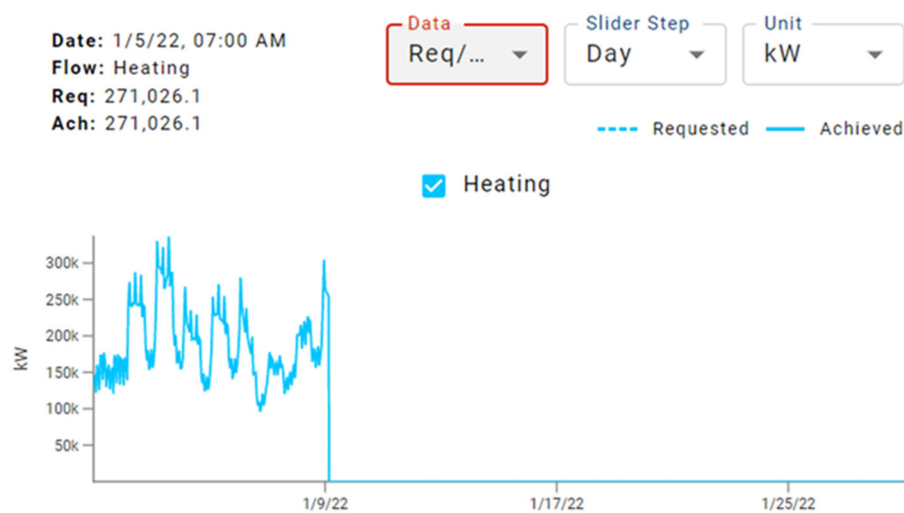


Figure 3-17. Portable boiler picks up load during event.

A comparison of Figures 3-16 and 3-17 reveals that the portable boiler meets the load that the powerhouse cannot supply. The added layer of redundancy from a separate source of heat helps to increase resilience. Now that the solution has been shown to be effective and has been prescreened by ERIN, it merits further investigation; next steps such as economic analysis can be used to determine the practicality of this solution vs. other strategies.

3.3 Conclusions

The ERIN tool is a useful part of the resilience toolkit. In both standalone and integrated applications, ERIN lets the user rapidly model and make adjustments during the resilience and master planning process. The two case studies presented provide useful insight into how the

capabilities of ERIN can be applied. The four modeled scenarios at Fort Wainwright revealed steps the installation can take to withstand and respond to threats.

A final part of Study 2 involved adding supplementary resilience measures to the powerhouse failure scenario in the form of a portable boiler. This scenario captured ERIN's ability to evaluate the effectiveness and applicability of mitigation strategies. This study also shows how the integrated user interface within SMPL 2 allows for the creation of much larger studies by more easily manipulating data and creating easily understood charts and graphs. Directly viewing the requested and achieved energy for a facility allows for quicker diagnosis of the cause(s) of an outage so the planning process can continue efficiently.

3.4 Advantages and Limitations of the Technology

3.4.1 Performance advantages

The EMP concept and the ERIN tool allow for a holistic approach to community energy master planning. The demonstrated tool is a unique, highly automated software package that can be used for an energy analysis on the community- or building-cluster levels. The analysis process, which establishes the baseline including data collection and analysis, follows these steps:

1. Setting up groups of building
2. Selecting energy efficiency measure (EEM) packages for building groups
3. Running EEMs building level model for the baseline and resulting data calibration against the metered data
4. Running EEMs building level model the Base Case and scenarios
5. Selecting building clusters for scenarios and establishing load profiles for these building clusters
6. Setting up data for energy generation and distribution for scenarios
7. Running energy generation and distribution models for scenarios
8. Modeling results in analysis and iteration as needed.

These steps of data collection and analysis, and establishing the baseline are not unique to this approach; they are required in all currently available EMP approaches and take the same effort and time, which depends on the data availability and experience of the team.

Grouping buildings by categories and era of construction can be done more quickly using the tool since it has a database with pre-set packages of technologies and energy use intensity (EUI) associated with different building types. This feature also eases the selection of EEM packages for different levels of building energy renovation.

Another unique feature of the tool is its ability to provide both building-level energy consumption modeling, and a cluster-level energy generation and distribution modeling and equipment selection, with an easy iteration of building models. For example, if optimization of the cogeneration process results in excessive waste heat, the energy efficiency at the building level can be adjusted.

3.4.2 Cost advantages and limitations

Development of an Energy Master Plan requires an up-front investment in long-term planning that can cost as much as a few hundred thousand dollars. However, these investments can be paid back from savings resulting from the implementation of one or few projects implemented under the holistic energy roadmap. Application of the EMP concept and the ERIN tool will require training and experience in energy master planning.

3.4.3 Social acceptance

The main barriers/bottlenecks to the development of energy-efficient installations/communities planning and implementation that must be addressed include defining the following vision and energy targets:

1. Process and organization
2. Management support and involvement
3. Skills and know-how
4. Understanding of technical concepts
5. Monitoring the progress
6. Familiarity with tools and methods for analysis
7. Project financing
8. Legal issues
9. Spin-offs.

Bottlenecks most commonly occur in the areas of large project financing; holistic project design; and the installations' commitment to deep energy retrofits, procurement, quality assurance, and collaboration between different trades. Bottlenecks are often characterized by short-term thinking, separation of implementation and operation, lack of incentives to achieve energy and resilience goals (including a lack of negative consequences for energy inefficiency and insufficient resilience), segmentation of organizations, lack of coordination between different projects executed within the same organization, etc.

4.0 PERFORMANCE OBJECTIVES

4.1 Demonstration of the EMP concept and the ERIN tool at two DoD installations

The goal of this project was to demonstrate the EMP concept and the ERIN tool at two DoD installations, and through that demonstration, to show how their use enables a streamlined energy planning and resilience analysis process that results in a roadmap to meet or exceed the installations' energy goals at a life-cycle cost less than that resulting from the implementation of the Base Case, which was developed using the current master planning process.

4.2 Scalability across DoD

Besides its use on pilot projects was funded by ESTCP, the ERIN tool is currently being tested at other installations. During its work on this project, ERDC collaborated with Big Ladder Software Company to conduct technology transfer to Federal and private sector teams that provide support to DoD installations. All DoD installations can therefore benefit from adapting this demonstrated concept, and from implementing and applying the associated software package.

5.0 PROJECT MANAGEMENT AND CUSTOMER INVOLVEMENT

This project was executed under the oversight of ESTCP management and its technical committee, by the ERDC team in collaboration with SC-B Company and Sandia National Laboratories, NREL, and Oak Ridge National Laboratory (Figure 5-1). The project manager developed clear, open communication channels with the management of each installation and their respective commands. Funding from ESTCP program was leveraged by collaboration, under the International Energy Agency's *Energy in Buildings and Communities Annex 73* program, with experts from 36 organizations representing eight countries: Australia, Austria, Denmark, Finland, Germany, Norway, the UK, and the United States (Figure 5-2).

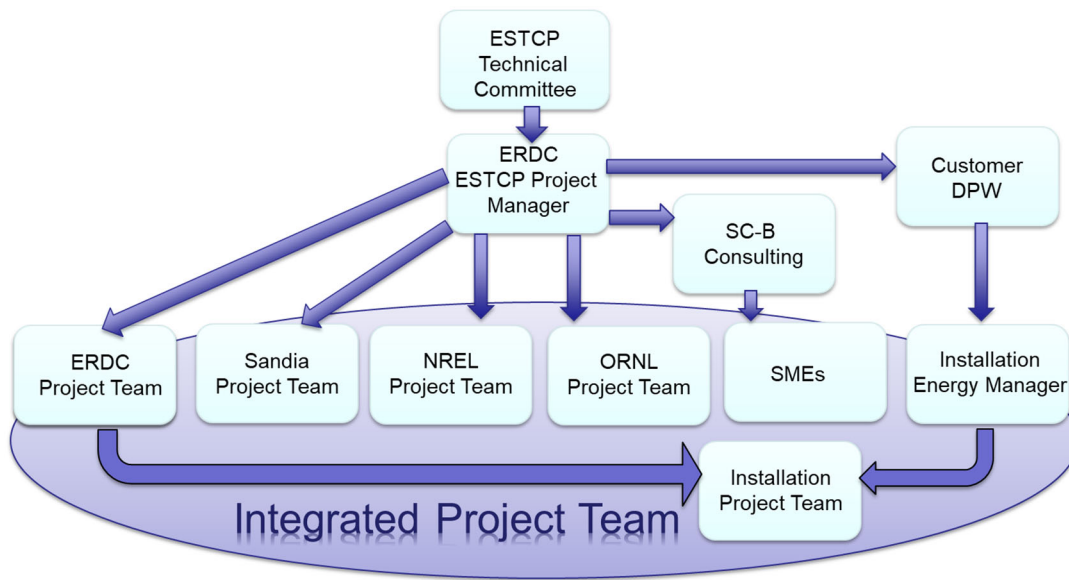


Figure 5-1. Project execution and oversight.



Figure 5-2. Broad collaboration under IEA EBC Annex 73 contributed to EW18-D1-5281 project.

6.0 COST ANALYSIS AND COMPARISON

This chapter will provide a comparison of time and cost necessary to conduct a resilience study by hand calculations, by using the standalone ERIN tool, and by using the ERIN tool with the SMPL GUI.

The data in Table 6-1 summarize the cost of the energy resilience modeling process based on model size and modeling method. Estimates for hand calculation reference the costs and time cited to perform an Energy Master Plan by hand in ESTCP report EW-201240 (ESTCP 2016). Researchers used their experience with the modeling process of Fort Wainwright, Fort Leonard Wood, and Training models to inform the estimates derived using the ERIN TOML and ERIN GUI methods. The provided cost totals assume that the typical installation will require three modeled networks (e.g. electric, steam, and chilled water). In general, the costs of the ERIN modeling process are made up of:

1. *Labor*: The total time it takes the subject matter expert (SME) to assemble the model and report. This work is typically performed by one to two people and takes several weeks to complete depending on the amount of information available before modeling begins. This work includes:
 - a. Discussion with site personnel to determine study scope and perform general information gathering
 - b. Initial data processing and study preparation
 - c. Creation and calibration of initial model
 - d. Creation of additional model scenarios
 - e. Bug fixes and adjustments to model
 - f. Report Preparation.
2. *Training*: The time and cost to *train* new users to conduct studies using ERIN. This cost should *decrease* over time as more users become familiar with the resilience modeling process

Table 6-1. Cost of labor hours by modeling method and installation size.

Model	Hand Calculation		ERIN TOML		ERIN GUI	
	Labor Hours	Total Labor Cost @\$100 per Hour (\$)	Labor Hours	Total Labor Cost @\$100 per Hour (\$)	Labor Hours	Total Labor Cost @\$100 per Hour (\$)
Small Model (0-100 Buildings)	1290	\$129k	75	\$7.5k	28	\$2.8k
Medium Model (100-200 Buildings)	1500	\$150k	150	\$15k	56	\$5.6
Large Model (200-300+ Buildings)	1725	\$172.5k	375	\$37.5k	105	\$10.5k

The data in Table 6-1 indicate that the example of a small model which includes networks for steam, electricity, and waste provides a good comparison of costs. A small model with three networks and 28 hours in labor has total modeling cost of \$2800 when using the ERIN GUI. Assuming report preparation time and cost is fixed regardless of the modeling method, using the ERIN tool provides significant savings over performing the same analysis by hand, which would consume 1290 hours of labor and \$129, 000 to conduct without the ERIN tool. Using these costs, the ERIN GUI provides a savings of 98% compared to performing analysis by hand.

The cost to develop IEWPs further highlights the benefit of the ERIN tool. Given that the typical IEWP has a budget of \$250k to \$500k, the small example installation consumes over half of the IEWP budget with a lower level of funding. As funding is expected to increase with the size of the installation for which the IEWP is being prepared, a large installation with 500k of funding would still see ~35% (\$172.5k) of the budget consumed by the resilience modeling process alone. This makes hand calculation for this type of analysis cost ineffective as compared to using the ERIN GUI. While these examples assumed three networks, costs will increase or decrease corresponding with the size and complexity of the model for ranges considered non-typical.

7.0 CONCLUSIONS

This project resulted in a number of novel and useful capabilities in the area of energy master planning and resilience analysis for military installations. As a starting point, an integrated Energy Master/Resilience Planning process was developed that explicitly identifies key additional inputs and steps required in the Energy Master Planning process to accommodate resilience planning (Figure 2-1).

The integrated approach developed under this project results in the cost-effective analysis of energy systems under normal (blue sky) conditions and in a less vulnerable, more secure, and more resilient energy supply to the community's critical mission functions during emergency (black sky) scenarios. The approach provides a framework for the planning process and outlines the following main steps: (1) establishment of energy framing goals and constraints, (2) assessment of a community's critical missions and functions, (3) assessment of community-specific threats, (4) establishment of energy requirements for normal and mission-critical functions, (5) assessment of the current situation (baseline) to understand existing gaps against framing goals and constraints, and (6) development of future alternatives, including "business as usual" (base case) and more advanced alternatives of energy systems.

The developed quantitative metrics for resilience include Energy Availability (EA), Energy Robustness (ER), Maximum Single Event Downtime (MaxSEDt), and Energy Quality (EQ). These metrics are described in section 2.6. In addition to capturing time with unserved critical loads, together they yield a measure of how quickly services are restored. An approach was also created to establish quantifiable resilience requirements, goals, and targets, and by differentiating mandated requirements from non-required (but good-to-have) goals. The resilience of energy systems in extreme climates such as arctic and hot/humid climates was addressed, and experimental and modeled data were analyzed to consider the thermal resilience component contributed by a building's envelope (Table 2-4). The ERIN tool developed by this project also informs an economic analysis of alternative configurations, which is important in both energy master planning and resilience planning, and which is further documented in the International Energy Agency Annex 73 guide documented at the following URL:

https://annex73.iea-ebc.org/Data/publications/EMP_GUIDE_20211026.pdf

One of the major objectives of this project was to develop a simulation tool (ERIN) that would address energy resilience in terms of the fragility of a given infrastructure to various types of threats. Key capabilities of the ERIN tool (described in section 2.8) include the ability to handle single (e.g., a building) and/or aggregated loads with any sort of energy or physical flow (e.g., electricity, water), threat-specific fragility of components, customizable probability distributions, the economics of mitigation strategies, as well as the many other capabilities documented above. By contrast, the DoD Energy Resilience Assessment excels at assessing aggregated critical loads under blue sky and black sky conditions, rather than assessing only threat-specific fragilities (<https://osdera.ll.mit.edu/era/home/#/>). The standalone tool can run as an executable application using text-based input files, which makes it ideal for incorporation into other planning tools.

This report considered two methods of conducting resilience analysis (ERIN TOML and ERIN GUI methods):

1. A manual method performed by running a standalone building energy analysis and spreadsheets, with the standalone text-file-based ERIN tool and with a version of ERIN integrated with the SMPL Tool. As discussed in the economics section above, the manual process was considered to be cost ineffective considering the available budget for most EMP projects. For very simple models, the text-based ERIN tool is completely adequate. Once they have become familiar with the tool, users can mentally conceptualize the model with ease. However, as the number of components and connections grow, it becomes increasingly difficult to manage the components, connections, statistical distributions, failure modes, fragility modes, and scenarios. Consequently, the text-based version becomes highly error prone and difficult to debug when the modeler introduces errors in the system. In addition, the user must manually create energy load profiles for components and conduct research to find input data for equipment component, especially with respect to MTBF, first cost, and operating costs.
2. In a second method, the ERIN tool was incorporated into the SMPL Energy Master Planning tool as a module. SMPL provides an easy-to-use GUI that simplifies creation and editing of models. When integrated with SMPL, components are dropped onto a map and connected graphically. SMPL contains a database of components (backup generators, boilers, fuel tanks, etc.) drawn from the guide produced for this project, including reliability information when available. The system reduces the complexity of the process by producing the input file, including potentially thousands of connections. It also post-processes and displays various reports produced by ERIN, making them more easily accessible and understandable by the user. Figure 2-9 shows an example of an ERIN network created using the SMPL GUI.

The SMPL/ERIN integration offers additional benefits, including automatic import of building energy loads, a database of energy components from the energy architecture library described in section 2.7. The research team found that the ERIN tool provides both cost and time savings benefits compared to other methods of resilience analysis or hand computation of similar data. This is to say, that the ERIN tool provides access to an analysis that is otherwise complex and time consuming to conduct by hand and is rapidly adaptable once the initial model is established. This means that changes can be made to accommodate shifting requirements without requiring a new model to be built from scratch. The use of the SMPL GUI provides some less tangible benefits in that it offers the ability to visualize the network and analysis results. This eases the debugging of electrical and thermal networks and the interpretation of results. In conclusion, the ERIN tool as implemented in the SMPL GUI was a usable, useful, and cost-effective tool for resilience analysis compared to more manual and labor intensive methods.

8.0 PROJECT BASED PUBLICATIONS

8.1 Technical Papers

- Axelarris, Lyle, Aaron Cooke, Craig Fredeen, Robbin Garber-Slaght, Emmett Leffel, Lorne Ricketts, William Rose, John P. Zarling, and Alexander Zhivov. 2021. “Best Practices for HVAC, Plumbing and Heat Supply in Arctic Climates.” *ASHRAE Transactions*. Vol. 127, Part 2.
- Dyrelund, Anders, Robert M. Neimeier, Hasmik Margaryan, and Anders B. Møller. 2021. “Energy Master Planning for Resilient Public Communities – Best Practices from Denmark.” *ASHRAE Transactions*. Vol. 127, Part 1.
- Fulterer, Anna Maria, Ingo Leusbrock, Gert Widu, and Dirk Jäger. 2021. “Energy Master Planning for Resilient Public Communities - Best Practices from Austria.” *ASHRAE Transactions*. Vol. 127, Part 1.
- Gudmundsson, Oddgeir, Anders Dyrelund, and Jan Eric Thorsen. 2021. “Comparison of 4th and 5th Generation District Heating Systems.” *E3S Web of Conferences: Cold Climate HVAC & Energy 2021*. Vol. 246. Article No. 09004. <https://doi.org/10.1051/e3sconf/202124609004>.
- Jeffers, Robert F., Amanda Wachtel, Avinash Srivastava, Calum Thompson, Alexander Zhivov, and Patrick Daniels. 2020. “Integration of Resilience Goals into Energy Master Planning Framework for Communities.” *ASHRAE Transactions* Vol. 126, Part 1.
- Leffel, Emmett. 2021. “Building Enclosure Testing on Alaska Military Base Projects.” *ASHRAE Transactions*. Vol. 127 Part 1.
- Liesen, Richard J., Brianna Morton, Brandy Diggs-McGee, and Alexander M. Zhivov. 2021. “Thermal Energy System Resilience: Thermal Decay Test (TDT) in Cold/Arctic Climates, Part II Modeling.” *ASHRAE Transactions* Vol. 127, Part 2.
- Morton, Brianna, Richard Liesen, Mike Case, Madison Wallace, Bjorn Oberg, and Alexander Zhivov. 2022. “Resilience Analysis of Thermal and Electric Energy Systems in Cold Climates.” *Conference Proceedings: ISEC- 2nd International Sustainable Energy Conference. April 2022. Graz Austria*.
- O’Keefe, Michael, Peter Ellis, Richard Liesen, Alexander Zhivov, and Anthony Latino. 2021. “A Tool for Modeling Energy and Resilience for Community-Scale Networks of Buildings and District Systems.” *ASHRAE Transactions*. Vol. 127, Part 1.
- Oberg, Bjorn, Angela Urban, Emmette Leffel, Jonathan Goebel, Matt Perry, Dragos Vas, Dayne Broderson, Richard Liesen, and Alexander Zhivov. 2021. “Thermal Energy System Resilience: Thermal Decay Test (TDT) in Cold/Arctic Climates, Part I Data Collection and Protocol.” *ASHRAE Transactions*, Vol. 127, Part 2.
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APPENDICES

Appendix A. Points of Contact

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