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Sun Prairie Library Microgrid Feasibility Analysis & Community Resiliency Planning

CITY OF
SUN PRAIRIE
Wisconsin

slipstream

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ACRONYMS

AVERT: Avoided Emissions and Generation Tool

BESS: Battery Energy Storage Systems

CRC: Community Resiliency Center

DER: Distributed Energy Resource

DOE: Department of Energy

EIA: Energy Information Administration

EOC: Emergency Operations Center

EPA: Environmental Protection Agency

GIS: Geographic Information System

HVAC: Heating, Ventilation, and Air Conditioning

kW: Kilowatt

kWh: Kilowatt-hour

NREL: National Renewable Energy Lab

NPV: Net Present Value

NO$_X$: Nitrous Oxides

PV: Photovoltaics

PSC: Public Service Commission

PM$_{2.5}$: Particulate Matter 2.5

SCADA: Supervisory Controls & Data Acquisition

SO$_2$: Sulfur Dioxide

SPPL: Sun Prairie Public Library

VAV: Variable Air Volume

VRF: Variable Refrigerant Flow

WWTF: Wastewater Treatment Facility

DEFINITIONS

Emergency Operations Center (EOC): An established control facility from which emergency operations can be directed and coordinated. In an EOC the local and State staff and officials receives information relating to an incident. This is where the decision makers and support agencies should report to supervise an evacuation. The main functions of EOC include: (1) provides direction, coordination, and support to emergency operations; (2) carries out disaster management functions at a strategic level in an emergency situation; (3) ensures the continuity of operation of a company, political subdivision or other organization; (4) collects, gathers, and analyzes data; (5) makes decisions that protect life and property; (6) maintains continuity of the organization, within the scope of applicable laws; and (7) disseminates those decisions to all concerned agencies and individuals.

Community Resiliency Center (CRC): Facilities designed to provide emergency heating and cooling capability to building occupants and vulnerable community members; refrigeration of temperature-sensitive medications, vaccines, and milk from nursing mothers; plug power for durable medical equipment (to include dialysis equipment and continuous positive airway pressure machines); plug power for charging of cell phone and computer batteries; and/or emergency lighting. A CRC may also be a designated location (by the city, county, or State of Wisconsin) for the distribution of emergency services during extended grid outages. This center would not necessarily be a replacement for an emergency shelter and should not be required to have food service capabilities, showers, or locker rooms.

Microgrid: A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.

Capital Asset Inventory: Capital assets related to community resiliency include roads and bridges, water, wastewater, and storm water systems; public buildings; parks and open spaces; and communication and information management equipment/infrastructure. Antero software is currently used at WWTP and a suitable candidate for a city-wide operational solution.

Roles & Responsibilities: These definitions are specific to the City of Sun Prairie and involves multiple departments and key points of contact. The following staff are involved in any emergency operations:

- City Administrator – Cross-departmental Facilitator
- Finance Director – Coordinates resources and funds related to emergency management
- Public Works Director – Identifies & mobilizes key city assets, equipment
- Fire Chief - Emergency management coordinator
- EMS Chief - Emergency management coordinator
- Police Chief – Designated Emergency Management Director
- Sun Prairie Utilities – Utility infrastructure monitoring & management

EXECUTIVE SUMMARY

As climate change normalizes extreme weather events, community resiliency is put to the test. In response, the City of Sun Prairie is actively working to identify needed resiliency efforts and strategy. As an initial step, the City of Sun Prairie undertook an assessment of the feasibility of establishing the Sun Prairie Public Library (SPPL) as the city's first Community Resiliency Center (CRC). The Public Service Commission (PSC) of Wisconsin funded the project and Slipstream led the technical analysis.

The goals of the study were to evaluate integrating a solar photovoltaic (PV) array and battery energy storage system (BESS) into a microgrid. City staff wanted to better understand the system configurations needed to provide emergency heating and cooling, lighting, refrigeration, and plug power for medical equipment or charging of essential devices at the library. The analysis considered the ability of the microgrid to provide those services between four hours and an entire day. The specific research questions were:

1. What are potential BESS configurations to meet load needs at SPPL, and what are the associated costs and benefits?
2. How does a BESS perform in comparison to a diesel generator at SPPL?

The feasibility analysis examined four scenarios in depth to consider financial, operational, resiliency, and environmental impacts. The scenarios included both an all-electric variable refrigerant flow (VRF) system and a conventional variable air volume (VAV) system with a natural gas boiler for the library, where a major expansion with all-new mechanical systems is currently being planned. We also included the option of only meeting a reduced electric load, the critical load, during an outage. All scenarios were required to be able to cover an outage starting on a summer afternoon and continuing for the defined length of the scenario. The final four scenarios were:

- All-electric VRF heating, 4-hour outage constraint at full load
- All-electric VRF heating, 24-hour outage constraint at critical load
- Conventional natural gas VAV, 4-hour outage constraint at full load
- Conventional natural gas VAV, 24-hour outage constraint at critical load

The study findings illustrate that a microgrid at Sun Prairie Public Library can help meet several community goals: increased use of renewable energy and improved resiliency communitywide. The microgrid can help provide these benefits and generate net financial savings over the lifetime of the system. As the city continues to study the feasibility of installing a microgrid during the renovation and expansion process, several key takeaways are important to consider:

- **All-electric heating systems improve the financial performance of a microgrid.** The all-electric heating systems performed better than a conventional VAV system with natural gas boiler. This is primarily a function of increased energy cost savings for the all-electric systems as more of their load corresponds with times when solar production is high.

The all-electric systems also performed better when the monetary value of resiliency was included as the microgrid covered a higher critical load that included all heating. The all-electric heating system is naturally a more resilient solution as it does not require natural gas distribution, which can often be negatively impacted during a winter emergency, to provide the benefits of a CRC.

- **Solutions designed to withstand 4-hour outages perform better financially when including only energy savings but have lower resiliency benefits.** Both scenarios that required the configuration to withstand a 4-hour outage had higher NPVs than their 24-hour counterparts. This is primarily due to the lower upfront costs for BESS.

  However, the systems have lower resiliency across the year, even if they only need to cover critical load. When considering the monetary value of these resiliency benefits, NPVs of the 24-hour systems improve. In fact, the all-electric 24-hour solution outperforms the all-electric 4-hour solution when those costs are included.

- **Resiliency is highest during the shoulder seasons and all system configurations examined have a lower probability of withstanding outages in the winter.** The highest amount of energy disturbances has historically occurred in the summer in Wisconsin. As we utilized that timing for our outage constraint, all systems were best suited to withstand outages in the spring and summer. Resiliency was highest in the shoulder seasons when space conditioning needs are low and solar production is high. However, all the scenarios and especially the all-electric VRF systems have limited ability to withstand an outage of any length in the winter months. A larger BESS and solar system would be needed to ensure winter outages were covered by the system.

- **Including societal benefits increases the NPV of the scenarios by at least 10 times as compared to having no distributed energy resources (DERs) on-site.** All scenarios provide significant environmental and health benefits by reducing reliance on fossil fuels and the resulting carbon and criteria pollutant emissions. The all-electric VRF scenarios result in ~50 percent of all energy coming from renewable sources while the natural gas conventional VAV scenarios result in ~25 percent of all energy coming from renewable sources.

  Across all scenarios, the monetary value of the reduced emissions is significant and leads to NPVs over 10 times higher than the NPV that only includes financial benefits.

Based on these takeaways, we recommend that Sun Prairie prioritize an all-electric VRF heating system upgrade and a microgrid that can withstand a 24-hour outage. The city should consider the upfront costs of the all-electric upgrade versus the natural gas conventional VAV system in their process – but recognize that the all-electric VRF system paired with the solar and BESS system gets the city much closer to its renewable energy and resiliency goals. We recommend the larger system as it still results in a positive net present value and ultimately provides much greater resiliency benefits. To offset upfront costs, the library can upgrade systems in a phased approach to enable an eventual microgrid. These steps can start with ensuring extensive efficiency upgrades are included as part of the renovation and then proceed with installing solar panels. The BESS can then be installed when the city is ready to further invest in creation of the microgrid.

Analysis Considerations Summarized

Table 1 demonstrates the takeaways by detailing the performance outputs for each of the four final scenarios. The NPV in this table is calculated over 25 years and includes the energy and demand savings and export credits as benefits. It does not include the difference between the upfront cost of the two heating, ventilation, and air conditioning (HVAC) systems. The results show that the 4-hour full load scenarios perform better financially due to the lower BESS size. However, the results show that the average resiliency hours are significantly higher for the 24-hour critical load scenarios.

The conventional VAV systems perform worse financially than compared to the all-electric VRF systems. This is primarily due to the increased BESS energy capacity compared to the all-electric VRF scenarios. The increased BESS energy capacity is related to the larger demand for cooling from the less efficient VAV system, while the smaller solar size is due to lower overall electric loads, especially in the winter as heat is provided by a natural gas boiler.

The percent renewable energy represents the total building consumption, including natural gas usage. The scenarios with a VAV system have a significantly lower percent renewable energy as a result as the entire space and water heating load being met by natural gas.

Table 1. Final scenarios key performance outputs.

	All-Electric VRF		**Conventional VAV**	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
Solar Size (kW)	144	128	132	112
BESS capacity (kW)	28	26	28	29
BESS energy (kWh)	45	128	48	159
Net Present Value	$27,000	$7,200	$14,900	($17,500)
Payback Period	17.2	18.9	17.9	20.6
Average Resiliency Hours	3.5	35.2	3.9	34.1
Percent Renewable Energy	54%	48%	28%	24%

INTRODUCTION

As climate change normalizes extreme weather events, grid and community resiliency are put to the test. To respond to this growing need, the city of Sun Prairie is actively planning its resiliency efforts and identifying needed resiliency centers. With funding from the Wisconsin Public Service Commission and in partnership with Slipstream, the City of Sun Prairie assessed the feasibility of the Sun Prairie Public Library (SPPL) serving as the city's first Community Resiliency Center (CRC). A CRC is a facility designed to provide emergency heating and cooling capability; refrigeration of temperature-sensitive medications, vaccines, and milk from nursing mothers; plug power for durable medical equipment; plug power for charging of cell phone and computer batteries; and/or emergency lighting.

The goals of the study were to evaluate integrating a solar photovoltaic (PV) array and battery energy storage system (BESS) into a microgrid. The city was particularly interested in an all-renewable solution to resiliency to also help meet its goals for 100 percent renewable electricity for city operations by 2025. City staff at Sun Prairie wanted to better understand the system configurations needed to provide emergency heating and cooling, lighting, refrigeration, and plug power for medical equipment or charging of essential devices at the library.

The analysis considered the ability of the microgrid to provide those services between 4 hours and an entire day. The specific research questions were as follows:

1. What are potential BESS configurations to meet load needs at SPPL and what are the associated costs and benefits?
2. How does a BESS system perform in comparison to a diesel generator at SPPL?
3. What are the considerations for a microgrid at sites with existing backup diesel generators?

The analysis also considered how a highly energy efficient building design, including a fully electric option, would impact the energy load in the future and the performance of the microgrid. In parallel to the library analysis, the city inventoried all diesel generators and associated city facilities to develop a larger plan around resiliency.

This report starts by providing project background. We then describe the methodology and results of the Sun Prairie microgrid planning. The results highlight the tradeoffs between different system configurations to inform future microgrid planning, however a more in-depth analysis would be needed if the city decided to proceed with a microgrid installation. We then detail Sun Prairie resiliency planning efforts that happened in conjunction with the feasibility study and conclude with a checklist of microgrid considerations for other sites in Sun Prairie and recommendations for SPPL.

PROJECT BACKGROUND

Built in 1998, the Sun Prairie Public Library's mission is to serve the community as an activity center. The library supports lifelong learning by providing educational, cultural, and recreational opportunities for all people with a vision to serve as a dynamic, positive force in the community. The library connects residents with the world of ideas, literacy, literature, and information. It aspires to create opportunities for all residents to participate, connect, and discover through their dynamic library resources and services.

With this mission in mind, the facility already serves a variety of functions that meet the current working definition of a CRC:

- The library community room is designed as a storm shelter room, with thicker walls and shutters that can allow it to serve as a hardened shelter during emergencies.
- The library serves as a vaccine clinic. The vaccine clinics are ongoing and operate every Saturday from 1 to 4 pm.
- The library is used heavily by under-resourced members of the community for a variety of critical activities and resources, including telehealth appointments, food assistance, online bill payment, tax preparation, test proctoring, academic and career test preparation, broadband access, and workforce development, including resume creation, job searching, and career coaching.
    - The library hosts non-profit and community action organizations that connect residents with various critical services, including workforce development programs, rental assistance, COVID-19 related resources, and mental health resources.
- The library building hosts the Sun Prairie Media Center, which helps with important communications during emergency situations across the community.

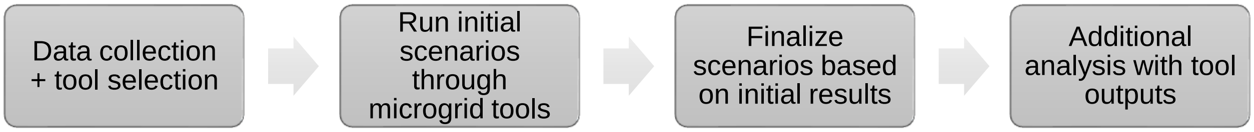
The SPPL is currently 36,000 square feet and has no distributed energy resources (DER). The city is currently engaged in a design and construction project with plans for a major renovation which will increase the library to 65,000 square feet and add a minimum of 100-kilowatt (kW) array of solar panels by 2024.

FEASIBILITY STUDY METHODOLOGY

We utilized four analysis phases to study the feasibility of the SPPL microgrid. We started with a data collection effort and review of available tools for analysis. We collected energy, cost, technology, and site data to use as inputs in the analysis. With a set of initial data, we ran several initial scenarios through the analysis tools and compared the high-level results to identify a set of final alternatives for the library. From there, we conducted additional analysis on the final alternatives of interest, including more advanced load modeling and additional analysis around resiliency benefits.

Figure 1 illustrates the four phases of analysis. The following section provides additional detail on the tool selection process and the data inputs utilized for the analysis.

Figure 1. Feasibility study analysis.



TOOL OVERVIEW

Through a literature review, we found seven reputable tools for microgrid and DER scenario analysis.[1] Once the candidate tools had been identified, we developed a critical features matrix to use when evaluating each tool. The features that were evaluated and the desired criteria are shown in Table 2. Features are listed in order of importance to the analysis.

Table 2. Microgrid analysis tool critical features and criteria for each site.

Feature	**Sun Prairie requirement**
Resiliency analysis	Satisfy minimum load and duration for backup coverage
Custom load profile	Model a known hourly load profile
BESS modeling	Optimize for BESS capacity and dispatch. Consider BESS degradation.
Hourly results	Provide hourly dispatch results to allow for supplemental analysis
Optimization	Optimization algorithm should select component size and dispatch to maximize life-cycle benefits
Back-up generator	Optimize for diesel generator size
License	Free and open-source products preferred to allow for dissemination of results across stakeholders.

Next, we reviewed the literature about these tools and consulted documentation and user forums to determine whether each tool met these requirements. We qualitatively analyzed each tool to determine if the requirement was fully met, partially met, or not met, represented through filled, half-filled, and unfilled Harvey balls, respectively (Table 3). In some cases, we could not

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[1] Krah, "Behind-the-Meter Solar + Storage Modeling Tool Comparison"; Tozzi and Jo, "A Comparative Analysis of Renewable Energy Simulation Tools."

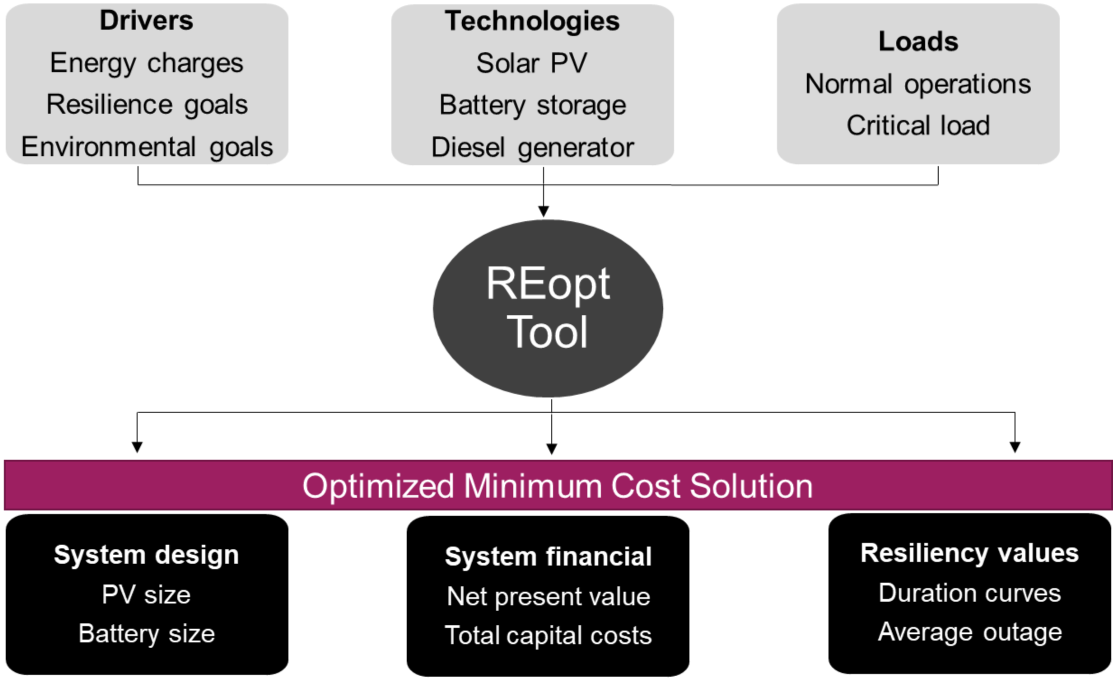
determine if a requirement was met, or we ended our evaluation after identifying that a tool did not meet the critical requirements. In these cases, the associated cell in the matrix is left blank.

Table 3. Critical feature matrix for the eight microgrid analysis tools considered.

Critical features	REopt	DER-VET	HOMER	DER-CAM	SAM	ESyst	MDT
Resiliency	●	●	●	◐	○	○	●
Custom load profile	●	●	●	◐	●	●	◐
BESS modeling	◐	●	●	◐	●	●	-
Hourly results	●	●	●	○	●	○	-
Optimization	●	◐	●	●	◐	○	●
Back-up generator	◐	◐	●	●	○	○	○
License	●	●	○	◐	●	◐	◐

Based on our analysis, we proceeded with REopt due to its ability to meet each of the priority features and its use of an open-source license and API (application programming interface, allowing the use of a scripting language to programmatically run scenarios). Figure 2 illustrates ReOpt's inputs and outputs.[2] The user inputs the technology of interest, resiliency or environmental goals, energy costs, and load profile. The tool finds the least-cost option that satisfies the goals and provides the recommended system size and the system financial and resiliency outputs. The least-cost option is based on NPV calculated over a 25-year lifetime.

Figure 2. Reopt optimization method.



To model resiliency, the tool requires the user to input the length and timing of an outage the optimal system should be able to withstand (e.g. June 19 from 1 to 5 pm). The tool then finds

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[2] Anderson et al., "REopt Lite User Manual."

the least-cost option system that can withstand an outage at that time while still providing the load required. After the tool finds the least-cost option for that constraint, it evaluates resiliency (or length of outage the system could sustain) at each hour of the year.

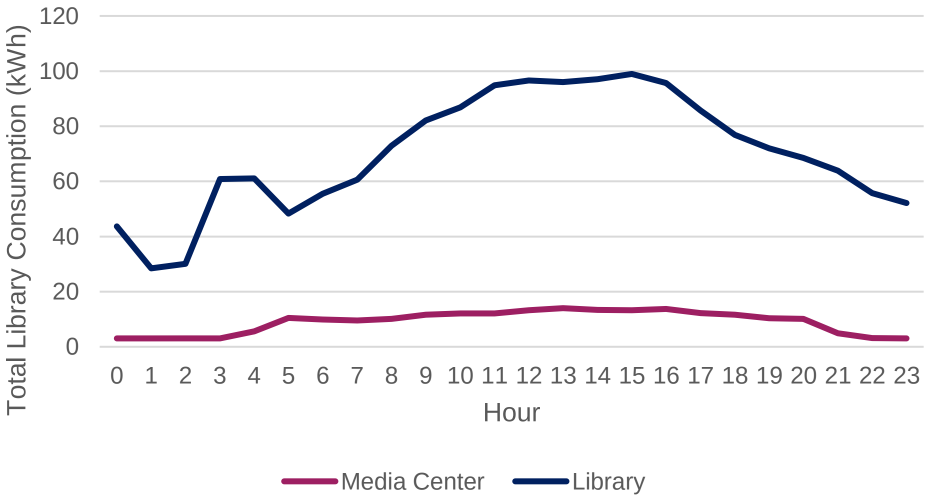
INPUTS

Energy Modeling + Critical Load Determination

We modeled the building with Sketchbox[3], Slipstream's simplified building energy modeling tool, to develop the load profile for the expanded library. This allowed us to account for the additional square footage and for energy efficiency upgrades. Through a site visit at the library, we identified substantial potential efficiencies including upgraded lighting, plug load control, and improvements to the HVAC system to reduce humidity issues and end extended run-time. The energy modeling utilized a prototypical library and considered two highly efficient HVAC and water heating systems; a traditional VAV system with natural gas-fired hot water reheat and a natural gas water heater, and an all-electric VRF system and electric resistance water heater.

To supplement the modeling, we also installed a submeter at the library building to better understand the load profile of the Sun Prairie Media Center. While energy load profiles for libraries are well-understood and straightforward to model, we anticipated that the media center would have a more unique load profile. Submetering allowed us to understand what proportion of the library load came from the media center and its occupancy patterns. The submeter data, monitored from June 3 to June 21, illustrated that the media center profile follows the pattern of the entire library load and represents about 10 percent of load (Figure 3). We opted to utilize the same modeling methodology for this space since its pattern followed the library profile.

Figure 3. Media center sub-load comparison.



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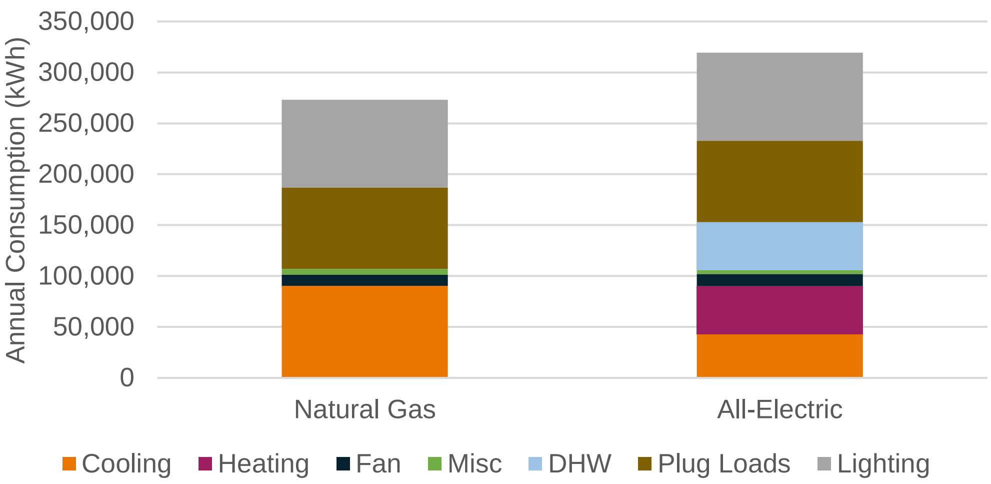
[3] Sketchbox is web-based modeling tool developed by Slipstream. For more details on the tool, see the Youtube playlist of Sketchbox videos: https://www.youtube.com/playlist?list=PL-mtgGdh8bvh3GsfC1Fpe8bJSO2uDRFo5

Figure 4 illustrates the annual electricity consumption of the all-electric VRF and conventional VAV system. The building with a conventional VAV system has lower annual electric consumption as energy for water and space heating is provided by natural gas. However, it has significantly higher cooling load as the system is less efficient than the all-electric VRF system. The rest of the end-uses use roughly the same amount of electricity across the two systems.

Figure 4. All-electric VRF vs conventional natural gas VAV system.



In addition to full building energy load, it was important to understand the critical energy load profile needed during emergency situations or outages. We utilized Clean Coalition's definition of tier 1, tier 2, and tier 3 loads to determine the library's critical load and resiliency needs.[4] Tier 1 loads are most critical and need power all the time, such as emergency lighting, exit signs, enough heat to prevent pipes from freezing. Tier 2 loads should have power if they do not threaten tier 1 loads, and tier 3 is everything else needed to operate at 100 percent capacity. Table 4 indicates the determination of tier 1, 2, and 3 at the library.

Table 4. Critical load determination.

Tier	Square Feet Percent	Rooms	Priority Energy Use
1	20%	Atrium, community room, media center, restrooms, mechanical rooms	HVAC, refrigeration, outlets, radio room, and servers
2	11%	Conference room, computer space, staff offices	HVAC, refrigeration, outlets
3	69%	Remaining public use space	

Figure 5 illustrates the differences in annual consumption across end-uses for the final load modeling profiles utilized in the analysis. During normal operations, we utilize the full building load consumption. The tiers 1,2,3 profile represents full load during outages and includes heating and cooling setbacks and slightly lower lighting use. For critical load scenarios which

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[4] Craig Lewis, "A Revolutionary Way to Easily Value Resilience for Any Facility."

includes only 30 percent of the total library space, we applied the load profile of tiers 1 and 2, which has significantly lower consumption.

Figure 5. Electricity consumption comparison: tiers 1, 2, and 3.

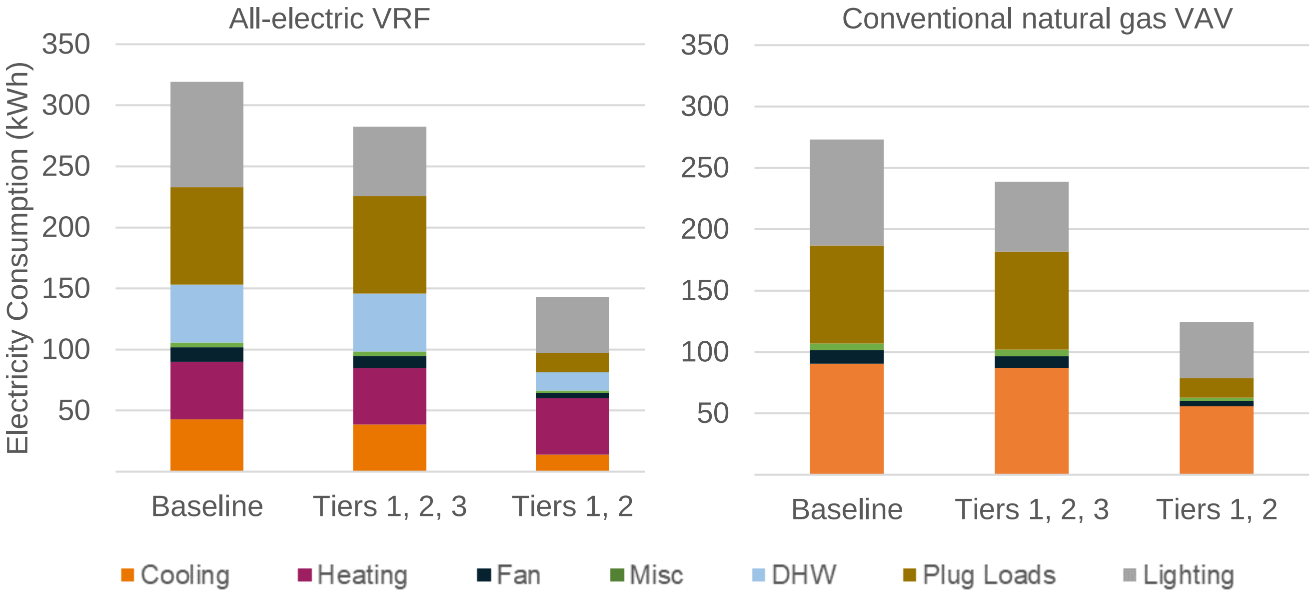
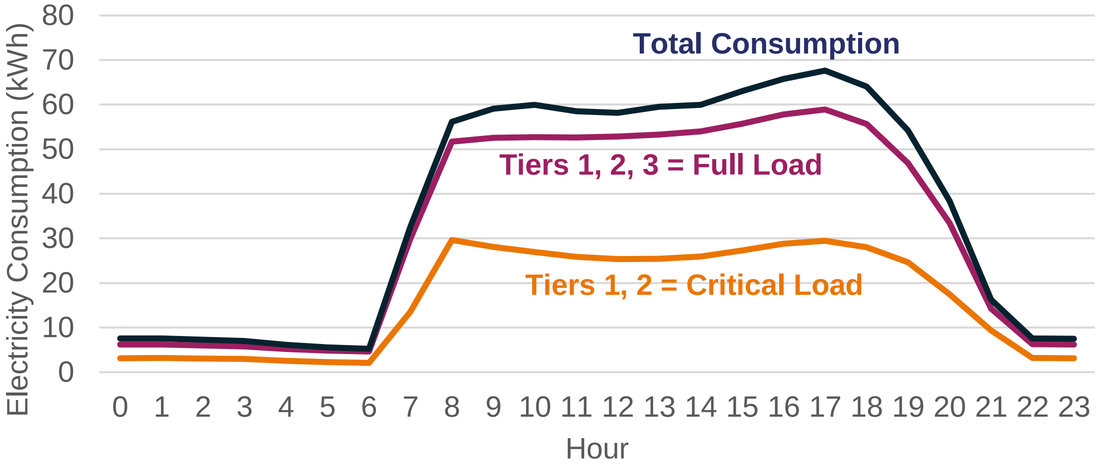


Figure 6 illustrates the differences between the three load profiles on an hourly basis for the all-electric VRF system. The graph emphasizes the small difference between total consumption and tiers 1, 2, and 3 profile and the much larger difference for tiers 1 and 2. The pattern looks similar for the conventional VAV system. Moving forward, we will refer to tiers 1 and 2 as critical load, tiers 1, 2, and 3 as full load, and total consumption as normal operations load.

Figure 6. Hourly average load profile for all-electric VRF: comparison of tiers.



Resiliency Inputs

There are two resiliency inputs of interest for this analysis: (1) length of outage for the system to withstand and (2) monetary value to assign to increased resiliency.

Length of Outage

To identify outage lengths of interest, we started by reviewing existing data on the length of outages over the past several years. Through this research, we identified two types of outages: routine outages and major disturbances/unusual occurrences. We reviewed Sun Prairie Utilities' data on typical outages[5] and the Energy Information Administration's data on major outage events across the Midwest over the last three years to understand key characteristics of each.[6] Table 5 illustrates these characteristics for each outage type.

The differences are that routine outages are typically more common and last for a shorter amount of time while major disturbances occur less frequently but last for anywhere between 1 and 5 days. The data illustrates that disturbances occur year-round, however a report from the Department of Energy stated that June was the month with the highest frequency of outages historically in Wisconsin.[7] Based on this data, we utilize outages in June as the constraint in each of the scenarios and tested varying outage lengths.

Table 5. Outage event characteristics.

Metric	Routine Outage	Major Disturbance
Frequency	Couple times a year	Once every few years
Impact	Low	High
Duration	2 hours	1 to 2 days and up to 5 days
SPU	< 1 hour	-
Time of Year	Year round	March to November

Resiliency Monetary Value

Installation of microgrids leads to resiliency benefits, which often make the difference between the system being cost-effective or not.[8] Although these benefits are widely acknowledged, there is not a standardized way to monetize these benefits.[9] Previous methods to quantify the value include willingness-to-pay surveys and tools to help facilities develop bottom-up monetary estimates for lost time spent on critical functions.

On the community resiliency side, there are limited studies that quantify the human benefits from microgrids. The best reference for these values is a study from Lawrence Berkeley National Lab that includes estimates from willingness-to-pay studies for the residential and

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[5] City of Sun Prairie, "Sun Prairie Approved Budget 2021."

[6] EIA, "Electric Power Monthly - U.S. Energy Information Administration (EIA)."

[7] Department of Energy, "Produced by Department of Energy (DOE), Office of Cybersecurity, Energy Security, and Emergency Response (CESER)."

[8] Anderson, Hotchkiss, and Murphy, "Valuing Resilience in Electricity Systems."

[9] Rickerson, Zitelman, and Jones, "Valuing Resilience for Microgrids: Challenges, Innovative Approaches, and State Needs."

commercial sector.[10] Table 6 illustrates the study's findings on the value of resiliency across outage lengths and sectors.

For our purposes, we utilize the residential values as the commercial values assume lost productivity from commercial or industrial processes. The main limitation is that the values do not extend past outage lengths of 16 hours.

Table 6. Value of resiliency across outage lengths.

Cost per kW	Momentary	30 minutes	1 hour	4 hours	8 hours	16 hours
Large Commercial	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Small Commercial	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Residential	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2

Cost Variables + Rebates

Upfront and ongoing costs of the solar PV and BESS technology as well as the energy wholesale, and demand charge rates are a considerable influence on the identification of a least-cost solution.

Table 7 details the upfront costs, which include the cost for the solar arrays and the components for the BESS.[11] The BESS cost is split into two components: energy capacity cost and power capacity cost. The energy capacity represents the cost of the battery pack while the power cost includes the costs for the interconnection of the system, such as the inverter and balance of the system. The two costs are additive and together represent the total cost of the BESS.

$$\begin{aligned} &Total\ BESS\ Cost \\ &\qquad = Energy\ storage\ cost\ (\$/kWh) * energy\ storage\ (kWh) \\ &\qquad + Power\ capacity\ cost\ (\$/kW) * power\ capacity\ (kW) \end{aligned}$$

The replacement costs after 10 years for the BESS system include the same two components and are substantially lower as the analysis assumes continued cost declines for the technology. The values in the table represent the point estimate used in the analysis; however, the true cost of the technology depends on building-specific and local context. Both NREL and Lazard provide cost ranges, which can be utilized during city planning.

The other costs include operations and maintenance (O&M) for solar, which represents current Sun Prairie costs for solar maintenance. We also include rebates for solar arrays, which include a WPPI $20,000 rebate and FOCUS ON ENERGY® rebates that scale with the system size.

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[10] Sullivan, Schellenberg, and Blundell, "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States."

[11] Ray, "Lazard's Levelized Cost of Energy Analysis—Version 15.0"; Feldman and Margolis, "Fall 2021 Solar Industry Update"; Anderson et al., "REopt Lite User Manual."

Table 7. Solar and BESS system costs – upfront, operations, maintenance, and replacement.

	Variable	Input	Source
Solar	Solar upfront cost ($/kW)	$1730	Probable Cost + NREL
	Solar O&M costs ($/kW)	$6.60	Current SP costs
	Utility rebates (max)	$20,000	WPPI
	State rebates ($/kW)	$250 - $310	Focus on Energy
BESS	Energy storage cost ($/kWh)	$388	NREL + Lazard
	Power capacity cost ($/kW)	$775	NREL + Lazard
	Storage capacity replacement cost ($/kWh)	$220	NREL + Lazard
	Power capacity replacement cost ($/kW)	$440	NREL + Lazard

Table 8 lists the utility and wholesale rates utilized in the analysis. Under Sun Prairie Utilities' rate structure, the most cost-effective option with solar at the library is the time-of-day rate. As the limit for net metering is 20 kW and the solar system size will be a minimum of 100 kW, we utilized wholesale rates for purchases of excess solar as defined by Sun Prairie Utilities. We also include the fixed demand charge to account for potential peak demand savings.

Table 8. Utility and wholesale energy rates.

Variable	Input	Source
Utility rate ($/kWh)	On-peak: $0.092 Off-peak: $0.045	SPU CP-1 TOD
Wholesale rate ($/kWh)	On-peak: $0.045 Off-peak: $0.032	SPU
Demand charge ($/kW of on-peak demand)	$7.5	SPU CP-1 TOD

We assume a 2.5 percent escalation rate for operations and maintenance costs, a 2.3 percent increase in electricity rates, and utilize a 3 percent discount rate.

Emissions Data + Prices

We utilized hourly emissions data to estimate the impact of each system on the environment. The emissions data include carbon dioxide emissions and criteria pollutants, including nitrogen oxides, sulfur dioxide, and particulate matter. The hourly emissions data for each comes from EPA's Avoided Emissions and Generation Tool (AVERT), which models marginal emissions rates for the region based on historical dispatch data.[12] The data assumes a gradual greening of the grid and reduces emissions factors by 1.1 percent annually.[13]

To estimate the monetary impact of the emissions savings, we apply cost per ton estimates to each. Table 9 lists the cost per ton for each of the major pollutants. The air quality pollutants have significant costs per ton as the reduction in emissions has the potential to prevent

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[12] US EPA, "AVoided Emissions and GeneRation Tool (AVERT)."
[13] Anderson et al., "REopt Lite User Manual."

premature death, which is valued at ~$9 million. The criteria pollutant costs are specific to Sun Prairie, and represent local demographic data on population age, health, and density.[14] The cost of carbon is the federal value for the United States.[15] The values in the table represent the cost for 2022, but all are modeled to increase over time.

Table 9. Pollutant costs per ton.

Pollutant	Cost per Ton	Source
Carbon dioxide	$51	Federal value
Nitrogen oxides	$19,542	CACES EASIUR model
Sulfur dioxide	$40,551	CACES EASIUR model
Particulate matter	$139,804	CACES EASIUR model

OVERVIEW OF SCENARIO SELECTION

To determine scenarios of interest for Sun Prairie, we started by modeling results across a large set of potential scenarios. Variables included the heating technology, the length of the outage the system should be able to withstand, how to define critical load, and whether to include environmental constraints. Based on city staff feedback on these scenarios and performance outputs, we selected a set of four final scenarios of interest.

Table 10 illustrates the key constraints for the scenarios. The scenarios below were modeled against both HVAC systems, the all-electric VRF and the conventional VAV system with a natural gas boiler. In this table and moving forward, ‘4 Hour Full’ refers scenarios set up to withstand an outage of 4 hours while covering tier 1, 2, and 3 loads. The ‘24 Hour Critical’ refers to the scenarios set up to withstand an outage of 24 hours while covering only tier 1 and 2 loads. The resiliency constraint for the scenarios is to cover an outage starting on June 19 at 1 pm and continuing for the defined length of the scenario. The final scenarios did not include any renewable energy requirements or health and energy costs in the optimization. The scenarios did set a requirement to have at least 100 kW of solar, as it is included in the expansion plans. The baseline scenario that each is compared to is a building with the same heating system (either electric VRF or conventional VAV with a natural gas boiler) and no DER on-site.

Table 10. Final scenarios and constraints.

Inputs	4 Hour Full Load	24 Hour Critical Load
Technology requirement	Minimum of 100 kW of solar	Minimum of 100 kW of solar
Critical loads	Tiers 1, 2, 3	Tiers 1 and 2
Outage length	4 hours	24 hours
Outage timing	June 19 1-5 pm	June 19 1 pm – June 20 1 pm
Renewable energy requirement	No constraint	No constraint
Health and climate costs	Not included	Not included

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[14] Heo, Adams, and Gao, “The Estimating Air Pollution Social Impact Using Regression (EASIUR) Model.”

[15] Interagency Working Group on Social Cost of Greenhouse Gases, “Technical Support Document: Social Cost of Carbon, Methane.”

SUN PRAIRIE LIBRARY RESULTS

The feasibility analysis examined the four scenarios in depth to consider financial, resiliency, and environmental impacts. We also completed a comparison analysis to illustrate the differences between installing a BESS versus a diesel generator.

Table 11 details the performance outputs for each of the four final scenarios. As noted above, ‘4hr Full’ refers to scenarios set up to withstand an outage of 4 hours at tier 1, 2, and 3 loads and ’24hr Critical’ refers to the scenarios set up to withstand an outage of 24 hours at tier 1 and 2 loads. The resiliency constraint for the scenarios is to cover an outage starting on June 19 at 1 pm and continuing for the defined length of the scenario.

Table 11. Final scenarios key performance outputs.

	All-Electric VRF		**Conventional VAV**	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
Solar Size (kW)	144	128	132	112
BESS capacity (kW)	28	26	28	29
BESS energy (kWh)	45	128	48	159
Net Present Value	**$27,000**	**$7,200**	**$14,900**	**($17,500)**
Payback Period	17.2	18.9	17.9	20.6
Avg. Resiliency Hours	3.5	35.2	3.9	34.1
Percent Renewable Energy	54%	48%	28%	24%

Solar size decreases and the BESS energy capacity increases as the outage length increases from 4 to 24 hours. The larger capacity represents the need to store more energy on-site to withstand an overnight outage when solar cannot provide power. The solar size decreases primarily to reduce upfront costs as the BESS costs increase. If the solar size stayed constant across scenarios, the NPV would be negative.

Similarly, the conventional VAV system includes more battery energy capacity and less solar capacity compared to the all-electric VRF scenarios. The increased battery energy capacity is related to the larger cooling load of the conventional VAV, while the smaller solar size is likely due to lower overall electricity loads, especially in the winter.

The NPV, calculated over 25 years, included in this table includes the energy and demand savings and export credits as benefits. It does not include the difference between the upfront cost of the two heating systems. The results show that the 4-hour full load scenarios perform better financially. However, the results show that the average resiliency hours are significantly higher for the 24-hour critical load scenarios. Lastly, the percent renewable energy represents the total building consumption, including natural gas usage. The conventional VAV systems have a significantly lower percent renewable energy as a result as the entire heating and water heating load comes from fossil fuels.

FINANCIAL AND OPERATIONAL IMPACT

Table 12 details the costs and benefits for all four scenarios. The financial calculations did not consider the difference in upfront costs for the two heating systems, and only focused on the financial performance of adding a microgrid to whichever heating system the library renovation included. For this reason, the costs from natural gas were also not included and we instead focus on the overall impact on electricity costs. All scenarios except the 24-hour critical load conventional VAV have a positive NPV over the 25-year lifetime.

The BESS and solar PV costs are upfront costs, and the BESS replacement and PV O&M costs are future costs that are discounted back to present value. As costs are directly related to size of the technology, the BESS upfront and replacement costs increase substantially from the 4-hour full load to 24-hour critical load configuration while the solar costs decrease.

On the benefit side, the energy savings make up the largest percent of total benefits across all scenarios. The export credits are significantly higher while the demand charge savings are lower for the 4-hour configurations compared to the 24-hour configurations. This is primarily due to the larger BESS size in the 24-hour scenarios and more excess solar production going to the BESS for future peak shaving rather than sending it back to the grid.

The 4-hour scenarios perform best financially primarily due to the increase in costs to have a larger BESS system. However, the all-electric VRF systems perform better financially than the conventional VAV systems due to the system's energy benefits. The total costs end up being roughly equal across HVAC systems with the conventional VAV system having lower solar costs but higher BESS costs. However, the energy savings and export credits are lower for the conventional VAV systems. The lower energy savings are a function of the smaller recommended solar size, which is a result of the lower electric load for the natural gas system.

Table 12. Financial impacts of the scenarios: total costs and benefits.

	All-Electric VRF		Conventional VAV	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
Upfront Solar PV Cost	-$249,500	-$221,900	-$228,800	-$194,100
Upfront BESS Cost	-$39,000	-$69,800	-$40,300	-$84,100
PV O&M Costs	-$22,300	-$19,900	-$20,500	-$17,400
BESS Replacement Costs	-$19,200	-$46,100	-$20,300	-$56,900
Incentives	$57,600	$55,200	$55,800	$52,800
Total Cost	-$272,400	-$302,500	-$254,100	-$299,700
Energy Savings	$244,700	$250,700	$220,000	$228,800
Demand Savings	$30,400	$50,800	$24,800	$49,200
Export Credits	$24,300	$8,200	$24,200	$4,200
Total Benefits	$299,400	$309,700	$269,000	$282,200
NPV	**$27,000**	**$7,200**	**$14,900**	**-$17,500**

Table 13 better illustrates the relationship between the different scenarios and how they utilize solar energy. This augments the financial data by showing the amount of solar production being exported to the grid versus being used to charge the BESS on-site.

For both HVAC systems, the 4-hour system exports a significantly higher percent of solar production (15%) compared to the 24-hour system (less than 5%). The 24-hour systems instead utilize a higher percent of the solar production to charge the on-site battery. This primarily reflects the BESS size of the 24-hour system and ability to store a larger amount of energy.

Table 13. Solar production data utilization.

	All-Electric VRF		**Conventional VAV**	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
Solar Size (kW)	144	128	132	112
Solar to Load (kWh)	132,600	125,000	118,000	109,400
Solar Average Energy Exported (kWh)	27,700	9,300	27,400	4,700
Solar to BESS	11,000	17,900	11,800	19,200
Solar Average Energy Produced (kWh)	**171,320**	**152,360**	**157,210**	**133,340**

RESILIENCY IMPACTS

We explored the resiliency impacts both across scenarios and across the year. There is limited variation in the resiliency performance of the all-electric VRF systems compared to the conventional VAV systems. The only notable variation is that for the 24-hour scenarios, the patterns differ slightly across the year. The conventional VAV systems have slightly increased resiliency in the winter due to not having to cover electric heating load during outages and slightly decreased resiliency in the summer due to higher cooling loads.

The all-electric scenarios have a higher guarantee of covering all resiliency needs, including heating, in the event of an emergency. Research shows that natural gas infrastructure is often impacted by emergency events and can take longer than electrical systems to restore.[16] For these reasons, we focus on the differences between the 4-hour and 24-hour scenarios with the all-electric heating system. We also tested a scenario where we assumed the 4-hour full load system size but assumed that the library would only cover critical load in the outage (Table 14).

Table 14. Resiliency scenarios summary.

	4hr Full	**4hr Critical**	**24hr Critical**
BESS capacity (kW)	28	28	26
BESS energy (kWh)	144	144	128
Battery Capacity (kWh)	45	45	128
Load	Full	Critical	Critical

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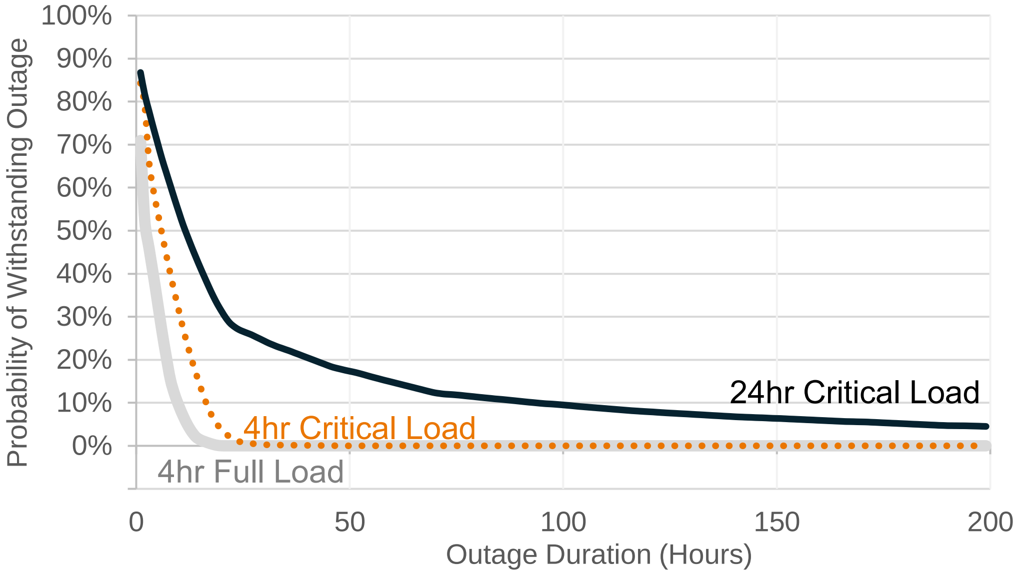
[16] Craig Lewis and Seth Mullendore, “Valuing Resilience in Solar+Storage Microgrids: A New Critical Load Tiering Approach.”

Across the three scenarios, we then compared the probability of withstanding various outage durations (Figure 7). REopt calculates this by simulating an outage at every hour of the year and identifying how long the microgrid could cover the power requirements at those hours.

At an outage duration of one hour, the probability of withstanding is below 90 percent for all three scenarios. This demonstrates that there are hours of the year where each system would not be able to cover an outage duration of any length. However, the configuration designed to withstand a 24-hour outage has a universally higher probability of withstanding an outage.

When comparing the two four-hour scenarios, it becomes clear that only requiring critical loads to be met significantly improves the ability to sustain outages. For example, at an outage length of 10 hours, the 4-hour system at full load has less than a 10 percent chance of withstanding the outage while the 4-hour system at critical load has almost a 30 percent chance of withstanding the outage.

Figure 7. Probability of withstanding an outage across all-electric VRF systems.

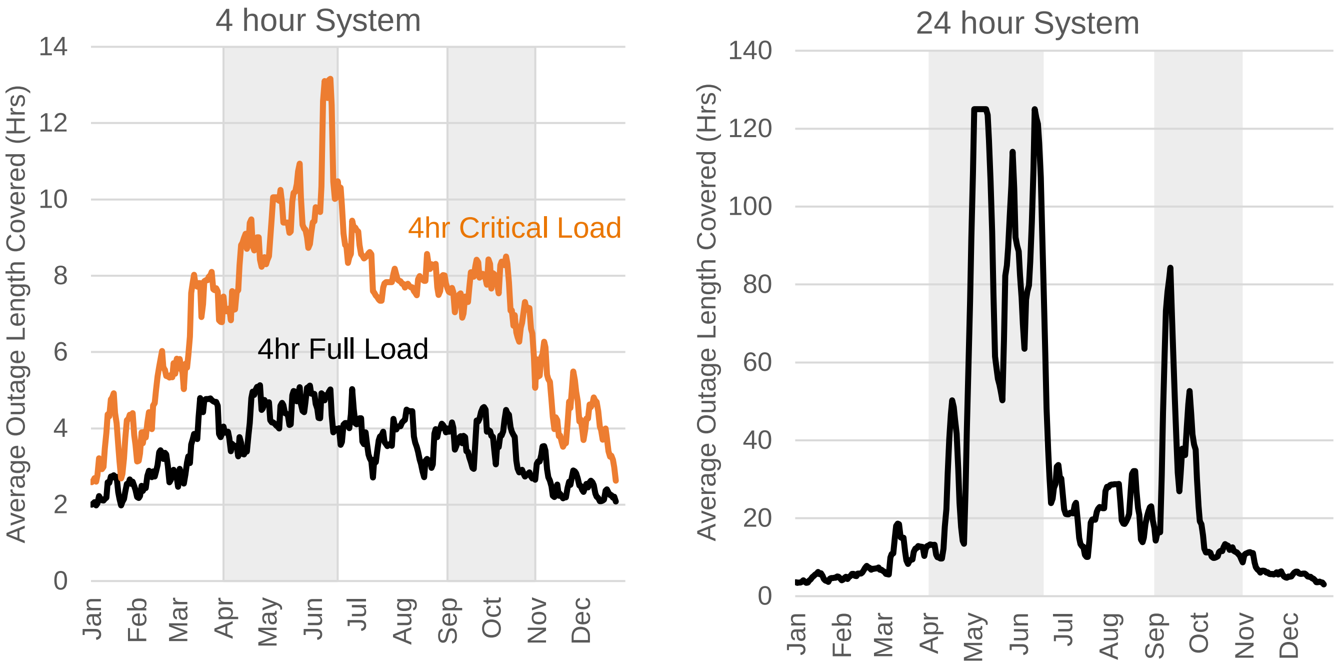


To better understand temporal trends in resiliency, we analyzed the average outage length the configurations can withstand across days of the year. Figure 8 illustrates this data for the 4-hour scenarios at both full load and critical load (left) and the 24-hour critical load scenario (right).

The general finding is that a microgrid can sustain the length of an outage best during the shoulder seasons. The 4-hour at full load scenario shows less variation across the year than the other two scenarios. The other two scenarios show highest performance in the springtime and early summer followed by the fall. This is due to the lower needs for space conditioning in the shoulder seasons accompanied by high solar production at those times of year.

The figure again illuminates the ability for the 4-hour configuration at critical load to withstand longer outages on average than the 4-hour configuration at full load.

Figure 8. Resiliency across the year: rolling daily average outage length sustained.



To examine these trends in more depth, we also looked at resiliency patterns across the year and hour of the day. The data represents the average length of outage the system could sustain if it started during that week and at the hour specified.

Figure 9 illustrates this data for the 4-hour full load system. The system has limited ability to withstand an outage of any length in the winter months. This is primarily due to the heating loads on the all-electric VRF system. In other seasons, the system can best withstand outages in the middle of the afternoon when the solar production is highest. It has little ability to withstand an outage that starts in the middle of the night when there is no solar production.

Figure 9. Resiliency across month and hour – 4-hour full load system.

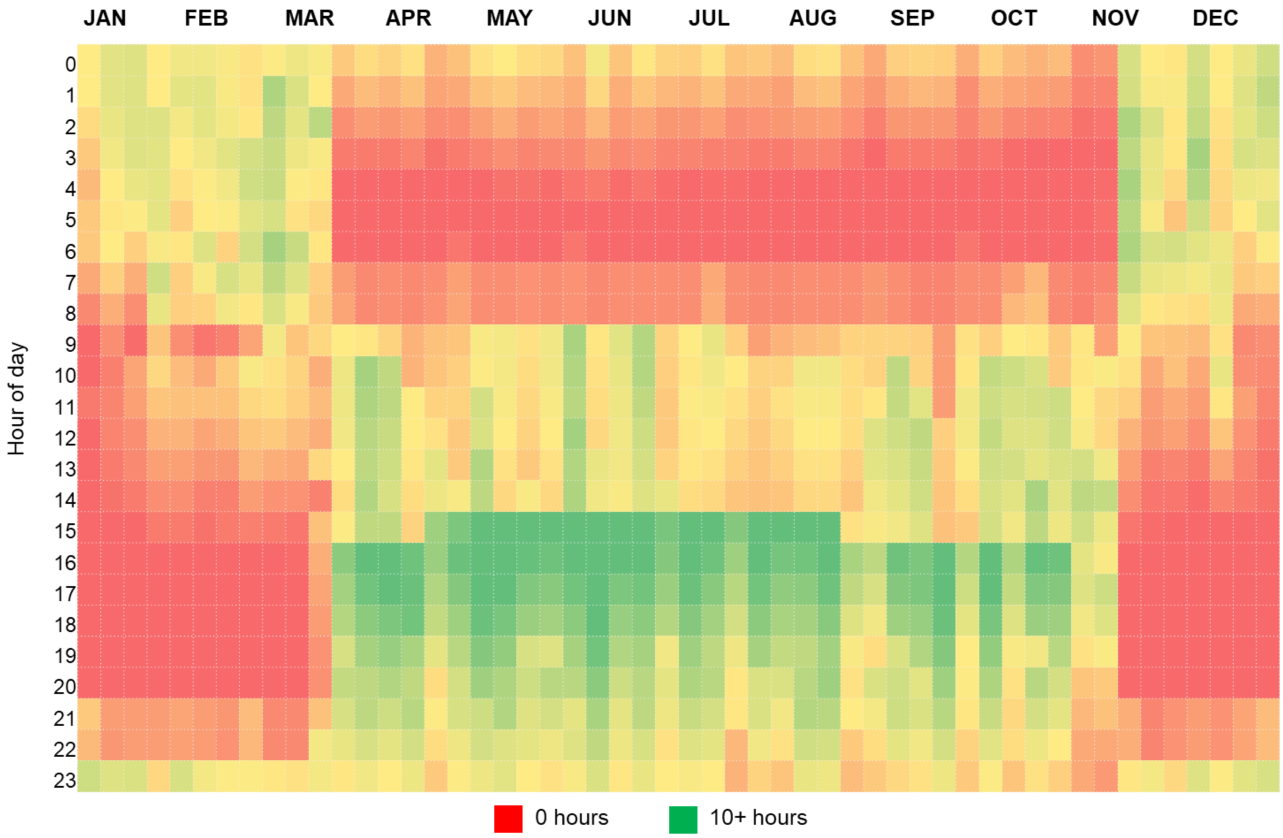


Figure 10 examines how these patterns change when using the 4-hour system but only requiring it to cover critical load. The resiliency improves compared to when the system is required to cover the full load, and general patterns across the year and time of the day stay the same.

By only requiring the system to cover critical load, the ability to cover an outage in the winter improves slightly. To further improve winter resiliency, the library could utilize an even more constrained definition of critical load to cover outages. For example, the library could decide to only power tier 1 loads, such as the atrium and community shelter room.

In the other months of the year, the system can withstand outages of 10 hours or longer that start during the afternoon hours. This corresponds to the time of day when solar production is high.

Figure 10. Resiliency across week and hour: 4-hour critical load system.

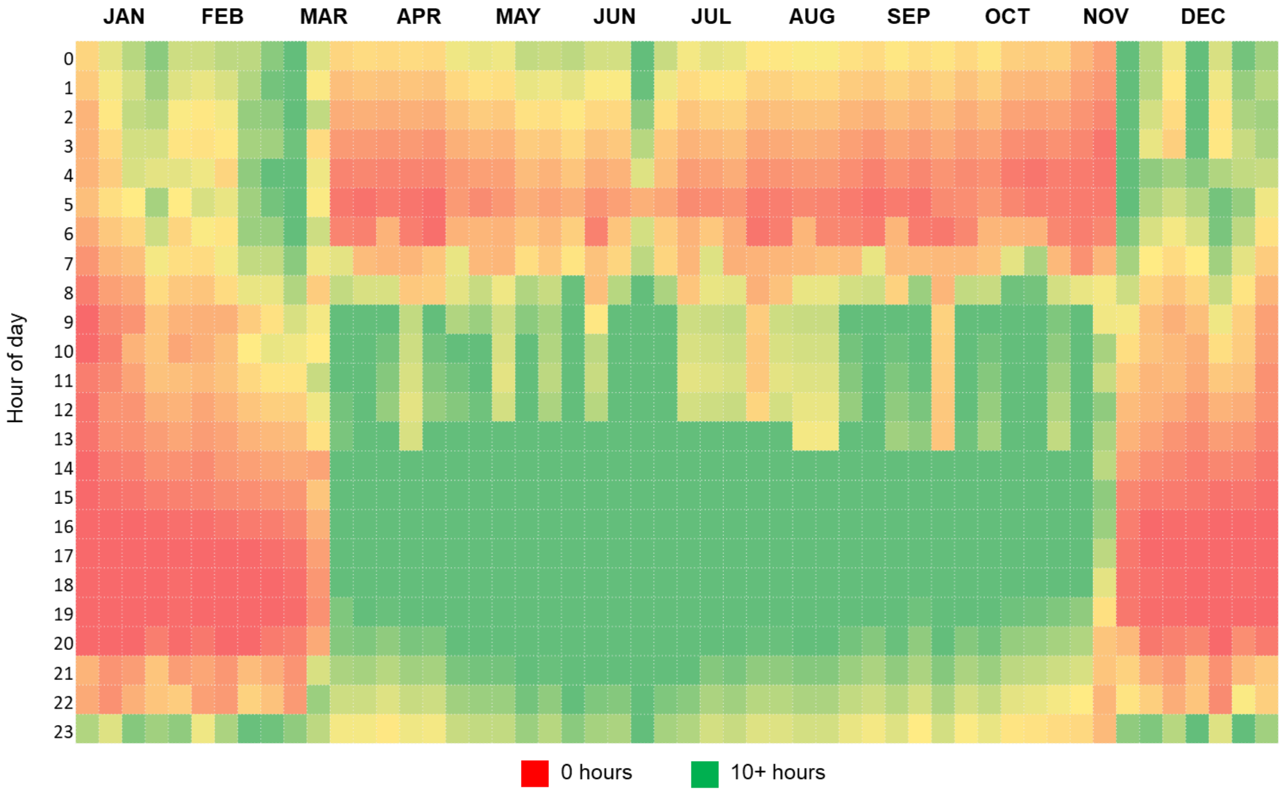
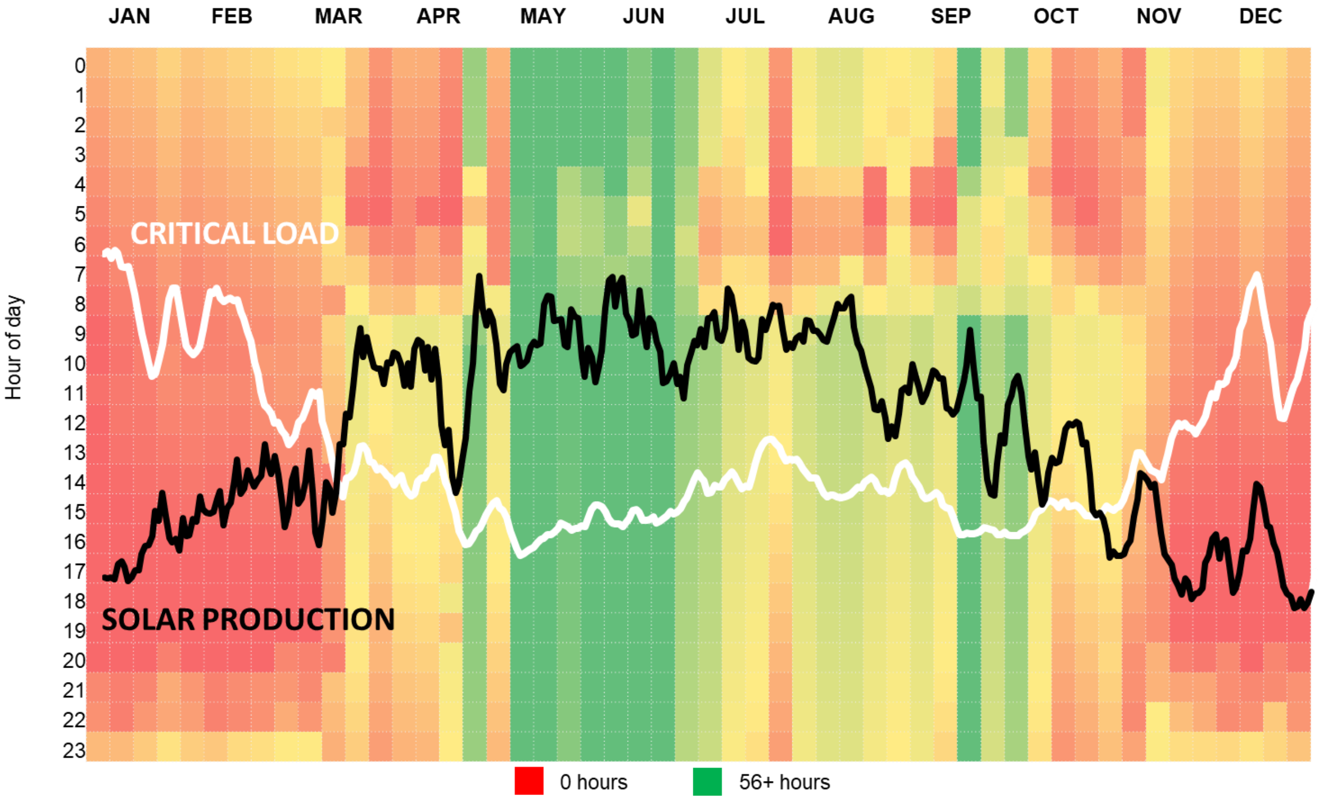


Figure 11 shows the same data for the 24-hour critical load system. The scale changes to reflect the system's ability to cover longer outage lengths. The figure also overlays the solar production and critical load data on the heatmap to explain how the two factors impact overall resiliency. For the 24-hour system, the hour of the day is much less significant than the time of the year. The system can withstand the longest outages in the shoulder seasons when the critical load is low and solar production is high. This decreases during the summer months when the space conditioning load, and associated critical load, increase.

The winter has limited resiliency as the solar production is low and electric load is high due to the electric heating load. To increase resiliency in those months, the library could further limit critical load to only include essential spaces, such as the atrium and the community shelter room. Another option is to increase the size of the battery to provide additional resiliency. We found that to cover an outage of the same length, 24 hours, in January, the battery would increase to 42 kW and 282 kWh with a negative NPV of ~$75,000.

Figure 11. Resiliency across hour and week – 24-hour critical system.



ADDITIONAL BENEFITS

A microgrid at Sun Prairie Public Library would provide significant monetary benefits beyond the energy, demand, and export savings. The benefits include the monetary value of resiliency, and the societal benefits of reduced carbon and criteria pollutant emissions. This section will highlight those benefits and show how the inclusion of the benefits impact NPV.

Resiliency Monetary Value

The monetary value of resiliency is calculated by taking the average hourly critical load multiplied by the average outage length and the deemed value of resiliency for an outage of that length. The value is then applied to any year in the project's lifetime when an outage is expected to occur and discounted back to present value.

Table 15 lists the inputs for the resiliency monetary value calculations across scenario. The resiliency value and average resiliency hours increase from the 4-hour to 24-hour scenario but the average critical load decreases. The average critical load is also lower for the conventional VAV systems as electric heating is not included.

Table 15. Inputs for resiliency monetary value calculations.

	All-Electric VRF		Conventional VAV	
	4hr Full	24hr Critical	4hr Full	24hr Critical
Average Critical Load (kW)	32.2	16.3	27.2	14.2
Average Resiliency Hours	3.5	35	3.9	34.1
Resiliency Value ($/kW)	$6.2	$21.2	$6.2	$21.2

The lifetime savings for resiliency depend directly on the frequency of outages. As these outages are irregular in nature, there is no way to know how often the outages will occur during the lifetime of the system. However, research does show that outages are expected to increase in frequency as extreme weather events increase and as the grid faces generation shortages.[17]

Table 16 lists the resiliency monetary value for different outage frequencies. In general, the 24-hour systems have significantly higher resiliency benefits. The all-electric VRF systems have slightly higher monetary values as the average critical load is larger.

Table 16. Monetary value of resiliency: comparisons depending on outage frequency.

	All-Electric VRF		Conventional VAV	
	4hr Full	24hr Critical	4hr Full	24hr Critical
Every Year	$12,100	$61,900	$10,200	$53,900
Every Two Years	$5,800	$29,700	$4,900	$25,800
Every Five Years	$2,300	$11,700	$1,900	$10,200
Every Ten Years	$900	$4,600	$800	$4,000
Once Ever	$500	$2,400	$400	$2,000

Utilizing the monetary values for an outage every two years, Table 17 shows the NPV when the value of resiliency is included. The all-electric VRF scenarios have higher NPV compared to the conventional VAV scenarios. For the all-electric VRF system, the resiliency benefits led to the 24-hour critical load system having a higher NPV than the 4-hour full load system.

Table 17. Resiliency monetary value impact on NPV.

	All-Electric VRF		Conventional VAV	
	4hr Full	24hr Critical	4hr Full	24hr Critical
Total Cost	-$272,400	-$302,500	-$254,100	-$299,700
Total Energy Benefits	$299,400	$309,700	$269,000	$282,200
NPV without resiliency	**$27,000**	**$7,200**	**$14,900**	**-$17,500**
Resiliency Benefit	$5,800	$29,700	$4,900	$25,800
NPV with Resiliency	**$32,800**	**$36,900**	**$19,800**	**$8,300**

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[17] Robert Walton, "MISO Prepares for 'worst-Case Scenarios,' Heads into Summer with Insufficient Firm Generation"; Rickerson, Zitelman, and Jones, "Valuing Resilience for Microgrids: Challenges, Innovative Approaches, and State Needs."

Emissions Benefits

The emissions benefits from adding solar and a BESS are significant. The systems would greatly reduce both criteria pollutant and carbon dioxide emissions. Criteria pollutants are directly linked to reduced health issues and generate significant monetary value as a result. Similarly, the monetary value from pricing the adverse environmental impacts of carbon dioxide emissions leads to significant benefits.

Table 18 illustrates the emissions reductions in tons and the resulting monetary benefits. The benefits are highest for the 4-hour full load system as it has the largest solar array and therefore displaces the highest percent of power plant emissions.

Table 18. Emissions reductions and monetary values.

	All-Electric VRF		**Conventional VAV**	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
NO_x Savings (tons)	2.1	1.9	1.9	1.6
SO_2 Savings (tons)	2.8	2.4	2.6	2.0
$PM_{2.5}$ Savings (tons)	0.2	0.1	0.1	0.1
Monetary Health Savings	$193,700	$166,800	$177,300	$142,200
CO_2 Emission Savings (tons)	3,080	2,680	2,820	2,310
Monetary Carbon Savings	$182,500	$158,800	$167,200	$136,900

Table 19 illustrates how adding the monetary value of the reduced air quality health impacts and reduced carbon emissions impacts NPV. The NPV is over 10 times higher when these values are included. The results interestingly show that the 4-hour scenarios end up having the highest NPV when these are included, which reflects the larger solar arrays and higher displacement of power plant emissions.

Table 19. Carbon and criteria pollutant monetary value impact on NPV.

	All-Electric VRF		**Conventional VAV**	
	4hr Full	**24hr Critical**	**4hr Full**	**24hr Critical**
Total Cost	-$272,400	-$302,500	-$254,100	-$299,700
Total Energy Benefits	$299,400	$309,700	$269,000	$282,200
Resiliency Benefit	$5,800	$29,700	$4,900	$25,800
NPV with Resiliency	**$32,800**	**$36,900**	**$19,800**	**$8,300**
Emissions Benefit	$376,200	$325,600	$344,500	$279,100
NPV with Emissions + Resiliency	**$409,000**	**$362,500**	**$364,300**	**$287,400**

DIESEL GENERATOR COMPARISON

Diesel generators are the traditional solution to power buildings during grid outages. The diesel generators are programmed to only run during outages. We compared this traditional solution to the BESS and solar solution modeled in this feasibility analysis. We include solar in all scenarios as it is already planned as part of the building renovation.

Table 20 illustrates the performance outputs for the BESS and solar scenario compared to the generator and solar alternative for the all-electric VRF heating system. The generator scenarios perform better financially, due to their lower upfront storage costs. The diesel generators also provide an average resiliency of roughly double the battery and solar systems as the fuel is already available on-site and does not rely on the intermittent solar energy.

Although the NPV of the systems is higher for the generator systems, they provide significantly lower energy, demand, and export credit savings throughout the year. One reason for this is that while a BESS can operate during grid normal operations to store excess solar energy and shift demand, a generator can typically only be operated during outages, and is not available to provide other services while the building is grid connected. Additionally, they perform worse when considering the environmental impact - the carbon emissions are significantly higher for the generator scenarios and the total health benefits are lower.

Table 20. Diesel generator comparison to all-electric VRF systems.

	4-hour full load		24-hour critical load	
	BESS + Solar	**Generator + Solar**	**BESS + Solar**	**Generator + Solar**
Net Present Value	$27,000	$34,400	$7,320	$41,000
Initial Capital Costs	$230,800	$172,600	$236,500	$141,200
Payback Period	17.2	16.0	18.9	15.2
Storage Size (kW)	28	32	26	26
Energy, Demand, Export Savings	$299,300	$226,400	$309,800	$204,400
Total Carbon Emissions (tons)	2,800	3,255	3,190	3,640
Total Health Benefits	$193,700	$165,700	$177,300	$140,700
Avg. Resiliency Hours	3.5	6.4	35.2	72.8

Table 21 illustrates the diesel generator in comparison to the conventional VAV scenarios. The results are very similar to the comparison to the all-electric VRF scenarios. The most notable difference is that the average resiliency hours for the 24-hour critical load generator scenario is much higher (457) than the resiliency for the BESS and solar system (34). It is also significantly higher than the resiliency provided by the generator under the 24-hour all-electric scenario. This is a result of a lower average critical load for the 24-hour conventional VAV system, especially during the winter months when heating load does not need to be covered by the generator.

Table 21. Diesel generator comparison to conventional VAV systems.

	4-hour full load		24-hour critical load	
	BESS + Solar	Generator + Solar	BESS + Solar	Generator + Solar
Net Present Value	$15,000	$26,100	($17,443)	$30,000
Initial Capital Costs	$213,300	$146,490	$225,300	$136,330
Payback Period	0.0	16.4	20.6	16.1
Storage Size (kW)	28	33	29	29
Energy + Demand Savings	$269,000	$195,500	$282,200	$188,600
Total Carbon Emissions (tons)	2,200	2,760	2,700	2,860
Total Health Benefits	$177,300	$142,700	$142,200	$135,360
Avg. Resiliency Hours	3.9	7.6	34.1	456.7

ENERGY EFFICIENCY CONSIDERATIONS

In our modeling of the load profile for the library expansion and renovation, we included several energy efficiency upgrades identified through the site visit. In addition to these upgrades, we identified other potential efficiency upgrades that should be considered. The list below summarizes the efficiency recommendations for the library renovation, with a focus on measures that will enhance resiliency and address known issues with the library today.

Lighting design and upgrades

The library staff identified that there are frequent complaints about light levels in certain sections of the library. In addition, the current lighting design employs fluorescent fixtures with minimal controls, leading to significantly increased energy use by the lighting system compared to what is achievable with LED fixtures and advanced controls. To address these issues, we recommend that all lighting in the existing structure be updated during the renovation and expansion process. Below we provide specific recommendations that could be included in an RFP or OPR document when seeking a lighting designer.

Lighting should be designed to Illuminating Engineering Society's recommended light levels, the industry best practice based on space type and the type of activity anticipated to occur in the space. In general, design to lower ambient light levels and provide task lighting where higher light levels are required for tasks such as the reading of fine printed text. Specify and install Design Light Consortium (DLC) premium certified 0-10V dimmable LED fixtures to ensure eligibility for Focus on Energy rebates.

The installation of basic occupancy and daylighting zone-based lighting controls is code required. However, Networked Lighting Control (NLC) products generally yield more savings through the implementation of advanced controls. A wireless Luminaire Level Lighting Control (LLLC) solution embeds sensors and control logic into each luminaire creating a more granular control network, enabling the implementation of advanced lighting control strategies such as dimming, daylighting, occupancy/vacancy control, and task-tuning. The use of LLLC also allows for fixtures to be programmatically divided into the three resilience tiers which will be used to manage load during emergencies and grid outages.

These control strategies support, on average, 63% additional lighting energy savings beyond just LED luminaires alone when implemented using a LLLC solution. Beyond energy savings, a LLLC solution is likely to improve overall lighting quality while also providing additional occupant controllability. Furthermore, wireless controls are easily configured and reconfigured if the space needs change over time. Material costs are higher for a wireless LLLC solution but are often offset by labor savings. The combination of wireless and LLLC avoids the need to run any low voltage control wiring and/or any wiring that might be required for dimming control.

For exterior lighting (including the parking lot) lighting reduction controls should be implemented during unoccupied hours, using either motion controls or exterior timeclock control zones. Zones should include one for low power building security lights on from dusk-to-dawn, and another for area lighting on at dusk and off via timeclock when the building is unoccupied. Motion controls can dim exterior lights rather than turn them off, but in either scenario the design should target a 50-70% exterior lighting power reduction during unoccupied nighttime hours.

Other general recommendations include:

- The design team should create a schedule to capture the lighting control design intent (sensor type, turn down, delay, etc.). This will serve as the reference for commissioning and should be included in the project’s construction documents.
- Lighting setup and configuration should be scheduled as soon after lighting installation as possible to ensure smooth hand-off between installation and commissioning.
- Lighting design team should coordinate with library or city IT staff to understand cybersecurity requirements, if applicable.
- Include a requirement within the specifications for training of maintenance and library staff on basic lighting system programing functions, ideally during lighting controls setup/configuration. Training should include materials intended for building occupants and library staff as well, to provide instructions on the new lighting.

HVAC system upgrade and controls

As part of the expansion project, Sun Prairie is planning to completely replace all existing mechanical systems. While this will address many of the issues with the current system, there are additional strategies which should also be considered.

The historical load profile for the existing structure indicates that the HVAC system is turning on around 3:00 am and running at the same level as it does later in the day when the building is fully occupied. Library staff indicated that this schedule is necessary to address an issue with high humidity levels later in the day, which is likely due to the existing system being oversized (resulting in the space reaching set-point temperature before the humidity has been sufficiently reduced).

While properly sizing the new HVAC system will help address humidity issues, another option is to implement zone-level humidity control, with setpoints and ranges set depending on the humidity sensitivity of the materials in each zone. By concentrating humidity-sensitive materials in specific areas of the library, humidity controls could be constrained to these areas, allowing humidity in other areas of the building to float during unoccupied periods to a broader control setpoint, thus reducing total energy use for dehumidification without risking preservation of sensitive materials.

Another energy-saving solution for humidity control is implementing hot gas reheat on the DOAS (dedicated outdoor air system). In a hot gas reheat system, reheat needs are met using the discharge from the compressor after air has been dehumidified and cooled. This allows for better control of humidity while reducing the energy needed for reheat. When combined with demand control ventilation and energy recovery ventilation, this design would reduce the energy needed by the ventilation system while ensuring sufficient humidity control, and occupant thermal comfort.

Plug load control

Plug load control will be important both to reduce energy costs at the library, but also to reduce the load from non-essential equipment during outages to improve resiliency. For any workstations provided by the library, a computer power management policy should be implemented to reduce power usage when computers are not actively being used. Where power strips are provided, advanced power strips can be used to shut off peripherals such as speakers and lamps based on occupancy.

Finally, the electric power layout should group plugs and circuits by load tier, so that a microgrid controller could be implemented to easily power down tier 3 loads during an outage to ensure power availability for tier 1 and tier 2 loads.

Small-embedded data center

Both the library and the media center currently have several small data server closets. To improve efficiency, we would recommend moving as much of this functionality to cloud services as possible and combining the remaining data centers. Because the data centers will likely need a dedicated cooling system, combining them allows for a higher capacity, more efficient system to be installed.

On site servers should be consolidated to as few units as possible, and Energy Star equipment should be specified. Cooling equipment that serves the rooms should be highly efficient; CEE Tier 2 is a good starting recommendation. Finally, the temperature setpoint in the data closet should be calibrated to avoid over-cooling; the air entering the server rack should be 75 °F.

Thermal regulation with phase change materials and radiant heat

Phase change materials (PCM) for space conditioning function by storing and releasing thermal energy. The PCM material is “tuned” to change phases (freeze or melt) at the desired room temperature. When the indoor air is above this temperature, the PCM absorbs excess heat by melting – below this temperature, the PCM freezes, and releases stored heat back to the space. These properties result in spaces with PCM having a passive thermal buffer, improving thermal comfort, and reducing the number of times that HVAC systems must cycle. HVAC controls can also be tuned to use this property to pre-cool or pre-heat spaces or shift peak demand.

The ability of PCM to provide thermal stability is of particular interest when considering a community resilience center, as it will reduce the total demand for power during grid outages, and even maintain safe temperatures when power is not available.

Another option for providing thermal stability within the space would be slab radiant heating. As the library will likely be single story construction on a concrete slab, radiant floor heating may be a cost-effective solution to provide stable, consistent heating.

SUN PRAIRIE COMMUNITY RESILIENCY & EMERGENCY OPERATIONS PLANNING

The City of Sun Prairie recognized the opportunity to review its community resiliency planning (typically described as emergency management in existing documentation) through city operations as part of the feasibility grant. This project provided a unique opportunity to work across departments, look at existing processes, clearly define terms, and work collaboratively to update information, processes, and facilitate coordination to further resiliency planning efforts. The National Institute of Standards and Technology (NIST) defines community resilience as *the ability to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions. Activities, such as disaster preparedness—which includes prevention, protection, mitigation, response and recovery—are key steps to resilience.* The 2020 Dane County Climate Action Plan addresses Resiliency/Security as one of its six guiding principles in developing climate action recommendations, including providing critical infrastructure and giving vulnerable communities increased energy security.

The Sun Prairie Fire Department (SPFD) has been working on this effort, and to date has provided information and trainings to city staff and the community. Both the Fire Department and Police Department host “Citizen Academies” which provide city residents and staff the opportunity to learn more about department operations, including community resiliency efforts. SPFD encourages staff to complete the following National Incident Management System (NIMS) trainings:

1. NIMS 700: FEMA - Emergency Management Institute (EMI) Course | IS-700.B: An Introduction to the National Incident Management System
2. NIMS 800: FEMA - Emergency Management Institute (EMI) Course | IS-800.D: National Response Framework, An Introduction
3. NIMS 100: FEMA - Emergency Management Institute (EMI) Course | IS-100.C: Introduction to the Incident Command System, ICS 100
4. Public Information Officer Overview: FEMA - Emergency Management Institute (EMI) Course | IS-29.A: Public Information Officer Awareness

Additional internal resources and documentation on the City’s nework drive include Incident Command (Incident Command), Dane County Emergency Management Hazard Mitigation Plan (_DC Emergency Mgmt Hazard Mitigation Plan 2021), and existing Mutual Aid Agreements with nearby communities to share personnel and equipment depending on the type of emergency response and community need.

The Sun Prairie municipal Code of Ordinances (Chapter 2.88, Sections 2.88.010-2.88.090) details the city’s emergency management policy. Several relevant sections have been provided and can be seen in Appendix A.

CROSS-DEPARTMENTAL DISCUSSIONS

This information provides an overview of the activities and roles for various emergency management activities. City Staff met across departments several times over the course of the feasibility study to collect information and discuss processes.

Examples of past emergencies in Sun Prairie

- 2008 Severe Flooding: event led to acknowledgement that any EOC should be on higher ground; Wastewater facility at a lower elevation compared to future Public Works Campus location.
- 2017 Straight-line winds: downed trees and power outages associated with utility infrastructure.
- 2018 Natural Gas Explosion: significantly affected several operations. City Hall was activated as the existing designated EOC (acknowledgement that City Hall is not an ideal EOC due to its downtown location).
    - Consideration to explore alternate/back-up EOC locations, particularly as the new Public Works Campus is in the design phase (2028-2029).
    - Consider a new EOC location, a back-up EOC location, and what controls/capabilities exist within each designated facility. Dane County facilities could also be a back-up location.
- 2020 Civil Unrest/Protests: located near City Hall
- Multiple years - Bomb threats at City Hall

Criteria for activating an emergency

Any CRC would be one piece of a broader emergency management plan, as a designated location for specific activities (shelter, microgrid back-up power to support critical systems and/or plug load for emergency equipment). The CRC would serve the most vulnerable Sun Prairie residents and the nearby geographic area (city center, surrounding neighborhood, patrons already in the facility) if an event were to occur. Criteria for emergency activation are not easily defined; Police, Fire, EMS Chiefs, Wastewater, Public Services, and other Directors can activate through their staff/personnel as needed in coordination with the Mayor and City Administrator. Various activities could be reactive (natural disaster or unplanned event) or proactive (upcoming elections, major events, larger gathering where the potential for a community threat is heightened). Directors are aware of major potential concerns and prepare accordingly for any potential events, disruptions, etc. In short, all staff across departments are involved with emergency management while the following departments have more involved roles:

- EMS
- Fire
- Police
- Public Services (buildings, equipment, coordination)
- Finance
- Council/Mayor
- WWTP
- IT (networks, configurations)
- All staff can contribute (NIMS training 100, 200); basic knowledge of planning/preparedness framework.

Resource & Infrastructure Considerations

This section describes the equipment and resources typically required to manage an emergency. This can include facilities, vehicles, and designated spaces including EOC/CRC, and specific process and equipment/loads powered by emergency backup generation.

Community resources include equipment such as generators, food, water, beds, depending on the length and scale of the emergency. Of note is the value of a microgrid system within city operations as a redundant, self-contained energy generation resource. Technically, the Wastewater Treatment Facility could be considered an existing microgrid as it regularly tests back-up diesel generation in an “islanding” capacity, running monthly simulations that power the facility with back-up power only. The intent of SPPL as a microgrid resource would be more community-facing in nature.

- <u>Facilities:</u> Critical equipment includes SCADA controls for Sun Prairie Utilities and Wastewater Treatment, IT network infrastructure for emergency communications systems, GIS systems for asset management. In conversations with staff, it was noted how important networking and communications infrastructure (internet and cellular connections) is during an emergency. The location and operation of this hardware is critical and should have multiple staff trained on these criteria (for example, physical access to the Public Services facility, access to GIS systems via servers with uninterruptible power supply). Generators for electrical power, barricades/cones/traffic controls, water valves/utility access holes (trucks with equipment), WWTF gas meters, hand-held equipment that would be deployed as needed should also be inventoried for quick access. Equipment inventory management systems (distributed in multiple locations), personnel access, who deploys what resource and which time during an emergency response should all be planning factors considered in the emergency management plan.
- <u>Vehicles:</u> Front-end loaders, dump trucks, pick-up trucks, and Police/Fire/EMS vehicles may all be utilized in an emergency. Consider fuel access and availability (both on-road diesel for vehicles and off-road diesel for back-up generators; the WWTF has ~3,000 gallons of diesel on-site). If an emergency exists across a larger geographic area, vehicles will serve a particularly important role in quickly transporting personnel and resources. The city also has a *Vehicle Maintenance Emergency Response* Plan available to staff (accessible on the internal network) that details procedures prior to a severe weather event, after an event, along with priority repairs of vehicles.
- <u>Community Resiliency Centers (CRC):</u> Locations (designated, planned) of where people and pets can go for temporary shelter include schools (served well during 2018 incident, which occurred in the Summer/out of session) and the library facility as a potential CRC with microgrid system as a centralized location. Consider CRC capabilities dependent on the duration of an event, ability to locate resources, and the total number of community members/ neighborhoods affected. A best practice would be to develop a CRC map with total capacity and assigned neighborhoods, so the community has clear guidance on where to shelter depending on what emergency exists. The more CRCs available, the better equipped the community is to handle an emergency. Sites could include city facilities, school district facilities, houses of worship, community centers; along with volunteers that are willing to help guide the community or distribute resources. Public/private partnerships such as groceries and big box stores are also drawn upon during an emergency.
- <u>Generators/Food/Water/Beds:</u> Off-road diesel fuel supply for existing diesel generation, microgrid operations manual to provide the appropriate amount of electricity for a target duration. Identify additional community partners who can provide resources such as Red Cross, Sunshine Place, food banks, Neighborhood Navigators, and other facilitators identifying partners, having contact information available.
- <u>Emergency Operations Center (EOC):</u> Consideration to relocate this function outside of City Hall. Location selection and preferred criteria for site selection; future Public Works Campus, Fleet facility, secondary/back-up functions at additional locations (Westside Community Building, Media Center Communications equipment at the Library). Existing

benefit of City Hall EOC is proximity to dispatch. Prior example of a bomb threat at City Hall, where the EOC was located, and which had to be evacuated.

  - If Public Works Campus is a preferred EOC location, consider capabilities to be included in the building design (equipment, wiring, networking, back-up IT server, etc.) Other conversations have involved co-located critical services such as WWTP, generators, and New Construction opportunities (hardened rooms/locations within PWC campus, training spaces, equipment for training a variety of city staff Police/Fire/EMS for different events, activities). Open spaces, auxiliary rooms, flexible based on the need and dynamic use during an emergency.
  - Communication towers in Public Works Campus, Wastewater Treatment Facility site vicinity; Bird St. Tower may be closest location. Cell phone reception being the primary need, in addition to radio communication.
  - Monthly operational backup power simulation for readiness, convene various departments/staff for rehearsal; exercises in coordination with Federal Department of Homeland Security including running full-scale physical EOC simulations.
  - Communications equipment provided to staff would include desk phone, cell phone, radios with numbers pre-programmed and clear roles identified. At EOC, running redundant internet connections such as multiple Ethernet cords, WiFi systems, and power supply to those systems.
  - Existing EOC City Hall – backup generation consideration to review existing loads and processes. Consider a future battery system upgrade if feasible based on this study findings, determine which uses in the building are critical loads battery system that's load leading/ covers emergency lighting/HVAC/EOC room for certain time duration. Current configuration for the IT network room which houses the main city servers has an uninterruptible power supply (UPS) and is also likely tied into the backup diesel generator for the facility.
- <u>Back-up EOC/CRC considerations:</u> consider an interim plan that would include the Library CRC, and future Public Works Campus design. This planning effort could provide an opportunity to serve as a "bridge" between what the city currently operates and what opportunities future facilities could provide. An option for secondary EOC would be the Fire Training room (EMS/Fire Station #2 – Grand & Main; Westside Community Building), and a third could be Dane County facilities (Madison location; back-up in Fitchburg). If an emergency occurred in Sun Prairie, Dane County facility might be at capacity. Library determined as a low priority EOC candidate and a better option for CRC functions, one reason being that Fire/EMS/Police personnel have more control of the facility at the secondary location Westside Community Building.

As planning efforts continue, staff would benefit from the following discussions and planning efforts, building on existing activities already completed:

- Equipment analysis considerations such as a completed asset management database for all equipment and resources to be used in an emergency
- GIS dataset of equipment location, general conditions, operational details such as duration potential of backup generation
- Maintenance logs and operations manuals
- Condition assessment of existing assets, and gap analysis of what equipment might be needed in the future with associated budgeting activities (SCADA/IT systems, vehicles, generators, equipment)

- What other staff, departments might be needed in the planning process (Finance, Administration, Public Works)
- Create a clear policy framework when EOC, CRC, or both are activated. Clearly define the sequence of events, and relevant personnel responsibilities. Defined form and function for both EOC and CRC activation, in a clear process that staff have access to.

EXISTING BACK-UP GENERATION OPERATIONS

The WWTF Director provided additional detail on the operations of existing diesel back-up generators, for both operational and cost considerations when considering best practices for operating and maintaining existing backup generation assets. This context and financial information regarding existing backup generation for city operations is important to inform broad planning efforts related to any backup generation resource the city operates and create a cost baseline basis for comparison when considering battery energy storage microgrid technology.

The facility tests their diesel generators weekly. A process checklist of activities is maintained, tying the data/results into the SCADA system. The facility operates in “island mode” during these tests and running true monthly real-life simulations. Conducting a monthly load test, tracking diesel fuel consumption, and completing a maintenance checklist to monitor the systems.

Preventative maintenance is ongoing and different activities are completed at different intervals on a weekly/monthly/annual basis. The facility purchases off-road diesel fuel for backup generation (1,000 and 1,500 gallon tanks for both generators), approximately 500-600 gallons (70/30 off-road diesel winter blend) annually consumed based on regularly scheduled running of the generators. Based on available invoices, the facility spends approximately $3,000 annually on off-road diesel for these backup generators (combined capacity of 2,200 HP, 1,600kW, two 800kW nameplate capacity units). A new 800kW generator would cost about $1 million, an 80kW portable unit costs about $60,000. With supply channel disruptions there is currently a ~1 year lead time on equipment.

For other city backup generation assets, operations & maintenance costs (oil, filters, PM/systems check) are completed by a vendor for about $5,000 annually. There are $1,800 in diesel fuel costs from generators not located at Wastewater facility annually. Annual maintenance costs for generators (excluding Wastewater) include service calls, preventative maintenance agreements, standby generator services, and equipment replacements (Table 2).

Table 22. Existing generator O&M costs – city accounting software information excluding WWTF.

Year	Existing Generator O&M Costs
2022	$3,993.26
2021	$2,649.36
2020	$5,045.12
2019	$3,913.76

The diesel generator maintenance checklist the Wastewater facility utilizes was recreated and saved to be used for other city facilities with generators as a best practice. These activities would also inform planning efforts of potential battery deployment and integration, as a broad microgrid maintenance framework including all generation assets. Activities range from asset to management to ongoing services such as installing sensors on fuel tanks to gauge fuel levels and automate the refill process, which Wastewater currently tops off on a bi-monthly schedule. This department also deploys a portable 80 kW diesel generator for powering lift stations in an emergency, in addition to other use cases that portable generation assets could serve. Over the next four-year period one permanent backup generator will be installed at various lift stations (Shonas, Park Circle, Hickory, and Business). The city is also exploring fleet electrification opportunities for heavier duty equipment that could also serve as portable power generation assets, depending on the vehicle battery capacity is use case.

For this facility, each generator can power the entire facility; each generator is tested bi-weekly, and overall, one full real-life simulation of power transfer switch to backup generation is completed weekly. Generator test but also a load test is done in the “simulation” to reflect realistic operating conditions in an emergency.

In general, EOC and CRC facilities with microgrid capabilities should test back-up power generation monthly at minimum. Emissions testing typically is determined by size and if it participates in capacity contracts with its utility. Annual emissions inventory adheres to EPA/DNR guidelines, including handling testing and requirements.

Table 23. Diesel generator inventory for city facilities.

Nameplate	**Location**	**Operations, Critical Loads being powered (methodology)**	**Comments (note transfer panel location)**
800kW	WWTF	Campus-wide operations	
800kW	WWTF	Campus-wide operations	
80kW	WWTF	(2) Portable units; lift stations	
80 kW	City Hall	Emergency zones, loads defined on the breaker panel	Transfer switch with circuits labeled; Includes emergency lighting, IT and PD dispatch, not entire facility
100 kW	WSCB	Emergency zones, loads defined on the breaker panel	Transfer switch with circuits labeled; not powering the entire facility
12 kW each (3 units)	Museum, Bird St. Water Tower, Sheehan Park Water Tower	Emergency zones, loads defined on the breaker panel	Communication towers power associated communications equipment
67 kW	EMS/Fire #1	Emergency zones, loads defined on the breaker panel	

Table 24. Diesel generation assets - models & maintenance agreements.

Your ID Name	Cummins Unit#	Model	Serial#	Cummins Site Name	Site Address	Status
WCSB	COMM CENTER	150.0DGFA	C060894354	COMMUNITY CENTER	2598 WEST MAIN STREET	Active PM Agreement
Station 1	H030532550	100.0GGHH	H030532550	SAFETY BUILDING	135 N BRISTOL STREET	Active PM Agreement
Water Tower 1	BIRD STATION	44560	3531041	BIRD STATION	990 N BIRD ST	In progress
Museum	MUSEUM	44562	3868602	MUSEUM	115 MAIN ST	In progress
Water Tower 2	SHEEHAN PARK	40794	3508214	SHEEHAN PARK	910 LINNERUD DR	In progress
City Hall	TOWN HALL	80ROZJ71	317786	TOWN HALL	300 E MAIN ST	In progress

Table 25. Emergency equipment –equipment on hand for sewer emergencies.

Description	Model	Qty	Capacity	Year Purchased
Sewer Jet/Vac Combination	VacCon	1	10 Yard	2014
Dump Truck	International	1		2006
End Loader	John Deere	1		2006
Utility Truck	Ford F350	1		2016
Portable Generator	Onan	1	80 Kw	1996
Portable Generator	Generac	1	3500 watts	2003
Portable Pump – 6”	Thompson	1		2001
Portable Pump w/controls – 4”	Flygt	1		2005
Portable Pump – 4”		1		2021
Flow Monitors	Isco	2		2005
Lateral Inspection Camera	Aries	1		2013
Televison Truck	Aries	1		2020
Suction Hose – 6”		100 Ft.		
Suction Hose – 4”		60 Ft.		
Suction Hose – 3”		250 Ft.		
Discharge Hose – 6”		500 Ft.		
Discharge Hose – 4”		600 Ft.		
Discharge Hose – 3”		75 Ft.		

CHECKLISTS AND BEST PRACTICES

Through this process, we identified best practices for generators and microgrids at other city sites. The following section summarizes these considerations for existing diesel generators and for analysis of microgrids across city facilities.

EXISTING DIESEL GENERATOR RECOMMENDATIONS

- **Maintain *Diesel Generator Maintenance Checklist* records for on-site generation**
    - Create a standardized preventative maintenance checklist and collect consistent documentation for all microgrid assets.
    - Capture all name-plate information and store in one virtual location, have an emergency fix vendor on standby with an executed service agreement.
- **Finalize generator system information (city-wide inventory)**
    - Capture vendor information, service/maintenance schedules, equipment costs (fuel, maintenance, staff time for testing) in asset management system.
    - More broadly, utilize this effort when planning a transition to a city-wide asset management system.
- **Transition from existing preventative maintenance agreement with outside vendors to internal staff service call capabilities**
    - Preventative Maintenance; complete monthly checklist, annually fluids/filter replacement, indicator lights, testing transfer panel, refueling + fuel cost, etc.
- **Conduct real-life simulation system testing on a regular frequency**
    - Monthly at minimum; including transfer switch activation and critical load powered by back-up generation.
- **Ongoing review of utility curtailment program for eligible backup generation assets**
    - Emissions testing is a combination of size and runtime; detail minimum generation size and asset requirements, along with any potential upgrades that would make existing units eligible.
    - Explore associated steps such as interconnection agreements and meeting additional emissions requirements (testing costs time and money – utilize thermal gas flow meters for example).
    - Consider technological improvements such as new transfer panels that can auto-test generators at a regular frequency. WPPI Energy program, MISO ISO – 500kW minimum capacity.
- **Map out CRC facilities located in the community**
    - Define criteria in which community would utilize CRC based on event type, duration, capabilities.
- **Work with emergency management staff to utilize resources in this document**
    - Further formalize and refine all documentation and community efforts for both facilities and continue compiling resources (CRC maps, roles & responsibilities, operational planning, G: consolidation).

MICROGRID CHECKLIST

Compare all available technologies for performance and lifecycle cost for back-up generation assets

In any planned replacements, unplanned or emergency replacements, and new asset additions, analyses of the performance tradeoffs and lifecycle costs should be compared across potential technologies. The technologies to consider may include BESS, diesel generator, natural gas generators, and fuel cells. The analysis should compare upfront equipment costs, ongoing O&M costs, the potential energy and demand cost savings, and the ability of the technology to hit key resiliency metrics. Utilize the equations on Pages 18-19 and current battery costs, from NREL and Lazard, to calculate estimated BESS costs based on expected size.

This analysis should also consider the financing options available for each technology. For example, there are likely more federal and state grant programs for BESS systems than a diesel or natural gas generator.

Sites with existing generators should consider lifetime of generator

At sites with existing diesel generators, it is generally not cost effective to replace a generator with battery storage when just looking at resiliency and energy benefits. The diesel generators provide needed resiliency and the upfront costs for batteries is too high for the energy benefits to outweigh the cost. Additionally, if the diesel generator is only running occasionally, the environmental impact can be small.

For these sites, the most financially feasible option for a microgrid installation is likely at the end of the generator’s lifetime. At that point, the BESS and its associated benefits can better compete with the generator and provide additional emissions benefits. The site should start by installing solar to lower its emissions and then can upgrade to a full microgrid at the end of the diesel generator’s lifetime or when the city is at a point where the emissions reduction is important enough for its net-zero goals.

Adding a BESS to a site with an existing generator may be cost-effective for sites where a large solar PV array is existing or planned. The load shifting and demand limiting benefits of a BESS can be fully utilized at such sites, especially where excess solar generation may otherwise need to be exported to the grid at the lower wholesale rate.

Utilize microgrid ready design during renovations and construction

The upfront capital costs associated with establishing a microgrid are often a deterrent. One solution is to install the microgrid components piece by piece based on their own value proposition, while ensuring they are microgrid ready. For example, solar PV arrays can be installed first, with inverters confirmed to be microgrid compatible. NREL provides suggestions on RFP language to include to ensure solar panels and inverters are microgrid-ready. Language should be included that inverters should comply with applicable provisions in the IEEE Series of

Interconnection Standards and that the inverters should be multi-mode DC to AC inverters with islanding functionality.[18]

During renovations or planning, the site should also consider how to save or make enough space for the future BESS installation. In the case of the systems recommended for the SPPL, the space requirements would be relatively minimal. However, for larger installations, this becomes a larger concern.

Consider energy efficiency and demand management to decrease solar and storage capacity needs

When sizing a solar plus storage system, the baseline load is the single most important factor. If there are ways to decrease total energy use through energy efficiency and demand management, this can allow for a smaller and less costly system. As part of an evaluation of the microgrid installation, consider if there are ways to improve efficiency in the building, such as lighting improvement or HVAC system upgrades, or ways to manage demand through plug load or lighting controls.

For sites intended to provide resiliency benefits, it will be important to consider what measures can be installed that can shed or shift load to reduce the amount of energy needed during an outage.

Consider BESS replacement strategy in the bidding process

The battery cells used in a BESS today naturally degrade over time, a fact which must be accounted for in the design of the system. To ensure that the BESS provides all the expected benefits for the site, there are three typical strategies which the city could consider at installation; replacement, augmentation, and oversizing.[19] The first option is a full replacement ~10 years into the project lifetime. With an augmentation strategy, new cells would be added periodically to offset the degradation of older cells, and older cells would be removed as their capacity degrades below acceptable limits. The last option is to oversize the system at the onset, so that as the system degrades, it still hits the minimum capacity needs.

The city should weigh these options against cash flow considerations. For example, if the city has a grant that is covering the cost of the battery, it may make sense to proceed with the oversizing option. However, if the city is covering the cost itself, the augmentation or full replacement options are likely more financially viable, as it is expected that battery costs will continue to decline over time. Regardless, the location where the battery is to be housed should be designed to accommodate an oversized or augmented battery to ensure that any of the three options can be employed.

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[18] Booth, “Microgrid-Ready Solar PV - Planning for Resiliency.”

[19] EPRI, “Energy Storage, DER, and Microgrid Project Valuation: EPRI DER-VET Analysis in Action”; Shin and Hur, “Optimal Energy Storage Sizing With Battery Augmentation for Renewable-Plus-Storage Power Plants.”

When sizing DER components, determine the critical loads at the facility

The amount of load that must be sustained during an outage is a key factor in the size of storage required for a microgrid. Stakeholders familiar with the building load and needs could likely estimate which functions should be considered critical load.

It may also be useful to utilize the Clean Coalition's VOR123 methodology.[20] The methodology suggests that most buildings can split their load into three tiers. Tier 1 represents ~10 percent of load and are critical items that require power always. Tier 2 represents ~15 percent of total load and are all other priority loads, and Tier 3 represents the last 75 percent and all discretionary loads. To utilize this methodology, split all the major spaces in the building into tier 1, tier 2 and tier 3. From there, data such as square footage, occupancy, or submetering can be used to estimate energy needs for each tier.

Include resiliency benefits in calculations of cost-effectiveness

Resiliency benefits are one of the primary reasons to install a microgrid system and are often significant. It is important to consider the monetary value of these benefits when making decisions about investment. There are several methods a site could use to value resiliency:

- Utilize national estimates from LBNL. This is one of the most cited values of resiliency but is limited as it only includes values for outage durations up to 16 hours.[21]
- Estimate the value using NREL's Customer Damage Function Calculator. This tool allows the user to input any damaged equipment costs, lost data costs, food or product spoilage costs, or any other interruption costs.[22]
- Estimate human health benefits for a CRC. Other studies have considered their population and estimated how many people would need electricity dependent medical care or heating and cooling centers to estimate health impacts and associated avoided costs.[23]

Consider various financing options

The upfront cost of BESS and solar PV can be a deterrent to installation. In addition to the piecemeal installation discussed above, there are several financing options the city can consider.

Grant programs are a potential source of funding for microgrids. State and federal grants have historically funded installations; however, this requires a funding opportunity to be open around the time of installation.

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[20] Craig Lewis and Seth Mullendore, "Valuing Resilience in Solar+Storage Microgrids: A New Critical Load Tiering Approach."

[21] Sullivan, Schellenberg, and Blundell, "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States."

[22] "Customer Damage Function Calculator."

[23] Rolon, Calven, and Aytjanova, "Solar and Energy Storage for Resiliency."

Another future option could be third-party ownership financing. Active dockets with the PSC are requesting that the agency rules that third-party distributed energy resources are not defined as public utilities.[24] If the PSC rules on this case, it would open up the possibility for third-party ownership of both solar and BESS systems.

Lastly, there are utility pilot programs across the county on resiliency as a service. For example, Xcel Energy is currently running a program in western Wisconsin where the utility installs BESS for large industrial customers that need added reliability, and the customers pay off the projects over ten years.[25] WPPI also currently provides a back-up generator program for systems over 500 kW. This could be an option for larger installations at the city of Sun Prairie, and as programs evolve, this type of partnership could become a more viable financing option.

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[24] Midwest Renewable Energy Association, "Verified Petition for Declaratory Ruling."

[25] "Resiliency as a Service RFP | Xcel Energy."

CONCLUSION

A microgrid at Sun Prairie Public Library can help meet several community goals: increased use of renewable energy and improved resiliency communitywide. The microgrid can help provide these benefits and generate net financial savings over the lifetime of the system. To offset upfront costs, the library can make piecemeal upgrades to enable an eventual microgrid. These steps can start with ensuring extensive efficiency upgrades are included as part of the renovation and then proceed with installing solar panels. The battery can then be installed when the city is ready to further invest in creation of the microgrid.

The results in this study highlight the tradeoffs between different system configurations to inform the decision around microgrid installation. The important findings include the following:

- **Battery sizes and costs increase as the load requirements and outage duration requirement increase.** There are two primary factors that impact battery size – the critical load profile and the length of outages the center wants to be able to cover. As more of the building load is categorized as critical load, the size of the battery increases, which decreases net present value. Similarly, as the length of the outage the system should cover increases, the size of the battery increases. Sun Prairie will need to decide how to balance these tradeoffs – whether they want to be able to cover longer outages at decreased load or if they want to cover more load at decreased outage length. The last option is that the city could decide that resiliency is important enough to include a larger battery system and potentially have a negative net present value.

- **All-electric heating systems improve the financial performance of a microgrid.** The all-electric heating systems performed better than a natural gas conventional VAV system. This is primarily a function of increased energy cost savings for the all-electric systems as more of their load corresponds with times when solar production is high.

  The all-electric systems also performed better when the resiliency benefits were included as the microgrid was able to sustain the entire critical energy load. The all-electric heating system is naturally a more resilient solution as it does not require natural gas distribution (which can often be negatively impacted) during a winter emergency to provide the benefits of a CRC.

- **Solutions designed to withstand 4-hour outages perform better financially when looking only at energy savings but have lower resiliency benefits.** Both of the scenarios that required the configuration to withstand a 4-hour outage had higher net present values than their 24-hour counterparts. This is primarily due to the lower upfront costs for battery storage.

  However, the systems have lower resiliency across the year, even if they only need to cover critical load. When considering the monetary value of these resiliency benefits, net present values of the 24-hour systems improve. In fact, the all-electric 24-hour solution outperforms the all-electric 4-hour solution when those costs are included. Sun Prairie will have to balance the tradeoffs between increased resiliency and increased cost when determining battery size.

- **Resiliency is highest during the shoulder seasons and all system configurations examined have a lower probability of withstanding outages in the winter.** The highest amount of energy disturbances have historically occurred in the summer in Wisconsin. As we utilized that timing for our outage constraint, the considered systems were best suited to withstand outages in the spring and summer. Resiliency was highest in the shoulder seasons when space conditioning needs are low and solar production is high. However, all the scenarios and especially the all-electric VRF systems have limited ability to withstand an outage of any length in the winter months. However, the library could further limit critical load during the winter to continue to provide resiliency benefits or the city could consider the installation of a larger BESS to ensure winter outages are covered.

- **Including societal benefits increases the net present value of the scenarios by at least 10 times as compared to having no DERs on-site.** All the scenarios provide significant environmental and health benefits by reducing reliance on fossil fuels and the resulting carbon and criteria pollutant emissions. The all-electric VRF scenarios result in ~50 percent of all energy coming from renewable sources while the natural gas conventional VAV scenarios result in ~25 percent of all energy coming from renewable sources.

  Across all scenarios, the monetary value of the reduced emissions is significant and leads to net present values over 10 times higher than the net present value that only includes financial benefits.

Based on these takeaways, we recommend that Sun Prairie prioritize an all-electric VRF heating system upgrade and a microgrid that can withstand a 24-hour outage. The city should consider the upfront costs of the all-electric upgrade versus the natural gas conventional VAV system in their process – but recognize that the all-electric VRF system paired with the solar and BESS system gets the city much closer to its renewable energy and resiliency goals. We recommend the larger system as it still results in a positive net present value and ultimately provides much greater resiliency benefits across the year. The phased approach to installation could lessen the financial concerns of this recommendation.

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APPENDIX A: CHAPTER 2.88 EMERGENCY MANAGEMENT

2.88.020 - Emergency management—Definitions.

A. Emergency Management. Includes "emergency government" and "civil defense" and means all measures undertaken by or on behalf of the city:

1. To prepare for and minimize the effect of enemy action and man-made or natural disaster upon the civilian population;
2. To effectuate emergency repairs to, or the emergency restoration of, vital public utilities and facilities destroyed or damaged by such action or disaster.

B. Emergency Government and Civil Defense. All measures undertaken by, or on behalf of the state, county and municipalities to prepare for and minimize the effects of enemy action upon the civilian population.

(Ord. 392 § 1 (part), 1997)

2.88.030 - Emergency management director.

A. Director. There is created the office of emergency management director.

1. Appointment. The emergency management director shall be the chief of police, unless otherwise appointed by the mayor.
2. Duties and Powers. The director shall be the executive head of the city emergency government organization and shall have direct responsibility for the organization, administration and operation of the organization, subject to the direction and control of the mayor and the common council. In addition to such powers and responsibilities as may be imposed on him or her from time to time by the common council, he or she shall have the authority and it shall be his or her duty to:
    - a. Coordinate all activities for emergency management within the city;
    - b. Maintain liaison and cooperation with emergency management agencies and organizations of other political subdivisions and to the state and federal government;
    - c. Oversee city participation in county and state emergency management activities, such as training programs and exercises, upon request;
    - d. Oversee city participation in city emergency management training programs and exercises;
    - e. Prepare a comprehensive general plan for the emergency management of the city based on an all-hazards approach which cites methods the city can use to mitigate and prepare for, respond to and recover from emergency, and present such plan to the common council for approval;
    - f. Subject to the approval of the common council, enter into a mutual agreement with other political subdivisions and file copies of any such agreements with the state director of emergency management;
    - g. Upon the declaration of an emergency, issue all necessary proclamations as to the state of emergency and such disaster warnings or alerts as shall be required in the emergency management plan.

(Ord. 577, § 1, 10-7-2014; Ord. 392 § 1 (part), 1997)

2.88.040 - Emergency management coordinator.

A. Coordinator. There is created the office of emergency management coordinator.

1. Appointment. The emergency management coordinator shall be the fire chief, EMS director, and assistant chief of police, or unless otherwise designated by the emergency management director.
2. Duties and Powers. The emergency management coordinator shall execute daily operations of emergency management, execute emergency functions in support of the

director pursuant to Section 2.88.030 of this chapter and perform, in his or her absence, duties pursuant to Ch. 166, Wisconsin Statutes.

(Ord. 577, § 1, 10-7-2014; Ord. 392 § 1 (part), 1997)

2.88.050 - Utilization of existing services and facilities.

A. Policy. In preparing and executing the emergency management plan, the director shall utilize the services, equipment, supplies and facilities of the existing departments and agencies of the city to the maximum extent practicable. When the common council has approved of the plan, it shall be the duty of all municipal agencies and departments of the city to perform the duties and functions assigned by the approved plan and are directed to cooperate and extend such services and facilities as are required of them.

B. Responsibility. In order to assure that in an emergency all the facilities of the existing city government are expanded to the fullest to meet such emergencies, department and agency heads and employees assigned to specific responsibilities under the city emergency operations plan will fulfill emergency and nonemergency duties as prescribed in the plan. (Ord. 392 § 1 (part), 1997)

2.88.060 - Declaration of emergencies.

Declaration of emergency shall be made by the governor, the mayor, or in his or her absence, by the director. Such state of emergency shall continue until terminated by the issuing authority, provided that any declaration not issued by the governor may be terminated by the common council.

(Ord. 577, § 1, 10-7-2014; Ord. 392 § 1 (part), 1997)