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DOE Connected Communities
Design and Analysis Case Study M3.5.2
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Introduction

Grid-interactive efficient buildings (GEBs) allow for energy efficiency, load shifting, shedding, and on-site electricity generation, benefiting the grid system and consumers.[1] As part of the Department of Energy's (DOE's) Connected Communities project, Slipstream, with project partners the City of Madison, Madison Gas & Electric (MGE), RMI, the American Council for an Energy-Efficient Economy (ACEEE), and bluEvolution, is currently developing a GEB pilot in Madison, Wisconsin. The project involves a GEB demonstration in City of Madison buildings, followed by a GEB pilot led by MGE.

The goals of the GEB project in Madison are to reduce energy usage and greenhouse gas (GHG) emissions through load management, to reduce energy costs for building owners and all utility customers, to increase the resilience of buildings, and to create a model for GEB deployment that can be replicated.[2] In the first stage of the project, Slipstream and the project team are implementing GEB strategies including load shaping,[3] electric vehicle (EV) managed charging,[4] smart inverter management,[5] and battery deployment[6] in seven City of Madison buildings. In the second stage, MGE will develop a pilot GEB program for its customers. The vision of the multi-stage project is to demonstrate the cost effectiveness and scalability of GEBs.[7]

In this iterative case study series, we aim to capture replicable elements of the GEB project deployment process that can inform the work of building owners, operators, and designers undertaking future GEB projects. The first two editions of the case study series will focus on the GEB design and analysis process and highlight early lessons from the project. This is the second edition, which builds on the first and includes insights from year 2 of the project.

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[1] DOE (Department of Energy). 2021. *A National Roadmap for Grid-Interactive Efficient Buildings*. May 17. https://gebroadmap.lbl.gov/A%20National%20Roadmap%20for%20GEBs%20-%20Final.pdf.
[2] Slipstream. 2023a. "Connected Communities for Sustainable Solutions." Presented by Scott Hackel at DOE Peer Review in April.
[3] For the Madison project, load shaping will involve load shedding strategies through use of automated demand response (ADR) of HVAC and lighting.
[4] Managed EV charging involves use of an aggregator that responds to changes in loads and shifts EV charging periods accordingly, with grid connection (NREL (National Renewable Energy Laboratory). 2023. "Electric Vehicle Smart Charging at Scale." https://www.nrel.gov/transportation/managed-electric-vehicle-charging.html).
[5] Smart inverters integrate solar photovoltaic (PV) systems with the grid and provide grid support functionality (IREC (International Renewable Energy Council). 2023. "Smart Inverters." Accessed July 14. https://www.irecusa.org/our-work/smart-inverters/). In the Madison project, the smart inverter functionality will include dynamic volt-var, volt-watt, and fixed power factor control.
[6] Batteries allow for energy to be stored. Batteries will be used in the Madison project to increase self-consumption of solar energy, provide resilience at host buildings, and allow for load shedding and shifting.
[7] Slipstream 2023a; Slipstream. 2023b. *Connecting Communities for Sustainable Solutions: Measurement and Verification Plan.* https://connectedcommunities.lbl.gov/connecting-communities-sustainable-solutions.

GEB customer value streams

GEB measures can provide multiple direct value streams to building owners.[8] By decreasing the peak demand of a building, GEB measures can reduce energy demand charges. In addition, by improving the efficiency of a building's operation, GEB measures can lower energy use and decrease energy costs. GEB measures can also generate revenue for building owners through participation in demand response programs. GEB case studies have demonstrated short payback periods,[9] as well as additional benefits to building owners including lower GHG emissions, increased health and comfort of building occupants, and enhanced resilience of buildings.[10]

GEB Program Design

Project partners

In the initial design process for the City of Madison GEB demonstration, it was important to identify key project partners. In general, a GEB project will involve building owners, facility operators who are familiar with the existing systems and able to navigate issues as they arise, building occupants, utility personnel, systems integrators, energy modelers, cybersecurity experts, and technology vendors. The Madison project has involved the City of Madison as building owners, operators and occupants, utility personnel from MGE, cybersecurity experts and system integrators from bluEvolution, and technology vendors including ACE IoT for the Energy Management Information System, Lutron for the Network Lighting Controls, and OpConnect for the EV managed charging. Slipstream supported system integration and energy modeling.

Building site selection

The selection of building sites for a GEB project is an important initial step in the project design. The seven City of Madison buildings selected for the demonstration include a large office building, two buildings with office and vehicle garage space, a vehicle maintenance space with minor office space,

Madison Municipal Building (Slipstream 2023b)

Fire Station 14 (Slipstream 2023b)

[8] DOE 2021; Jungclaus, M., C. Carmichael and P. Keuhn. 2019. *Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: A Cost-Benefit Analysis.* Rocky Mountain Institute. http://www.rmi.org/GEBs_report.

[9] In an analysis of GEB measures in the General Service Administration (GSA) portfolio, Jungclaus et al. (2019) found the payback period on a project level to be under four years, with utility incentives reducing the payback period further.

[10] DOE. 2019. *Grid-interactive Efficient Buildings Technical Report Series: Windows and Opaque Envelope*. December. https://www1.eere.energy.gov/buildings/pdfs/75387.pdf; DOE 2021; Jungclaus et al. 2019.

a fire station, a police station, and a community center.[11] The age of the building systems was one factor in site selection for the City of Madison demonstration, as newer digital systems (for example, networked lighting and HVAC controls) allow for easier GEB measure integration and controllability without significant hardware upgrades. In addition, the existing building technologies and controls and outstanding opportunities for energy efficiency upgrades are additional considerations for GEB design.

Analysis of existing building operation

Following the selection of building sites for the City of Madison GEB demonstration, Slipstream conducted an initial analysis of building energy data. Slipstream established the current energy use intensity (EUI) of the building sites using historical energy usage data; current EUI will serve as a baseline for calculating energy savings from GEB measures in the future. In addition, preliminary data analysis for the project included collection of interval meter data to establish the conditions under which peak demands occur and the degree to which the existing on-site PV generation is exported back to the grid. Other initial analysis for the project design included the use of Reopt, an NREL energy optimization tool, to approximate the size of batteries needed for the pilot GEBs.

GEB system procurement

To select building-specific GEB measures within the overall project design, it is necessary to understand the applicable systems for a given building and identify the gaps between the building's existing operations and desired GEB functionality. Such analysis will enable the design of measures such as smart inverters and batteries, and the selection of networked lighting controls and energy management information systems (EMIS).

For the City of Madison sites, the project team developed a comprehensive procurement process. The first step was a request for information, or RFI, which identified the functionality currently available from EMIS vendors. These data informed a subsequent Request for Proposal (RFP), which ultimately selected the vendor to provide those functionalities. City of Madison selected a project team comprising of ACE IoT Solutions LLC (ACE IoT) and Hammel, Green, and Abrahamson, Inc. (HGA) to build and deploy the EMIS automation platform.


CITY OF MADISON

REQUEST FOR PROPOSALS

RFP #: 12036-0-2023-BG

Title: Integration and Automation Platform for Grid-Interactive Efficient Buildlings (GEB)

City Agency: Engineering

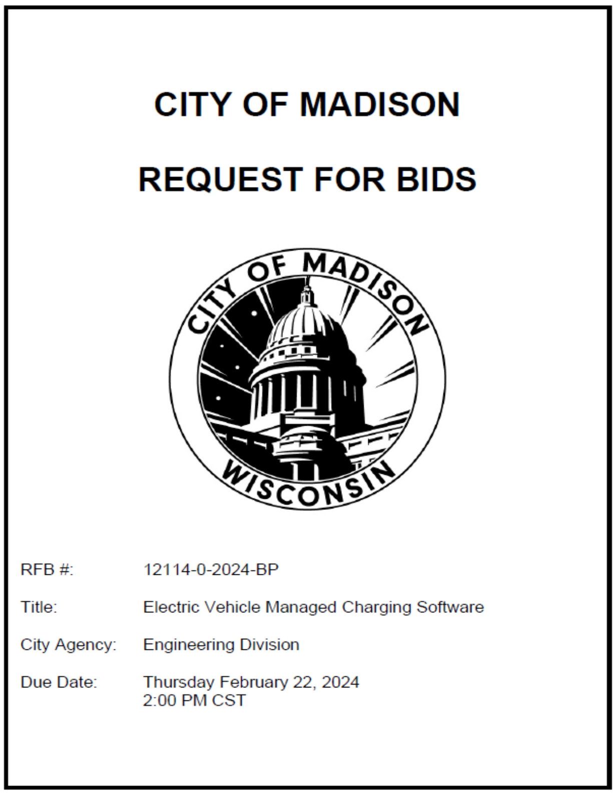
Due Date: June 29, 2023
2:00 PM CST

[11] Slipstream 2023b

A Request for Bid (RFB) was developed for EV managed charging. An RFB differs from an RFP in that it is evaluated solely on the vendor bid's ability to meet the selection criteria and overall cost. The RFB criteria was developed by reviewing vendor's capabilities in comparison with the City of Madison's priorities. This review illuminated the range of capabilities that were available in the market and provided confidence that the RFB criteria could be met by multiple vendors.

The RFB selection criteria included:

1. Previous experience deploying EV managed charging
2. Ability to communicate via OpenADR or other signals such as OCCP
3. Ability to provide the following capabilities


CITY OF MADISON

REQUEST FOR BIDS

RFB #: 12114-0-2024-BP

Title: Electric Vehicle Managed Charging Software

City Agency: Engineering Division

Due Date: Thursday February 22, 2024
2:00 PM CST

Capabilities	Description
Load Shed (ADR)	Capable of EV load shed during an automated demand response event, either through receiving the ADR signal directly from the utility or via the EMIS.
Load Optimization	Manages power to each charger, charger group, or site below a pre-defined limit.
Charge Prioritization	Setup a priority logic to distribute power among charging stations. Identify and prioritize business-critical EV charging.
Tariff Optimization	Automate charging based on electricity rates (energy and demand charges) to maximize fuel savings while considering fleet need (departure time and energy needed for each EV).
	Can be integrated with building meter for demand limiting.
Solar Charging	Maximizes solar charging while respecting fleet charging needs. Optimizes EV charging, predicting solar and computing the best charging schedule to use it.
Real-Time Charging Data	Full visibility with real-time monitoring and role-based alerts, real-time visibility of EV station status and health, telematics.
Restricted Access	Set vehicle access groups, track users by RFID (by vehicle, synced with VIN) or driver ID.
Billing	Setup groups of users with different charging billing rates and permissions.
Network Resources	Cloud-based, via cellular or wifi

After reviewing the submitted bids, OpConnect was selected as the managed charging vendor.

Lutron is the existing Networked Lighting Controls (NLC) provider to the City. To maintain consistency, they were selected as the NLC provider for this project. Lutron's team developed a design and associated Bill of Materials for the lighting retrofit. However, several of the fixture types did not meet the Build America Buy America (BABA) requirement, resulting in delays in procurement.

The project team conducted a similar procurement process for battery technology; a draft RFP was circulated to battery and microgrid vendors and contractors for feedback, followed by publication of the final RFP. In year 2, vendors were shortlisted; however, identifying battery manufacturers who met the BABA requirement proved to be difficult, resulting in delays in vendor selection and battery deployment.

In year 2, MGE lead an RFI process to solicit detailed information about Distributed Energy Resource Management System (DERMS) provider capabilities to help integrate, manage, and optimize GEB resources on the utility grid. Findings from the RFI included the state of the DERMS platform market in terms of technical and functional capabilities, implementation approaches and pricing structures; and will help MGE develop an RFP for a DERMS platform provider. The RFI was based on a guidebook of DERMS functionality requirements created by the Smart Electric Power Alliance (SEPA) for utilities seeking to implement DERMS platforms[12]. Because the DERMS deployment will extend beyond Connected Communities, MGE is exploring alternative building-level communication and control options for the pilot.

Technology integration

In year 2 the project team developed controls algorithms for demand management and load shedding for HVAC and lighting systems. They then integrated these controls with existing building systems and commissioned them.

To help guide the design, the following Key Performance Indicators were developed.

Reduce City of Madison peak demand charges	15% reduction in customer peak demand and associated monthly demand charges. Note that this target will be an average over the months that demand management is active. Ideally, this will include summer, shoulder, and winter months.
Respond to MGE demand response events	15% reduction in demand over the defined event period compared to baseline. Note that this target will be an average across a minimum of 5 events.
Develop functional EMIS	EMIS and dashboarding that clearly details continuous demand management controls and includes real-time power displays for each site including load, generation, previous peaks, target peaks and overlays demand response events. It will additionally provide feedback on zone temperatures and whether they are outside of defined comfort thresholds.
Minimize negative impacts of project to occupants	Minimize negative impacts to occupants from the GEBs implementation as measured by the number of complaints received. Goal is to reduce complaints to less than 5.
Minimize negative impacts of project to operations	Minimize negative impacts to operations from the GEBs implementation as measured by the number of disruptions. Goal is to have 0 operational disruptions.

The following control algorithms were developed.

Increase zone temperature setpoint deadband	For all thermostats associated with the main air handler, increase temperature deadband from 2°F to 4°F(adj). Provide 3 categories of space types to stage triggers based on occupancy type.
Implement AHU supply fan reset	Adjust duct static pressure setpoint

[12] https://sepapower.org/resource/distributed-energy-resource-management-system-derms-requirements/

Adjust AHU min outside airflow values from LEED to code min	Adjust the AHU minimum outside airflows from LEED to Wisconsin code minimum requirements
Light level adjustment	Decrease lighting power by 33%

Smart inverter functionality was also developed and deployed during year 2. The smart inverter modes tested included:

- Constant Power Factor (CPF) at 0.95
- Volt-Var at 44% reactive power output
- Volt-Var at 31% reactive power output
- CPF at 0.95 combined with Volt-Watt
- Volt-Var at 44% reactive power output combined with Volt-Watt
- Volt-Var at 31% reactive power output combined with Volt-Watt

In a later phase, MGE will deploy a method for allowing the utility to communicate with the GEBS (such as a distributed energy resource management system (DERMS).

GEB Deployment Lessons

The GEB technology procurement process and technology integration can be both time-consuming and complex. For instance, developing the specifications for the RFPs and RFBs took months. Now that these requirements are created, future procurements will be much more streamlined as the technical specifications in the RFP and RFB documents can be used as templates by others. In addition, the domestic procurement preference under the BABA Act, restricted the selection of battery and lighting vendors, resulting in delays to the installation timelines for the City of Madison demonstration projects and completion milestones. A request for BABA waiver was submitted and a decision is awaited. As the industry better understands the BABA requirements and shifts their production to more closely align, this requirement should be easier to meet.

Integrating the services and measures procured after the RFPs with the existing infrastructure requires intricate planning and time. For example, the City of Madison and the EMIS service provider encountered multiple unexpected issues while integrating data into the EMIS platform. While the city has a very active and responsive facilities management team, there were still several cases of finding optimizations and control sequences that were thought to be active but not performing as specified. There are often uncertainties around controls specifications and how they perform in the building due to equipment failure and communications protocols not working as intended. The project team should plan to include buffer in budgets to support the repair or replacement of malfunctioning equipment and make the control sequences work correctly, to allow for proper GEB technology integration.

Additionally, HVAC control strategies for demand response and continuous demand management were tested extensively and will require further testing under actual weather conditions (over periods of hot weather) to validate savings and confirm the system operates according to its intended design.

EMIS implementation

To streamline EMIS implementation, the project team needs to set goals, define EMIS capabilities, and determine the data needs beforehand. The ACE IoT and HGA team developed and tested the EMIS functionalities while prioritizing occupant comfort, data and reporting support to capture benefits to the building owner and power companies, and the replicability of control sequences. While testing the EMIS controls the team identified gaps between existing system capabilities and desired GEB functionality and decided to opt for open-source EMIS controls and optimization solutions.

Prior to the start of the project, the building owner must assess existing Building Automation System (BAS) and ensure it is BACNET-enabled, and all its capabilities are fully operational. It is critical to confirm whether the system has these capabilities or if the controls integration team needs to plan and budget for enabling GEB technology integration. For example, the City of Madison project work scope pre-supposed an existing BACnet BAS. However, upon deploying to the buildings it was discovered that much of the infrastructure was simply BACnet capable, not BACnet Enabled or Native. Often the specification for EMIS systems includes BACnet interoperability, but that is never tested or validated until a third-party interoperable system is deployed. A careful evaluation of the actual systems in the field is therefore necessary to de-risk projects.

Another lesson came while deploying the temperature setpoint adjustments for peak demand limiting. During deployment, the team discovered several existing control sequences across the site, with incompatible override inputs. While the EMIS is flexible enough to handle this situation, it took additional time to implement. Pre-project evaluation of existing controls, with subsequent programming work to increase sequence consistency, would reduce the GEB project's time and associated budget.

Furthermore, the EMIS element within the Madison GEB project established an independent data layer, which enables the exchange of data between building subsystems, GEB components, and any potential new applications that may be added to enhance the building's functionality in the future. A controls dashboard was also developed to facilitate real-time data trends and create selective data reports and visualizations.

Electric vehicle managed charging deployment

The City of Madison had previously standardized and deployed dozens of EnelX's Juicebox chargers in the municipal buildings. Unfortunately, EnelX withdrew their operations from North America in the middle of this project. The EV charging software vendor, OpConnect, determined the EnelX chargers were not fully Open Charge Point Protocol (OCPP) compliant.[13] OCPP is an open-source communication protocol for networked electric vehicle chargers, that helps make any EV charger work with any charger management software. OpConnect could therefore not communicate with the existing chargers, thus requiring their replacement to move the project forward. New LiteOn chargers are being deployed that will allow proper communication, thereby facilitating better services, and enhance reliability, interoperability, and scalability in existing networks.

[13] OCPP, is a system of rules that allow EV charge points and charging station networks (central management system) to communicate with each other.

Smart inverter management

Throughout the testing process, several challenges were encountered in remotely configuring voltage control modes via the monitoring platform. Firmware updates were required for certain inverters to enable remote modifications, while others (particularly at the Fleet Headquarters site) could not be updated remotely and required on-site manual adjustments. Even after updates, some inverters intermittently failed to accept remote settings changes. Despite these hurdles, all six sites successfully participated in the testing, generating sufficient data for comprehensive analysis.

The results of the testing periods confirmed the initial observations from the historical data analysis, which indicated that inverter voltages across all City of Madison sites very rarely fall out of the ±5% tolerance range of the nominal voltage. This means that the effect of the smart inverter functionality were difficult to discern. To see their effect more fully, the project team adjusted Volt-Var mode parameters to include a 1% deadband and a 3% reactive power output range, the Volt-Watt mode parameters to begin functioning when the voltage increases above 3% of the reference voltage, and the voltage tolerance range was tightened to ±3%. This adjustment demonstrated a marked improvement in voltage stability. Baseline data showed that the voltage fell out of the ±3% tolerance range 9.2% of the time. During the testing period, this percentage decreased significantly to 2.9%, representing an overall 69% reduction in the percentage of time that the voltage was out of range. This reduction strongly supports the functionality of the Volt-Var mode at 44% with the reduced curve in mitigating voltage deviations.

Key Takeaways

Site and technology considerations

During the design and analysis phase of the GEB demonstration, Slipstream identified building site selection as a critical element of the process. The selection of appropriate buildings for a GEB project requires understanding building capabilities, whether a given building can accept a GEB system, and what technologies would be required to equip the building with GEB capabilities. For example, suitable buildings would need to have specific HVAC capabilities and control systems to shift and shed loads.

Another key ongoing element of design is the controls and integration process. This process includes programming and testing procedures, as well as data collection and analysis. Within the overall GEB system, there are different subsystems with unique datasets that are likely to vary across GEB projects. In addition, the EMIS element within the Madison GEB project provides the benefit of an independent data layer that allows for free exchange of data between building subsystems, GEB components, and potential new applications that could be added to make the building smarter in the future. Through this technology, building automation data are more easily accessible for future applications. As the design and implementation of these elements are essential to GEB functionality, Slipstream highlights controls and integration work as a central element of project design and analysis.

It is also important to understand the potential return on investment that a building owner will receive from a GEB project. Slipstream identified the size of a building as another consideration in facility selection, as smaller buildings may not have ample loads to shift and may have longer payback periods for GEB measures.

Emerging technology challenges

One challenge that Slipstream has encountered in the design and analysis of the City of Madison demonstration is working with new technologies, namely an EMIS that is GEB-capable. Given the nascency of that technology capability, the development of an RFP was a complex and lengthy process. In addition, other GEB technology like EV managed charging and smart inverters are often new services that vendors are offering, so procuring these technologies can require extra time.

Smart inverters also present market-specific challenges. For building owners, there is typically no additional cost for smart inverters as the industry has largely standardized on IEEE 1547-2018, the code that defines smart inverter functionality. However, while smart inverters have a clear benefit to the utility grid, there is usually no direct benefit to building owners. Through the City of Madison demonstration, Slipstream and project partners tested the potential of smart inverters to stabilize voltage on the grid.

Stakeholder collaboration

Slipstream worked with the City of Madison, that is, the building owners, operators, and occupants, to identify candidates for the GEB demonstration. In addition, engagement with utility personnel, technology vendors, cybersecurity experts, and other stakeholders is key to understanding existing building capabilities and appropriate technologies for GEB deployment, highlighting the importance of collaboration with project partners in this process.

In the Madison demonstration, an additional key factor in facility selection has been the interest of a building operator or facility manager in participating in the GEB project. Given the work required on the ground to execute GEB deployment, facility managers are key stakeholders in the collaborative process. Therefore, it is critical that a facility manager of a prospective GEB building be willing to engage in the project.

Incremental approach to GEB development

Slipstream notes that it may be economical for building owners to take an incremental approach to GEB development. In considering strategies for integrated GEB technologies, it may be advantageous to first procure an EMIS platform for enhanced control of existing systems, such as a heating, ventilation, and air-conditioning (HVAC) system. In this approach, a building owner would only incur operational expenses on controls in the first stage of GEB development, allowing planning for longer-term investment in capital improvements, such as PV arrays and smart inverters. A building owner could integrate these systems as they are added. An incremental approach to GEB development may be key to scaling GEB projects and allowing more building owners to participate.

Utility program design considerations

Based on considerations for the MGE program, it is critical to identify the value propositions for key customer categories that can benefit from a GEB program. Additionally, existing utility infrastructure, including Advanced Metering Infrastructure and newer digital systems in buildings, should be considered, as these technologies enable communication between the utility and the buildings, thereby facilitating easier GEB integration.

MGE is leading development of a utility pilot with support from Slipstream, RMI and ACEEE. The main goal is to validate the technical approach for controls and communications. To expedite regulatory approval from the Public Service Commission (PSC), pilot incentives will focus on reducing the installed cost for enabling technologies instead of changes in utility rate design. MGE plans to seek feedback from the PSC to inform the plan for the pilot. Additionally, MGE is also conducting research into enterprise DERMS options and system capabilities by reaching out to vendors, to identify any solutions that may be relevant to implementation within the pilot timeframe.

Conclusion

In the first and second year of the Madison project, Slipstream and its project partners have undertaken the initial deployment of GEB technologies, design and development of EMIS controls, and analysis of the building data. Slipstream identified the selection of building sites and the controls and integration process as two key elements of project design. It may be helpful for other building owners, operators, and designers approaching GEB projects to focus on these elements, as well as to consider potential challenges like the nascency of a GEB-capable EMIS, smart inverters, and other GEBs technologies prior to the design of full-scale programs.