Federal Energy Management Program

Key Grid-Interactive Efficient Building Technologies for Federal and Commercial Facilities

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DRAFT REPORT

Disclaimer

Authors

The authors of this report are:

Valerie Nubbe, Guidehouse

April Weintraub, Guidehouse

Mark Butrico, Guidehouse.

The editors of this report are:

Jason Koman, U.S. Department of Energy Federal Energy Management Program

Jay Wrobel, U.S. Department of Energy Federal Energy Management Program.

List of Acronyms

CHP	combined heat and power
ESCO	energy service company
ESPC	energy savings performance contract
GEB	grid-interactive efficient building
GSA	U.S. General Services Administration
HVAC	heating, ventilation, and air conditioning
PV	photovoltaic
TES	thermal energy storage
UESC	utility energy service contract

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1 Introduction

1.1 Background and Purpose of this Report

Growing peak electricity demand, transmission and distribution infrastructure constraints, and an increasing share of variable renewable electricity generation are challenging the electrical grid. As the grid becomes increasingly complex, demand flexibility can play an important role in helping maintain grid reliability, improving energy affordability, and integrating a variety of generation sources. Grid-interactive efficient buildings (GEBs) can provide flexibility by reducing energy waste, helping balance energy use during times of peak demand and/or plentiful renewable generation, and reducing the risk of frequency deviations. The GEB vision is the integration and continuous optimization of distributed energy resources for the benefit of building owners and occupants, as well as the grid.

While grid-interactive technologies are still nascent in buildings today, several federal buildings have deployed smart building and grid-interactive technologies successfully. The U.S. General Services Administration (GSA) Oklahoma City Federal Building demonstrated GEB-ready strategies and technologies (including a photovoltaic [PV] array, lighting controls, building automation system upgrades, battery energy storage system, and advanced power strips) can be deployed across buildings with minimal investment [1]. In addition, the Veteran's Affairs Carl T. Hayden Medical Center in Phoenix, Arizona, demonstrated a successful energy retrofit project that reduced energy consumption by 25% and utilized energy storage and on-site generation to shift loads to align with time-of-use pricing and reduce peaks to avoid demand charges [2].

This report serves as a resource for building owners and managers interested in deploying GEB technologies in federal and commercial facilities. This document also provides an overview of smart buildings and the prioritization and categorization of GEB technologies that have a high potential to provide grid services.

Several key sources were used to categorize, prioritize, and describe the technologies in this report.

- The U.S. Department of Energy Building Technologies Office GEB technical reports [3] provide background information about GEB services and technologies. There are five technical reports referenced in this report that analyze different areas of building technology, including heating, ventilation, and air conditioning (HVAC), Envelope, Lighting, Controls, and an overview of research challenges. Information in these reports is used to categorize technologies and evaluate the potential of the technologies to provide grid services. Each of the reports provides general descriptions of the specific technologies and contains details about how the technologies provide grid services.
- The *Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: A Cost-Benefit Analysis* [4] report provided insight into the analysis of GEB cost and energy savings. This report uses the findings from the *Value Potential for Grid-*

Interactive Efficient Buildings in the GSA Portfolio: A Cost-Benefit Analysis document to help quantify the potential savings for GEB and prioritize the different technologies. This report references background information about GEBs and cost data from the GSA document.

- The *Blueprint for Integrating GEB Technologies* [5] report analyzes a multitude of GEB measures and how those measures are categorized into the different grid services. The descriptions of the technologies from the Blueprint are referenced in this report and used to categorize and prioritize different GEB measures. This report used details about the referenced measures to build out the technology lists in the later sections.
- The *GEB Project Summary* report [6] provides background information and descriptions for ongoing and completed projects related to GEBs. This report references several projects in the GEB Project Summary to expand the number of potential GEB technologies described in future sections. Background information about these GEB technologies and information about the projects is used in this report to categorize technologies.

1.2 What Is a Grid-Interactive Efficient Building?

Buildings offer a unique opportunity for cost-effective demand-side management because they are the nation's primary users of electricity: 75% of all U.S. electricity is consumed within buildings, and perhaps more importantly, building energy use drives a comparable share of peak power demand. The electricity demand from buildings results from a variety of electrical loads that are operated to serve the needs of occupants. However, many of these loads are flexible to some degree; with proper communications and controls, loads can be managed to draw electricity at specific times and at different levels, while still meeting occupant productivity and comfort requirements [6]. New and existing technologies can be implemented to create smart buildings that provide an opportunity to reduce electricity consumption in the building sector.

The U.S. Department of Energy Building Technologies Office defines a smart building or a GEB as "an energy-efficient building with smart technologies characterized by the active use of distributed energy resources to optimize energy use for grid services, occupant needs and preferences, and cost reductions in a continuous and integrated way" [7]. Smart buildings use advanced strategies and technologies to manage peak demand and electricity loads without compromising occupant needs. There are four demand management strategies utilized in GEBs, as illustrated in Figure 1.

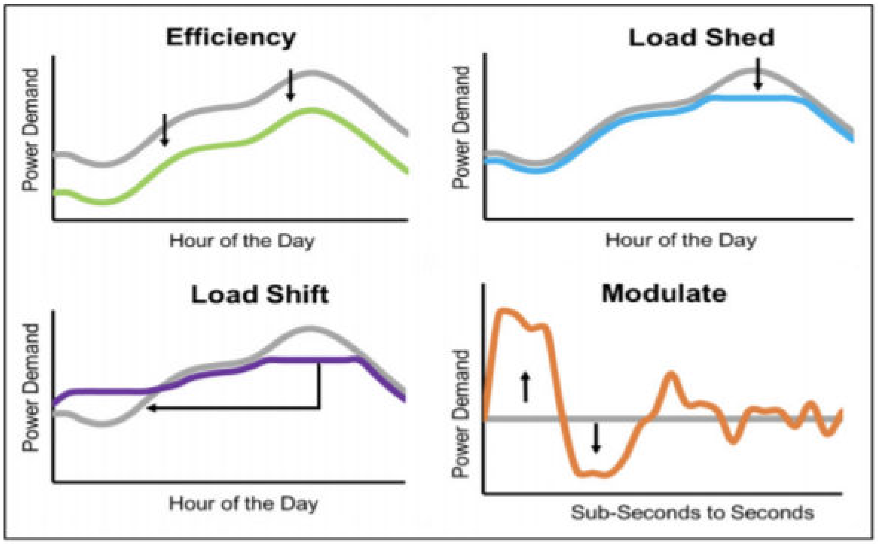

Figure 1. Building flexibility load curves [7]

1. **Energy efficiency**: The ongoing reduction in energy use while providing the same or improved level of building function.
2. **Load shed**: The ability to reduce electricity use for a short period of time and typically on short notice. Shedding is typically dispatched during peak demand periods and during emergencies.
3. **Load shift**: The ability to change the timing of electricity use. In some situations, a shift may lead to changing the amount of electricity that is consumed. Some of the main focus areas within load shift are on intentional, planned shifting for reasons such as minimizing demand during peak periods, taking advantage of lower electricity prices, or reducing the need for renewable electricity generation curtailment. For some technologies, there are times when load shed can lead to some level of load shifting.
4. **Modulation**: The ability to modulate the electrical load at the sub-seconds-to-seconds level. This enables the capability to provide small-scale, distributed grid stability and balancing services by automatically increasing or decreasing a building's power or reactive power production.

There are also four key characteristics of GEBs or smart buildings. They are energy-**efficient** buildings with **connected** and **smart** technologies characterized by use of **flexible** distributed energy resources to optimize energy use for utility benefits, occupant benefits, new manufacturer offerings, and/or societal benefits in a continuous, integrated manner.

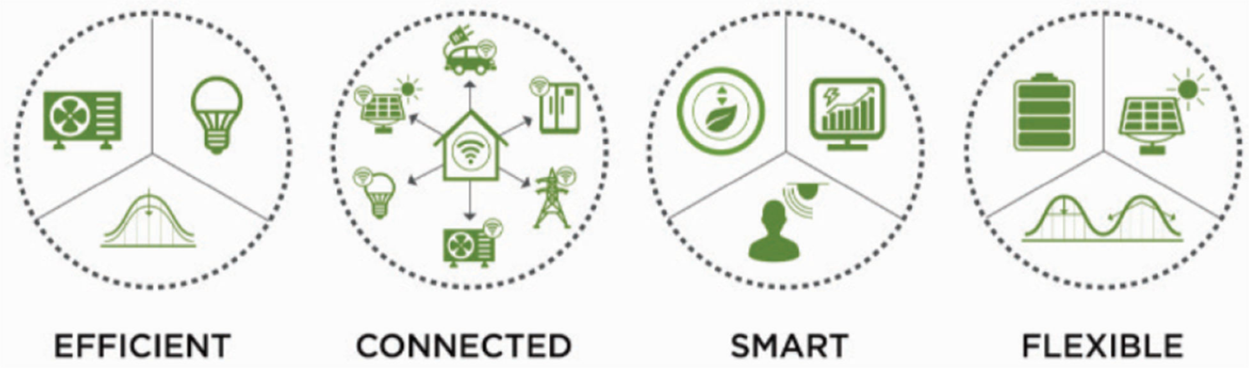

Figure 2. Characteristics of GEBs [7]

1. **Energy-efficient design**: To high-quality walls and windows, high-performance appliances and equipment, and optimized whole building design
2. **Connected**: The ability to send and receive "signals" to respond to grid needs and/or other externalities
3. **Smart**: Appropriate sensing and responsive controls that use data to benefit operations
4. **Flexible**: The building energy loads can be "shifted" in time to help mitigate solar generation, electric vehicle charging, and/or energy storage.

1.3 Energy Usage by Building Type

Before identifying key GEB technologies for federal facilities, it is important to understand typical energy usage by equipment and end use. The most common building types for federal facilities in the United States are office buildings, laboratories, and data centers,[1] so the total annual energy usage of these building types was analyzed to understand the breakdown of energy consumption using the 2018 EIA Commercial Buildings Energy Consumption Survey microdata. Figure 3 through Figure 5 show the total U.S. energy consumption for by fuel type and major end use for these three building types that are common in federal facilities. The different loads identified in each building type indicate which types of GEB technologies typically have higher potential to reduce energy consumption and provide flexibility to the grid. The largest three end uses in office buildings and labs are heating, ventilation, and lighting and heating, ventilation, and computing technologies for data centers. Generally, these results indicate that HVAC controls (building automation system), thermal storage technologies, lighting controls, and computing controls will likely have higher potential to provide energy savings and load flexibility in these three building types.

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[1] Data centers are not listed as a primary building type in the data so this includes all building types that have a data center in them.

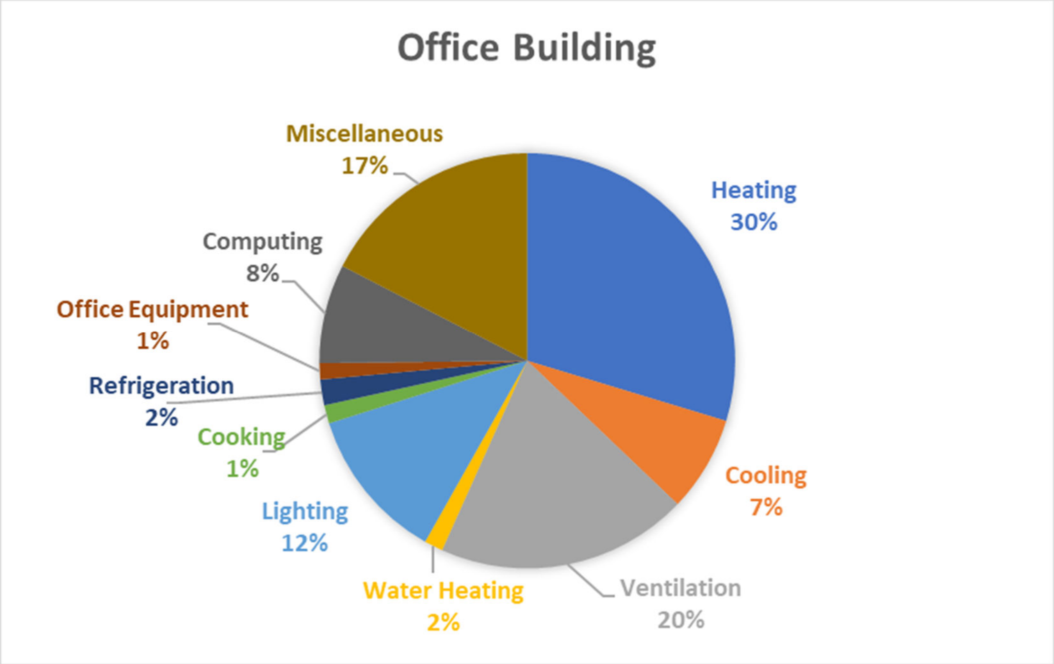

Figure 3. Office building energy consumption by fuel use category [25]

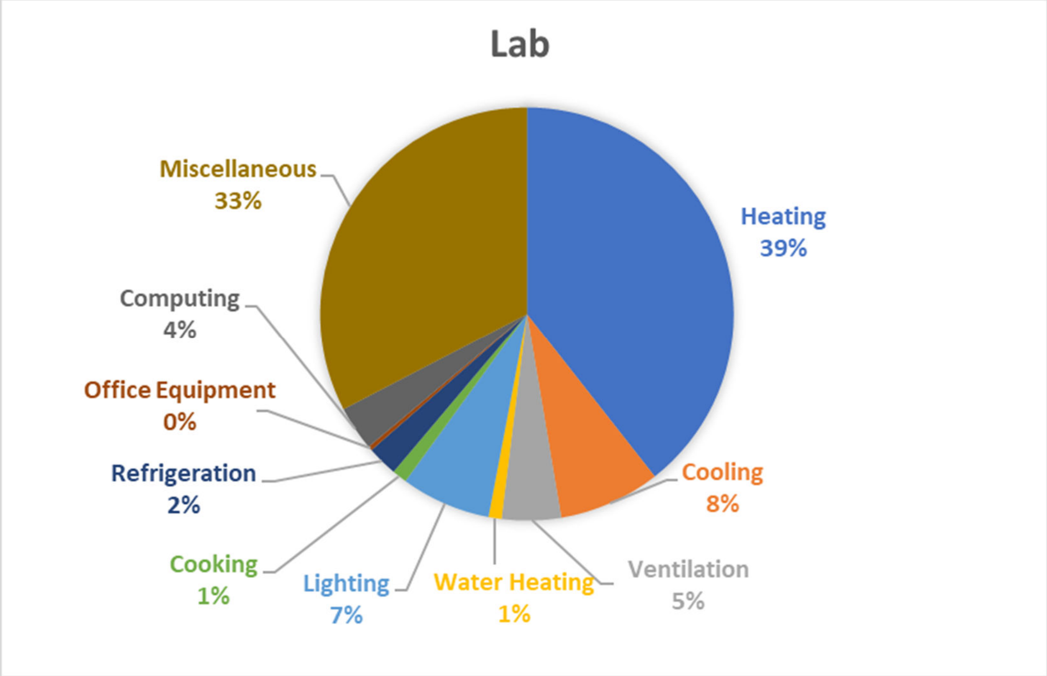

Figure 4. Laboratory energy consumption by fuel use category [25]

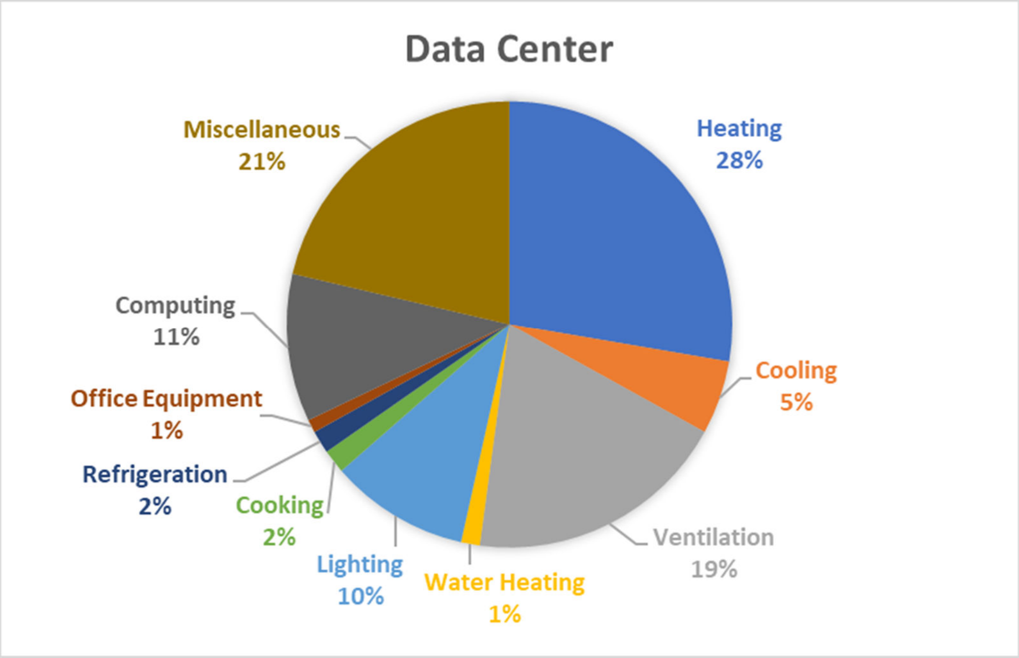

Figure 5. Data center energy consumption by fuel use category [25]

1.4 Technology Categorization

This report provides an overview of all key GEB technologies that can be deployed in federal and commercial facilities. First, each of the following GEB technologies in Sections 2–8 is given a qualitative rating based on its capability to provide grid services in the following subcategories: Decarbonization Potential, Cost, Efficiency, Load Shed, Load Shift, and Modulate. The qualitative ratings for the categories are summarized as follows:

○ **Not Applicable**: Unable to provide the demand-side management strategy and no decarbonization potential. No cost data available.

◑ **Low Potential:** May be able to provide the demand-side management strategy and some decarbonization, but it is not well suited. Is a high-cost technology (over $50,000).

◐ **Medium Potential**: Able to provide the demand-side management strategy and has moderate decarbonization potential, but in a limited capacity (other barriers exist that limit the capacity). Is a medium-cost technology ($25,000–$50,000).

● **High Potential**: Well suited to provide the demand-side management strategy and decarbonization or possesses high potential through continued R&D. Is a low-cost technology.

▨ **Emerging High Potential:** The technology is not yet commercialized and does not have an estimated cost yet. Some or all emerging technology costs may be covered by the manufacturer for demonstration and pilot projects.

The technologies were categorized based on their overall potential to provide grid services, which is a culmination of the ratings in the previously mentioned capability subcategories. Only high potential commercial GEB technologies are included in this report. Technologies not applicable to commercial federal facilities and buildings were also removed from the list. The data published in the U.S. building energy efficiency and flexibility as an electric grid resource is utilized in this report to prioritize the decarbonization potential for different technologies. The data represents the near- and long-term technical potential for building efficiency and flexibility measures. This report also used modeled energy savings data to prioritize the technologies based on the decarbonization potential. The *Grid-Interactive Efficient Building Technology Cost, Performance, and Lifetime Characteristics* [8] report is also referenced in this report to help categorize and prioritize the cost of the different technologies.

1.5 Prioritization Method

After each subcategory described in Section 1.5 is rated as low, medium, and high potential, a prioritization score is calculated: not applicable has a score of 0, low has a score of 1, medium has a score of 2, and high has a score of 3. Each factor is weighted to reflect its importance in this report's prioritization. Decarbonization and cost are weighted as most important with the highest weight of 4, efficiency has a weight of 3, the ability to load shed and shift has the weight of 2, and the ability to modulate has the smallest weight of 1. The weights and scores are then used to provide each technology with a prioritization score from 0 to 48. The technologies in each section are listed in order of highest to lowest priority based on this scoring method.

While prioritizing the technologies, certain assumptions were made. Cost is calculated for an average federally owned commercial building in 2020 of 40,000 square feet, [9] with 2,100 klm lighting demand [10] and 27 kW energy consumption.

Emerging technologies are defined as technologies with substantial grid-interactive capabilities and/or storage capabilities that are currently in development or pilot stages (not commercially available). The emerging technologies in the tables below (tables 1-11) are labeled with an asterisk (*) and have the emerging high potential categorization symbol (see Section 1.5) in the cost column. Because the technologies are not commercially available, there is no published cost data. It is assumed in this report that the emerging technologies have a low cost because they are not yet commercialized and there is potential to pilot the new technologies and have some or all of the costs covered by the manufacturer.

2 Generation Technologies

The following GEB technologies describe energy generation methods that have high potential for grid services. Generation methods like small wind turbines and PV panels have strong potential to decarbonize the grid and, when implemented, provide enough power to meet net-zero energy. These technologies tend to be relatively costly.

○	**Not Applicable**	◑	**Low Potential**	◐	**Medium Potential**
●	**High Potential**	▨	**Emerging High Potential**		

Table 1. GEB Generation Technologies

<table>
<tr><th>Generation Technology</th><th>Decarb</th><th>Cost</th><th>Efficiency</th><th>Load Shed</th><th>Load Shift</th><th>Modulate</th><th>Score</th></tr>
<tr><td>Small Wind Turbines</td><td>●</td><td>◑</td><td>◐</td><td>◐</td><td>◑</td><td>◐</td><td>30</td></tr>
<tr><td colspan="8">• Description: Smaller-scale wind turbines that fundamentally function the same as large wind turbines by capturing kinetic energy from the wind and converting it to mechanical power.
• Small- to medium-size wind turbines typically connect to the grid through a variety of generator and power electronic configurations.
• Wind turbines employing inverters can be used to provide grid services and assist with volt-amp-reactive (VAR) output, dynamic reactive current support, and other grid services, depending on resource availability.
• As a renewable source of energy, wind turbines decarbonize the grid especially when paired with storage technologies described in Table 2.
• $5,760-per-1-kW capacity wind turbine system, but costs vary due to construction and zoning [11].</td></tr>
<tr><td>PV Panels and Inverters</td><td>●</td><td>◑</td><td>◐</td><td>◐</td><td>◑</td><td>◐</td><td>30</td></tr>
<tr><td colspan="8">• Description: Panels used to capture solar energy and convert the generated DC current into AC current.
• Solar PV includes semiconductor devices that convert sunlight directly into electricity. PV systems are widely deployed in distributed generation applications. Size and scale can vary from 1 kW up to 10 MW+ on a single site.
• Smart PV inverters can be used to provide grid services and assist with VAR output, dynamic reactive current support, and other grid services, depending on resource availability.
• As a renewable source of energy, PV panels decarbonize the grid especially when paired with storage technologies described in Table 2.
• Average costs range from $40,000 to $500,000 but can be offset from tax credits and net metering [12].</td></tr>
<tr><td>Building Scale Combined Heat and Power (CHP)</td><td>◑</td><td>◑</td><td>●</td><td>◐</td><td>◐</td><td>○</td><td>25</td></tr>
<tr><td colspan="8">• Description: Using natural gas or other fuel sources, CHP systems capture wasted heat from the electricity generation system (e.g., engine, turbine, fuel cell) to satisfy space, water, and process heating loads.
• CHP systems can improve the overall energy efficiency of electricity and thermal energy consumed at the building by reducing grid-tied electricity losses and capturing waste heat.
• CHP systems are typically designed for consistent electricity output for baseload demand, but some systems can increase their output for brief periods to provide short-term grid flexibility.
• Many larger CHP systems include thermal energy storage (TES) to shift the generation of chilled or hot water to off-peak periods.
• CHP systems typically cost $40,000-$60,000 for a 5-kW system [13].</td></tr>
</table>

3 Energy Storage Technologies

The following GEB technologies describe energy storage methods that have high potential for grid services. Energy storage methods can shift and shed loads particularly well to meet grid demand. In combination with energy generation technologies, these methods provide resilience to power outages and the potential to develop a microgrid.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**

● **High Potential** ▨ **Emerging High Potential**

Table 2. GEB Energy Storage Technologies

Energy Storage Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
Lithium Battery Storage	◐	●	◐	◐	●	●	39
• **Description:** A type of rechargable battery with a relatively high charge density. • Batteries (e.g., Li-ion, lead acid, flow) can be used to store electrical energy during times of excess generation or off-peak periods and discharge during peak periods to reduce demand. • Most compatible with PV panels and turbines, or within microgrids. • Current battery units can have a capacity in the range of 10–30 kWh per unit. • Lithium battery storage is typically $700 per kWh [14].							
Electric Vehicles and Chargers	●	●	◑	◐	●	◐	39
• **Description:** A vehicle that runs on stored electricity and the associated charger that provides power to the battery. • Electric vehicles with managed charging will charge the connected electric vehicles according to the local utilities' operational priorities or a grid signal, rather than just charging the electric vehicle when it is plugged in. By using the electric vehicle battery to store energy from the grid, it is able to load shed, shift, and modulate. • Electric vehicles eliminate carbon associated with gasoline and diesel in cars and other transportation. • Costs on average are $6,000 per charger [15].							
Non-Vapor-Compression Materials and Systems*	◑	▨	●	◐	●	◐	37
• **Description:** Technology for space heating/cooling, refrigeration, and water heating that uses unique properties of specialized materials or alternative system designs that do not use the traditional vapor-compression cycle. • **Examples:** Thermoelectric, magnetocaloric, and electrocaloric systems produce useful temperature differences based on the intrinsic material properties of their core solid-state substance when activated through electrical input; membrane, thermoelastic, Stirling, liquid desiccant, and thermoacoustic systems use electrical or thermal input to alter the phase or other properties of a working fluid or material to pump heat. • Researchers estimate energy savings of 20% and greater for some non-vapor-compression technologies and building applications but require further R&D to develop the core material technologies and system designs. • Some non-vapor-compression technologies offer separate sensible and latent cooling and variable capacity control, which can allow buildings to shed load and operate at lower energy consumption levels during peak demand events.							

<table>
<tr><th>Energy Storage Technology</th><th>Decarb</th><th>Cost</th><th>Efficiency</th><th>Load Shed</th><th>Load Shift</th><th>Modulate</th><th>Score</th></tr>
<tr><td colspan="8">• Some non-vapor-compression technologies offer energy storage through hydronic thermal storage or battery-powered personal comfort devices that can shift grid-tied energy use to off-peak periods and still maintain occupant comfort.
• Many non-vapor-compression technologies have a high degree of capacity control and can modulate their load by varying the speed of specific components (e.g., fan, pump, and other motors) or electrical input to solid-state cooling materials.</td></tr>
<tr><td>Liquid Desiccant TES*</td><td>◐</td><td>▨</td><td>◐</td><td>◐</td><td>●</td><td>○</td><td>36</td></tr>
<tr><td colspan="8">• Description: Dehumidification energy storage via chemical means without the need for insulated containers.
• Load shifting is the primary flexibility value from liquid desiccant TES because the liquid desiccant will always have to be recharged at a later time.
• Use of solar thermal or renewable electricity overgeneration (e.g., midday PV on cool days) for desiccant regeneration enables substantial efficiency value.
• Applicable in humid climates for cooling season only; generally coincides with summer-annual-peaking regions.</td></tr>
<tr><td>Solid State Tunable Energy Storage</td><td>◐</td><td>◑</td><td>●</td><td>◐</td><td>◐</td><td>○</td><td>29</td></tr>
<tr><td colspan="8">• Description: Tunable thermal conductivity materials can dynamically adjust their thermophysical properties. The methods by which these materials change their properties vary widely, but the ultimate objective is to enable dynamic control over the operation of the envelope assembly in a manner that yields energy savings and has the potential to provide grid benefits as well.
• Phase change materials undergo solid-solid phase change and allow for dynamic tunability of the transition temperature. This will enable a next generation of grid-interactive building thermal management schemes, capable of micro-zoned thermal energy control, spatial and temporal control of TES, and dynamic control of heat flow throughout the building.
• Phase change materials are integrated into chilled water plants for TES and can also be integrated into rooftop units and building envelope materials. For building envelope applications, the buildings are pre-cooled to charge the TES and reduce daytime cooling loads.
• Tunable TES can provide substantial (e.g., 7x) improvement in energy storage utilization over the year.
• Thermal switches enable greater capacity to utilize temperature swings to maximize energy savings (e.g., 5x savings) and the ability to shape thermal demand (time shifting).
• This technology costs $5–$10 per square foot, depending on organic or inorganic phase change materials.</td></tr>
<tr><td>TES</td><td>◐</td><td>◑</td><td>◑</td><td>◑</td><td>●</td><td>◑</td><td>24</td></tr>
<tr><td colspan="8">• Description: Storage of heated or cooled material for later use of the thermal energy; may store sensible and/or latent heat.
• Examples: Heating only, in which ceramic bricks, water, or phase change materials are preheated using a wide range of heat sources (e.g., gas/oil/propane burner or hot water boiler, electric resistance coil, or vapor compression heat pump); electric cooling only, in which ice slurries or other phase change materials are precooled (or frozen) using a vapor compression cycle and stored in large insulated vats.
• Well suited to predictable daily load shifting/leveling to reduce demand charges.
• Great applicability in all HVAC and most commercial refrigeration; more economical with large equipment.
• TES affords additional flexibility in providing services because the stored energy maintains proper conditions.
• Some efficiency may be possible by leveraging favorable environmental conditions to charge the storage medium more efficiently (e.g., precooling at night with colder ambient temperatures for outdoor condensers).
• Primary value is for load shifting, but load shedding is possible where the shift in energy use enables improved efficiency (e.g., higher energy efficiency ratio operation at night). However, round-trip energy losses generally mean slight increases in total energy use. Maximizing this benefit requires careful scheduling.
• Individual units have limited ability to provide frequency regulation because of slow response time, but it is possible through advanced control algorithms that manage a portfolio/fleet of units.</td></tr>
</table>

Energy Storage Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
• TES can also apply to natural gas systems, but for those systems, there is little efficiency benefit. The efficiency of gas furnaces and boilers does not vary with ambient temperature, so shifting operating time would not impact efficiency. There is some benefit in running gas heat pumps and chillers (engine or absorption) during more favorable weather conditions and storing the energy. • Costs are on average $10 per square foot, projected to get lower with time as product develops.							

4 Controls Technologies

The following GEB technologies describe building control hardware, software, and operation strategies that have high potential for grid services. Control technologies enable a GEB to communicate and interpret grid signals to implement methods throughout the building system to shift, shed, or modulate loads.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**

● **High Potential** ▨ **Emerging High Potential**

Table 3. GEB Controls Technologies

Control Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
Whole-Building Energy Management Information System	●	◑	●	●	●	●	40
• **Description:** Whole-building energy management information systems can be used to integrate all end uses (HVAC, lighting, plugs) and distributed energy resources. These systems typically use machine learning and model predictive control to predict day-ahead electrical load profiles and can be used to shed load for any building system connected to the energy management information system. • On average, an energy management information system costs $9 per square foot							
Transactive Control*	◐	▨	●	◐	◐	○	37
• **Description:** A robust, scalable hierarchical transactional control mechanism incorporating elements of model-free control and game theory to harness buildings to provide grid services. • Can achieve peak load reduction and profit maximization for the distribution system operator, as well as cost reduction for end users while maintaining their comfort. • Integrates economic theory and control technologies for active participation of price-responsive assets. • Electricity price is used as an input signal to instigate changes in control of the power demand.							
Model Predictive Control*	◐	▨				○	34

<table>
<tr><th>Control Technology</th><th>Decarb</th><th>Cost</th><th>Efficiency</th><th>Load Shed</th><th>Load Shift</th><th>Modulate</th><th>Score</th></tr>
<tr><td colspan="8">

- **Description:** Model predictive control uses optimization techniques to find the optimal control sequence over a finite but sliding time horizon.
- Analyzes system models, objectives, constraints, optimal setpoints, and disturbance forecasts to inform control strategy.
- Model predictive control can incorporate external predictions and reevaluate at regular intervals while updating its internal model parameters using measurements to optimize sequences.

</td></tr>
<tr><td>Machine Learning Weather Inference for Building Energy Forecast*</td><td>◑</td><td>▨</td><td>◐</td><td>◐</td><td>◐</td><td>○</td><td>30</td></tr>
<tr><td colspan="8">

- **Description:** Machine learning can identify energy savings potential in GEBs by integrating: site-specific weather forecasts provided by advanced machine learning methods to capture the spatiotemporal correlations between the local weather conditions and nearby weather station data, building energy forecasts from model predictive control, and data analytics for evaluating the accuracy of weather and building energy forecasts, and for understanding how the site-specific weather forecasts, building types, and climates affect the energy savings in buildings.

</td></tr>
<tr><td>Smart Thermostats</td><td>◑</td><td>●</td><td>○</td><td>◐</td><td>●</td><td>◑</td><td>27</td></tr>
<tr><td colspan="8">

- **Description**: Thermostats with internet connectivity, advanced algorithm controls, and compatibility with home automation systems.
- Smart thermostats are a key communication gateway to enable grid services from residential and light commercial HVAC equipment. They can provide load shifting, including management of complex scheduling and day-ahead service requests, while optimizing operations to minimize impacts on customer comfort.
- HVAC controllers and smart thermostats cannot provide pure load shedding. HVAC equipment can shed load temporarily, but most of that load will be required post-curtailment to bring the temperature back up/down, which constitutes load shifting. Any load shedding comes from the increased efficiency achievable during off-peak, cooler times when the system is recovering from curtailment.
- Third-party smart thermostats are not well suited to providing frequency regulation or voltage support on their own because they only have indirect equipment control via setpoints; it is possible that future smart thermostats (potentially made by the HVAC manufacturer) could have direct control and provide frequency regulation.
- Smart thermostats can reduce total energy consumption through smart control algorithms, but they have no ability to improve efficiency of individual systems (e.g., annual fuel utilization efficiency, coefficient of performance). Therefore, this efficiency provides value to consumers, but only during off-peak periods.
- Usually costs $100–$200 per unit, not including wiring.

</td></tr>
<tr><td>Smart Power Strips</td><td>◑</td><td>●</td><td>○</td><td>◐</td><td>●</td><td>○</td><td>26</td></tr>
<tr><td colspan="8">

- **Description:** Advanced power strip that can shut off unused outlets through various means of sensing (e.g., current sensing, infrared, motion).
- Tier 1 power strips use either programming/scheduling or current sensing to reduce energy consumption.
- Tier 2 power strips use additional sensors, software, and algorithms to sense real-time power use; Tier 2 power strips reduce standby and wasteful active loads. They provide flexibility by shifting plug loads (i.e., PC workstations). Load sensing detects energy use of the equipment, occupancy sensors detect motion, and infrared sensors detect heat.
- Cost ranges from $12–$16 per outlet depending on sensors and programming capabilities [16].

</td></tr>
</table>

5 HVAC Technologies

The following GEB technologies describe HVAC equipment and operation strategies that have high potential for grid services. These HVAC technologies can be used for their high energy efficiency (compared to conventional HVAC technologies). Their efficiency enables them to decrease a building's total energy use and thus decarbonizes the grid. Additionally, advanced controls allow HVAC equipment to run at optimal periods, enabling load shedding and shifting potential.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**

● **High Potential** ▨ **Emerging High Potential**

Table 4. GEB HVAC Technologies

HVAC Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
Air Handling Unit Advanced Control	◐	●	●	●	◐	◐	41
- **Description:** Direct Digital Controls and sequences of operation that allow greater interaction and flexibility for air handling units. - During peak cooling periods, air handling unit supply air temperature can be reset upwards to reduce zone cooling loads and decrease cooling energy. During peak heating periods, air handling unit supply air temperature can be reset downwards to reduce zone heating loads and decrease heating energy. - During peak periods, supply air static pressure for variable air volume air handling units can be reset to reduce variable frequency drive speed and electrical power for HVAC fans. - During peak periods, zone temperature setpoints for noncritical zones can be increased or decreased (depending on season) to reduce HVAC demand. - Typical cost ranges from $200–$500 per motor horse power [17].							
Chiller Setpoints and Staging	◐	●	●	●	◐	◑	40
- **Description:** The temperature the chiller will maintain and the process of switching between different capacities within a chiller or between other chillers. - During peak periods, chilled water setpoint can be increased to reduce electrical cooling load. Chiller demand or capacity limits can also be set in the building automation system to limit demand. - During peak periods, the sequence of operation for chiller staging can be modified to operate smaller chillers and turn off larger chillers to reduce cooling demand. - Costs can range from $65–$400 per ton-hr of cooling load.							
Rooftop Unit Advanced Control	◐	◐	●	●	◐	◐	37
- **Description:** Controls and sequences of operation that allow greater interaction and flexibility for packaged rooftop units. - During peak periods, rooftop units with advanced controls can limit fan speed and increase space setpoint temperature. For multiple rooftop units with advanced controls, compressors on the units can be cycled on and off for 15 minutes each to reduce demand. - During peak periods, zone temperature setpoints for noncritical zones can be increased or decreased							

HVAC Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
(depending on season) to reduce HVAC demand. • Costs are less than $10,000 total for software and hardware additions per rooftop unit [18].							
Separate Sensible and Latent Space Conditioning*	◐	◍	●	◐	◐	○	37
• **Description:** Independent control over space cooling and dehumidification for more precise, comfortable, and efficient control. • Research estimates that separate sensible and latent cooling systems could provide energy savings of 30% and greater [26]. Solid or liquid desiccant systems using solar thermal or waste heat resources would offer additional energy savings; equipment downsizing is also possible. • Systems could shed load by reducing the sensible cooling stage and only operating the high-efficiency latent cooling stage to maintain occupant comfort during peak events and allowing for longer curtailment periods without causing discomfort. • Some systems may offer load shifting by using TES of liquid desiccants and other materials (see liquid desiccant TES below). • Separate sensible and latent cooling systems do not provide significant load modulation capabilities.							

6 Refrigeration, Water Heating, and Appliances

The following GEB technologies describe refrigeration and water heating equipment, appliances, and their controls that have high potential for grid services. These technologies are beneficial due to their ability to load shift as needed by the grid. Advanced controls allow conventional equipment to become more efficient, grid-interactive, and able to decarbonize.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**
● **High Potential** ▨ **Emerging High Potential**

Table 5. GEB Refrigeration, Water Heating, and Appliances

Refrigeration, Water Heating, and Appliances	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
Miscellaneous Electric Loads: Water Heaters	◐	●	●	◑	●	○	37
• **Description**: Similar to other hot water heaters, hot water reservoirs provide TES value. • Examples include portable electric spas and pool heaters. • Hot water reservoirs provide thermal energy storage for loading up during off-peak or high renewable energy-generation periods (e.g., solar bulge), and shifting load out of peak demand periods.							
Water Heaters With Smart, Connected Controls	◐	●	◑	◑	●	◐	33
• **Description**: Advanced water heater controllers (embedded or external) can provide multiple forms of value to the grid by leveraging the water heater's energy storage capabilities, depending on the implemented algorithm. • Very valuable for predictable, scheduled peak load shifting via preheating (thermal storage) or for emergency (no preheating), curtailment. • Load shedding is possible, but only if water temperature remains low for an extended period of time, which reduces the standby losses. Ultimately, the water temperature must be brought back to the setpoint after the curtailment period. Load shifting with preheating will not have accompanying load shedding because the standby losses will increase. • Capable of providing some short-time-scale services, such as frequency response and other operating reserve products aimed at increasing the grid's distributed energy resource hosting capacity. • Grid value can be easily provided when controlling electric resistance water heaters, but with low efficiency. Use of heat pump water heaters increases efficiency substantially and provides much of the same grid value.							
Modulating, Advanced Clothes Dryers	◑	●	◐	◑	◐	●	31
• **Description**: Connected clothes dryers that can run at lower power by modulating heat input and delaying operation based on utility need. • Modulation of the heating system enables a better match of moisture removal rate to the heat input, reducing overdrying and improving efficiency (for heat-pump models that often run at a single-capacity heat output). • Lower-temperature drying improves efficiency despite longer cycle times (reduced partial overdrying of linens). This allows the modulating clothes dryer to provide a small amount of load shedding along with load shifting. • Load shifting can also be provided through delayed start. • This approach has been proven in the lab. Response can be provided quickly for electric resistance products							

Refrigeration, Water Heating, and Appliances	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
(within seconds) with no damage to the equipment. Fast response is valuable for load modulation. • Costs can range from $500–$1,400 for retrofit and new dryers [19].							
Advanced Controls for Commercial Refrigeration	◑	●	◐	◑	●	○	30
• **Description**: Advanced controls (embedded or external) that enable grid-friendly operation of commercial refrigeration equipment with limited impact on operations. • Well suited to load shifting via scheduled precooling or emergency curtailment. Annual energy savings are achievable via smart control of the equipment. However, there is no benefit in terms of continuous energy savings (e.g., coefficient of performance). Therefore, the efficiency provides benefits to consumers via reduced operating costs, but it offers little to no benefit to the grid because most savings will be achieved during off-peak hours. • Limited load shedding can be achieved in emergency grid events; usually this would be accompanied by load shifting because the equipment must bring the temperature back to the usual setpoint after the curtailment period. • Although temperature limits are generally stricter for refrigeration than for HVAC because of the need to prevent food spoilage, the potential is still substantial, particularly for large commercial refrigeration (e.g., warehouses) thanks to significant thermal mass to help maintain temperature setpoints.							

7 Fenestration Technologies

The following energy conservation technologies describe fenestration strategies that have high potential for grid services. These technologies increase the energy efficiency of the entire HVAC system by offsetting the use of heating and cooling equipment within the building by altering the natural heat gain or loss of the building. Fenestration technologies can also provide load-shifting capabilities when in sync with other grid-interactive HVAC equipment.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**

● **High Potential** ▨ **Emerging High Potential**

Table 6. GEB Fenestration Technologies

<table>
<tr><th>Fenestration Technology</th><th>Decarb</th><th>Cost</th><th>Efficiency</th><th>Load Shed</th><th>Load Shift</th><th>Modulate</th><th>Score</th></tr>
<tr><td>Thermally Anisotropic Systems*</td><td>◐</td><td>▨</td><td>●</td><td>●</td><td>◑</td><td>○</td><td>37</td></tr>
<tr><td colspan="8">• Description: Thermally anisotropic systems consist of materials or assemblies that have engineered layer(s) with alternating high and low thermal conductivities, thus yielding an anisotropic bulk material or assembly.
• Depending on the characteristics of available thermal sinks and/or sources for a given building, these systems could offset HVAC energy use, reduce peak electricity demand, and shift the timing of HVAC operation to periods when the system is more efficient
• Capacity for load shifting and shedding will also be affected by several building characteristics, including orientation, shading, thermal mass, and wall-to-floor area ratio.
• Coordinated controls with HVAC calibrated to the building are needed to minimize response time and maximize response magnitude.
• Fast response services (“Modulate Load”) are likely out of reach due to buildings’ thermal inertia.</td></tr>
<tr><td>Dynamic Glazing</td><td>◐</td><td>◑</td><td>●</td><td>●</td><td>◑</td><td>○</td><td>29</td></tr>
<tr><td colspan="8">• Description: Dynamic glazing includes a range of chromodynamic coatings applied to glazing that can switch between two or more states that block portions of the wavelengths that lead to solar heat gain in buildings.
• Reduces cooling load by controlling solar heat gain.
• Might be able to provide some faster-responding service by modifying perimeter zone conditions if HVAC operation can be controlled independently in perimeter and core zones.
• Coordinated controls with HVAC calibrated to the building are needed to minimize response time and maximize response magnitude.
• Dynamic glazing includes a range of chromodynamic coatings applied to glazing that can switch between two or more states and that block varying portions of the wavelengths that lead to solar heat gain in buildings.
• Electrochromic glazing offers grid-integrated operational potential because it can be actively adjusted in response to a control signal to reduce energy use or provide grid services, though the response time of the electrochromic glazing might be faster than the correlated reduction in electricity demand.
• Dynamic glazing provides benefit to the grid primarily through efficiency and load shedding (assuming the system is responsive to utility control signals) by controlling solar heat gain.
• Dynamic glazing costs on average $80 per square foot.</td></tr>
<tr><td>Automated Window Attachments</td><td>◐</td><td>◑</td><td>●</td><td>●</td><td>◑</td><td>○</td><td>29</td></tr>
</table>

<table>
<tr><th>Fenestration Technology</th><th>Decarb</th><th>Cost</th><th>Efficiency</th><th>Load Shed</th><th>Load Shift</th><th>Modulate</th><th>Score</th></tr>
<tr><td colspan="8">
• Description: Automated window attachments include interior devices, such as blinds, shades, and drapes, and exterior devices, including awnings and shutters, that can be adjusted automatically to reduce solar heat gain.
• Similar functionality to dynamic glazing, though effectiveness depends on attachment material and interior or exterior placement.
• Supplemental lighting might be required when attachments are deployed.
• In residential applications, opening attachments during non-occupied daytime hours can capture beneficial winter solar heat gains.
• Window attachments include interior devices, such as blinds, shades, and drapes, and exterior devices, including awnings and shutters. In some cases, these attachments are operable so that they can be repositioned to control glare, control perimeter zone heating, and provide privacy.
• Adding electric actuation, network connectivity, and lighting sensors enables the operation of attachments to minimize HVAC and lighting energy use while maximizing occupant comfort.
• Automated window attachments provide benefit to the grid primarily through energy efficiency and load shedding by controlling solar heat gain.
• Cost can range depending on the equipment from $32–$94 per square foot.
</td></tr>
</table>

8 Lighting and Electronics Technologies

The following GEB technologies describe lighting and electronic equipment and operation strategies that have high potential for grid services. These lower-cost technologies increase the energy efficiency of the building by reducing the power usage of lighting and electronics when not in use. In addition, lighting controls can provide some load flexibility through automated dimming.

○ **Not Applicable** ◑ **Low Potential** ◐ **Medium Potential**

● **High Potential** ◍ **Emerging High Potential**

Table 7. GEB Lighting Technologies

Lighting Technology	Decarb	Cost	Efficiency	Load Shed	Load Shift	Modulate	Score
Continuous Operation Electronics	◐	●	●	◑	◐	◑	36
• **Description:** Stationary computing devices and electronic equipment used for computing, data storage, network supply, and related purposes that require constant power supply to operate. • **Examples**: Network equipment, set-top boxes, desktop personal computers, gaming consoles, servers, AV equipment. • Power management controls can automatically transition computers and electronics into low-power modes as well as automatically power-down devices after periods of inactivity. • Power scaling by computing task can decrease power draw for specific operations so full computing power is not used for less sophisticated computing tasks (e.g., game console streaming video). • Sleep/idle/off power modes allow devices to draw a fraction of energy use while powered down to idle/off when not in use. • Deep sleep, minimal-latency mode for networked computers and electronics can allow devices to stay connected for activation (e.g., wake-on-LAN) while using a fraction of typical power. • Computers and electronics in continuous connectivity (e.g., servers) can potentially modulate or shed loads. • Staging of large electronics loads in can be used to avoid spike in building demand.							
Advanced Sensors and Controls for Connected Lighting	◑	●	●	◐	◐	◑	34
• **Description:** Connected lighting systems using advanced controls and algorithms to automatically modulate lighting levels or potentially other power-consuming lighting features (e.g., spectrum, reduced sensor or network communication interface power) in response to external grid/pricing signals. • Provides both efficiency gains and demand-responsive capabilities to shed lighting loads. • Additional energy savings are possible through the collection of real-time data on building environment and activity through lighting sensor networks as well as adjusting lighting and HVAC usage accordingly. • Has the capability to provide fast-response grid services through shedding and modulating, though in limited capacities that are not disruptive to occupant productivity/comfort/safety. • Estimated cost for this technology on average is $60/kilolumen.							

9 GEB Packages

To better categorize each technology for potential use in a GEB, four packages of GEB technologies (basic, intermediate, advanced, and advanced with emerging technologies) are listed below based on the effort and cost associated to implement the package. Some or all of these technologies could be installed at the site to provide varying levels of grid services.

The Basic GEB Package includes GEB technologies that could already be installed in federal buildings or are relatively affordable and easy to install or upgrade (some may require additional software to be installed with existing equipment). This package has the lowest average cost and some grid-interactive capabilities. The key value streams include load staging/shedding to use time-of-use pricing and avoid building demand charges and load shedding for peak event credits.

Table 8. Technologies in the Basic GEB Package

Technologies in the Basic GEB Package	Description	Score
Building Energy Management System	**Advantages:** More efficient operation of equipment and provides HVAC load shedding/shifting capabilities. **Disadvantages:** Higher initial costs and high cost to upgrade existing building automation system.	40
Air Handling Units Advanced Controls	**Advantages:** Customizable zone solution to provide conditioned air while being able to use controls to run more efficiently and to shift loads to off-peak periods. **Disadvantages:** More expensive and complex initially.	41
Chiller Setpoint and Staging	**Advantages:** Reduce energy consumption by running chillers at lower loads during peak periods. **Disadvantages:** More programming and associated labor.	40
Continuous Operation Electronics	**Advantages:** Simple implementation that offers reduction in unnecessary power consumption for computing and electronic devices; staging loads can be used to reduce building demand charges. **Disadvantages:** Additional installation and integration steps and may require software and controls purchases.	36
Smart Thermostats	**Advantages:** Provide automated demand response and scheduling capabilities at very low cost. **Disadvantages:** More suitable for smaller buildings.	27
Basic Lighting Sensors and Controls	**Advantages:** Monitor and turn off lights in zones based on schedules and occupancy sensors and can provide basic load shedding and staging.	26

	Disadvantages: Limited load reduction to unoccupied spaces.	
Smart Power Strips	**Advantages:** Inexpensive control technology with simple installation that can provide load shifting, scheduling, and reduce wasteful active loads. **Disadvantages:** More expensive than traditional power strips.	26

The Intermediate GEB Package includes GEB Technologies that are widely available, easily installed, but are more costly than technologies in the Basic GEB Package. Technologies in this package have additional grid-interactive capabilities, can participate in net metering, and increase resilience from power outages. Key value streams include net metering for direct payment, optimized renewable energy for low energy bills, and load shifting to avoid building demand charges and for peak event credits.

Table 9. Technologies in the Intermediate GEB Package

Technologies in the Intermediate GEB Package	Description	Score
Whole-Building Energy Management Information System With Advanced Analytics	**Advantages:** Provides granular insight into building operation and connectivity among devices for whole-building energy optimization. **Disadvantages:** Costly and complex to install and integrate among various devices.	40
Variable Frequency Drives	**Advantages:** Highly commercialized and affordable technology that allows equipment to run at lower speeds and draw less power; can be used for load shedding and modulating. **Disadvantages:** More expensive than constant speed drive.	39
Electric Vehicles and Chargers	**Advantages:** Provides external means of energy storage load shedding, shifting, and modulating. **Disadvantages:** High cost, along with complex installation and logistical challenges; relies on personal vehicle participation.	39
Lithium Battery Storage	**Advantages:** Efficient storage of unused generated electricity that helps shift grid usage during high-demand periods and optimize variable renewable energy use. **Disadvantages:** Additional cost and integration energy losses in conversion.	39

Advanced Sensors and Controls for Connected Lighting	**Advantages:** Use algorithms and sensors to shed lighting loads and reduce wasted lighting energy. **Disadvantages:** Load shedding is limited to levels that are not disruptive to occupants.	34
PV Panels	**Advantages:** Reduces dependency on power grid and provides free clean energy that can be used, stored, or sold to the utility. **Disadvantages:** High initial cost and installation barriers; light levels vary by region, time of year, and time of day.	30
Advanced Control for Refrigeration	**Advantages:** Provide load shifting from control scheduling for pre-cooling. **Disadvantages:** Limited flexibility because of strict refrigeration requirements.	30
Automated Window Attachments	**Advantages:** Improve occupant comfort and provide energy savings and load shedding by controlling solar heat gain. **Disadvantages:** Additional installation and higher cost.	29

The Advanced GEB Package includes GEB technologies that are commercially available and have significant real-time grid-interactive capabilities. This package has the potential for net-zero energy and grid independence through substantial generation and storage technologies. Technologies in this package can involve complex and expensive installation and integration, which may make them best suited for new construction or deep retrofits. Key value streams include very low utility bills, net metering for direct payment, and load modulating for real-time balancing services.

Table 10. Technologies in the Advanced GEB Package

Technologies in the Advanced GEB Package	Description	Score
Water Heater Smart Controls and Miscellaneous Electric Loads	**Advantages:** Ability to preheat and shift load through scheduling and algorithms; can also rapidly modulate loads for balancing services or store excess energy from variable renewables; retrofit packages available for easier adoption. **Disadvantages:** Higher initial cost and lack of nonpremium products with grid-interactive functionality.	33
Modulating Clothes Dryers	**Advantages:** Consume less power and can provide modulating services by modulating heating and lowering temperature throughout cycles.	31

	Disadvantages: Higher initial cost and lack of nonpremium products with grid-interactive functionality.	
Small Wind Turbines	Smaller-scale wind turbines that fundamentally function the same as large wind turbines by capturing kinetic energy from the wind and converting it to mechanical power.	30
Dynamic Glazing Fenestration	**Advantages:** Reduce peak cooling loads by reducing unwanted solar heat gain. **Disadvantages:** Higher initial cost and lack of nonpremium products with grid-interactive functionality; more difficult for retrofit applications.	29
CHP	**Advantages:** Grid flexibility through power generation, which can serve on-site loads or be exported to the grid depending on demand; thermal output can be used to offset other thermal loads. **Disadvantages:** High product cost and installation cost.	25
TES (phase change materials, water, ice, etc.)	**Advantages:** Allows HVAC and refrigeration systems to be more flexible with their power draw from the grid by leveraging thermal momentum during grid events. **Disadvantages:** Complex installation and commissioning; large space requirements; limited flexibility of materials for year-round use.	24

The Advanced GEB With Emerging Technologies Package includes technologies that have significant real-time grid-interactive capabilities and are currently in development or pilot stages (not commercially available). While these technologies may not be commercially viable, many may be available to pilot in buildings.

Table 11. Technologies in the Advanced GEB With Emerging Technologies Package

Technologies in the Advanced GEB Package With Emerging Tech	Description	Score
Transactive Control	**Advantages:** Provides peak load reduction and profit maximization for the distribution system operator, as well as cost reduction for building owner while maintaining their comfort. **Disadvantages:** Still in development.	37
Separate Sensible and Latent Space Conditioning	**Advantages:** Provides additional energy savings and could shed and shift loads through TES. **Disadvantages:** Still in development.	37

Thermally Anisotropic Systems	**Advantages:** Can offset HVAC energy use and shift timing of HVAC operation to reduce peak loads. **Disadvantages:** Still in development.	37
Liquid Desiccant TES	**Advantages:** Provides substantial energy storage and can help store energy from renewable overgeneration. **Disadvantages:** Still in development; limited to humid climates for cooling season.	36
Model Predictive Control	**Advantages:** Improves whole-building controls and optimizes energy use for programmed objectives. **Disadvantages:** Still in development.	34
Machine Learning Weather Interference for Building Energy Forecasts	**Advantages:** Identifies, provides, and forecasts for improved energy savings and flexibility control. **Disadvantages:** Still in development.	30
Solid-State Tunable Energy Storage	**Advantages:** Provides substantial energy storage for load shifting and renewable energy optimization. **Disadvantages:** Still in development.	29

9.1 Low- and No-Cost GEB Measures

In addition to the GEB technologies and packages described here, there are many low and no-cost GEB measures that energy managers can implement to provide demand response and load flexibility at federal and commercial facilities. A 2021 report from Rocky Mountain Institute identified key measures and upgrades that can be done with little to no capital investment (<$50,000) and actionable steps that GSA building managers can take to implement these [20]. As a first step, it is important to analyze the existing building control system to understand the capabilities, including load shifting equipment operation to off-peak times or to manage peak demand. Some of the key measures from the report are summarized below:

- **Optimize HVAC sequencing**: High-load HVAC equipment can be programmed to run in sequential stages to minimize peak demand in the building. Change the temperature setpoints to lower the runtime of HVAC equipment. Adjust fan flow and supply air temperature settings to minimize energy use and maximize space function [20].
- **Optimize building operations to occupancy patterns**: Modify temperature setpoints or HVAC settings to lower heating/cooling demand in lower-occupancy areas or transitional areas during peak hours [20].
- **Optimize thermal mass**: Core building spaces are able to store heat and resist heat transfer, so these spaces could potentially be preheated or precooled at off-peak times [20].

- **Maximize use of existing storage**: Examples of energy storage systems in buildings include ice storage, chilled water, hot water, phase change materials, and batteries. These storage systems could be used to shift energy loads to off-peak hours and to align with time-of-use pricing [20].
- **Automate lighting controls**: Lighting controls can be used to dim or turn off lighting in spaces with daylight or spaces that are infrequently occupied [20].

For more detailed information, see the full report from Rocky Mountain Institute [20].

10 How To Get Started

10.1 How To Analyze, Identify, and Implement GEB Retrofit Opportunities

1. **Analyze the current site energy systems and energy use**. The first step in a GEB technology retrofit is to understand where the site is currently, including both the state of the building equipment and technologies that are installed and the energy usage at the site. It is important to understand the hourly, monthly, and daily load profiles of the facilities as well as the seasonal variation. It is also important to understand the largest loads at the site that have the most potential for energy savings and load shifting—often HVAC loads and lighting loads.

2. **Establish the energy retrofit goals**. Next, it is crucial to establish what the energy goals are for the retrofit project, including energy savings, utility cost savings, decarbonization or emissions reductions, increased resiliency, etc. Goals should include a target reduction value and a timeline. A major consideration for building owners should be how to track and measure progress toward these goals each year.

3. **Understand utility rates, program offerings, and incentives**. In addition to energy usage analysis, it is important to conduct a utility bill analysis to understand the time-of-use rates, including differences between peak and off-peak periods, and the demand charges for the site. This will be crucial to developing demand management strategies for reducing utility bills. It is also important to research available utility program incentives and demand response programs available at the site.

   Every utility offers varying levels of demand response programs, so it is important to research and understand how the GEB site could benefit from the available strategies and offerings. The Federal Energy Management Program developed a list of demand response and variable utility pricing programs[2] available for major utilities throughout the United States.

4. **Identify potential GEB technology upgrades**. Building off of the facility's current installed technologies, current energy use by equipment, and energy retrofit goals, the next step is to develop an initial list of all potential GEB technologies and measures of interest for the site. This document can serve as a starting point regarding what technologies could be included.

   In addition, the Federal Energy Management Program's GEB Workbook is a helpful tool that provides guidance, recommendations, and prioritization of potential grid-interactive strategies, grid-interactive technologies, and electrification and controls upgrades in federal and commercial buildings. For an existing commercial or federal building considering a retrofit, users input key information about the building and are presented

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[2] Available at https://www.energy.gov/femp/demand-response-and-time-variable-pricing-programs.

with a breakdown of less- to highly applicable technologies and upgrades that could be implemented to the building. The workbook also highlights many different resources for the user to learn more information about the recommended technologies and strategies (**FEMP GEB Workbook**).

5. **Identify GEB demand management strategies for the site**. The first step in creating a GEB is to first analyze how to reduce demand (energy efficiency) to use less energy overall and operate existing equipment more efficiently. Next, based on the analysis and results from Steps 1-4 (energy usage, available demand response offerings, energy goals, GEB technologies list), identify which demand management strategies make sense for the facility, including load shifting, load shedding, peak management, load curtailment, etc. It is also beneficial to analyze how on-site energy generation can provide additional opportunities for demand management.

6. **Develop a retrofit project team with GEB stakeholders**. Once the goals of the retrofit have been established, an initial technology list has been created, and demand management strategies have been identified, a key next step is to develop a retrofit project team with key stakeholders who can help with GEB technology implementation. These stakeholder and project roles are defined in the following section. The building owner, facility manager, utility representative, energy service company (ESCO), project facilitators, and GEB technology subject matter experts are key stakeholders that should be involved in a GEB retrofit project to ensure successful implementation.

   The building owners and facility manager typically take a lead role as decision makers and project managers. GEB retrofit projects benefit greatly by working closely with the site's utility representative(s). The ESCO helps design the project and recommends technologies based on payback period, in addition to arranging financing through energy savings performance contracts (ESPCs) for projects that save energy [21]. GEB technology subject matter experts encompass a wide range of individuals, from controls experts to design consultants, that can be pulled into the project to provide design help, recommendations, and other insight to help the building owner make informed decisions about the GEB upgrades and review recommendations from the ESCO. For federal projects, a project facilitator is also a great asset who can assist with implementing ESPCs and utility energy service contract (UESC). Project facilitators are "experienced, unbiased advisors who guide the agency acquisition team through the project development and implementation process by providing technical and financial advice" [22].

7. **Establish a contract for financing GEB upgrades**. Many GEB upgrade projects will need to be financed through a UESC or ESPC.

   A UESC offers federal agencies an efficient way to engage local utilities for a wide array of energy conservation measures. In this arrangement, the utility partner evaluates possibilities and plans and executes energy conservation measures, spanning from lighting upgrades to renewable energy systems. They may also offer project financing. The agency has the flexibility to fund the project using a mix of savings from the energy conservation measures and financing. Many utilities offer UESCs as an option for financing retrofits, and building owners can work directly with their utility representative to learn more about them [23].

An ESPC involves a partnership between a building owner and an ESCO. The ESCO designs and implements energy efficiency improvements, and the owner pays for the services over time from the realized energy savings. Both UESCs and ESPCs share the common goal of reducing energy consumption and costs while promoting sustainability. The primary difference is that UESCs involve utilities, while ESPCs engage ESCOs. Despite this distinction, both contracts contribute to achieving energy efficiency objectives in a cost-effective manner [24].

10.2 Federal Case Studies

Though GEB technologies are still emerging, several U.S. federal facilities have successfully deployed GEB technologies and strategies as part of energy retrofit projects. Some example case studies are provided in the resources below, including information on the key project successes, challenges, lessons learned, and best practices.

The GSA Oklahoma City Federal Building: Smart Buildings Case Study[3] demonstrated that GEB-ready strategies and technologies can be deployed across buildings with minimal investment. Key GEB measures installed at the site include a PV array, lighting controls, building automation system upgrades, battery energy storage system, and advanced power strips. The Oklahoma City Federal Building is a four-story building that occupies 178,342 square feet and houses several different federal agency offices.

The VA Carl T. Hayden Medical Center: Smart Building Case Study[4] demonstrated a successful energy retrofit project that reduced energy consumption by 25% and used energy storage and on-site generation to shift loads to align with time-of-use pricing and reduce peaks to avoid demand charges. The Carl T. Hayden Medical Center is located in Phoenix, Arizona, and is a 279-bed medical facility in a campus of 25 buildings and a total floor area of 850,000 square feet.

Grid-Interactive Efficient Building Case Studies in the Federal Portfolio[5] provides background information, GEB practices and technologies implemented, and lessons learned from nine different case studies of federal buildings in the United States.

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[3] Available at https://www.energy.gov/femp/articles/gsa-oklahoma-city-federal-building-smart-buildings-case-study.

[4]

[5] Available at https://sftool.gov/Content/attachments/GSA%20GEB%20Case%20Study%20Report%20Mar%202021.pdf.

10.3 Key GEB Resources List

The following resources provide more information on GEB technologies and strategies, as well as how to implement them in federal and commercial facilities.

- *Blueprint for Integrating Grid-Interactive Efficient Building Technologies into U.S. General Services Administration Performance Contracts*[6] outlines a screening process that narrows down potential site characteristics for good GEB candidates and outlines challenges, solutions, and best practices.
- *Grid-Interactive Efficient Buildings Made Easy: A GSA Building Manager's Guide to Low- and No-Cost GEB Measures*[7] provides an overview of GEBs and lays out actionable steps for GSA building managers to implement these no- and low-cost measures.
- *The Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: A Cost-Benefit Analysis*[8] details the core ways GSA could leverage its size, its leadership in the industry, and its relationships with utilities and regulators to pioneer GEB opportunities across its portfolio.
- The *Grid-Interactive Efficient Buildings Technical Report Series*[9] evaluates state-of-the-art and emerging building technologies that have significant potential to provide grid services. The reports also identify major research challenges and gaps facing the technologies, as well as opportunities for technology-specific R&D.
- *A National Roadmap for Grid-Interactive Efficient Buildings*[10] identifies the most important barriers and outlines the key opportunities for full implementation of GEBs and associated demand flexibility.

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[6] Available at https://www.nrel.gov/docs/fy21osti/78190.pdf.

[7] Available at https://rmi.org/insight/grid-interactive-efficient-buildings-made-easy/.

[8] Available at https://rmi.org/insight/value-potential-for-grid-interactive-efficient-buildings-in-the-gsa-portfolio-a-cost-benefit-analysis/.

[9] Available at https://www.energy.gov/eere/buildings/geb-technical-reports.

[10] Available at https://gebroadmap.lbl.gov/A%20National%20Roadmap%20for%20GEBs%20-%20Final.pdf.

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[1] Nubbe, Valerie, and Mark Butrico. *GSA Oklahoma City Federal Building: Smart Buildings Case Study*. 2023. FEMP. https://www.energy.gov/femp/articles/gsa-oklahoma-city-federal-building-smart-buildings-case-study.

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