

# Peak and Flex Metrics to Benchmark Building-Grid Interactivity

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## ABSTRACT

To reach full economy-wide decarbonization, buildings must transition from a simple on-demand approach to energy use toward a symbiotic relationship with the electricity grid. Matching demand with variable carbon-free energy generation will require tremendous investment in new generating capacity, transmission, energy storage, and demand flexibility. Buildings that can both shed and shift energy demand can support the grid and the transition to a carbon-free power sector. Quantifying the demand flexibility inherent in a building is a critical step to assign its value to grid operators, building owners, and the real estate market. In-depth research through the GridOptimal Buildings Initiative and others has delivered various metrics. This paper proposes the core market-facing simplified metrics, analogous to energy use intensity (EUI), that can offer the market simple, comparable ways to answer key questions, such as: “How many kW can this building shed when electricity cost is highest for grid operators?”, “What is the relative contribution of this building on grid or system peak?”, or “What ability does this building have to shift and shape load compared to overall load?”. These metrics will be useful in policy and program applications to better value and encourage time-of-use energy efficiency and demand flexibility measures and strategies.

## Introduction

The electricity grid at large faces increased challenges from more frequent extreme weather events, an abundance of intermittent generation sources, and rapidly growing load from electric vehicles and electrification of fossil-fuel-based equipment. To serve this increased demand while decarbonizing the grid at large, system operators must invest in flexible resources to better match generation and demand, including demand-side solutions such as demand response or actively shifting building energy consumption earlier or later in the day. Buildings across all sectors collectively represent a large opportunity to make short-term energy demand shifts (one to four hours) with simple interventions such as temporary setpoint adjustments. Electric utilities across the United States already recognize this resource and incentivize demand response as a cost-effective approach to mitigate energy generation costs, improve system reliability, and reduce carbon emissions.

Building on the three-year GridOptimal Buildings Initiative, this paper introduces two metrics to characterize Grid-Interactive Efficient Buildings (GEBs) and their impact on the electricity grid: 1) grid peak contribution and 2) demand flexibility. The goal of these metrics is to assess how a building’s typical load shape impacts the grid as well as its potential to shift load. These metrics would inform the real-estate market, utilities, owners, and demand response market stakeholders about the potential individual buildings have to generate demand response income, support grid operations, and stress local distribution grids. Simply put, the metrics seek to answer, “How much does your building stress the grid and what can your building do about it?”

## Market Landscape

GEBs have gained popularity in the past several years thanks largely to their potential to provide cost-effective grid services, avoid carbon emissions, and mitigate power system costs. The concept of “virtual batteries” – the energy stored in the collective thermal mass of a group of buildings allowing for largescale power charging and discharging via HVAC, water heating, and other end-uses – has been around for over a decade as a distributed solution to reach grid-scale energy storage and load flexibility. and research surrounding the topic, including feasibility studies, pilot projects, tool development, and technical potential analyses. This foundational research culminated in the U.S. Department of Energy (DOE 2021) publishing a national roadmap for GEBs in May of 2021, laying out a goal tripling energy efficiency and demand flexibility in residential and commercial buildings by 2030 versus 2020 levels.

The GridOptimal™ Initiative (NBI 2020), launched by New Buildings Institute and the U.S. Green Building Council, developed research metrics, a LEED pilot credit, and market-facing resources for designers and utilities to support the nascent GEB market. The Initiative, working with an industry-based technical advisory committee, developed nine metrics to characterize GEBs, evaluating the impacts of efficiency measures, energy demand patterns, and demand flexibility in the context of a building’s forward-looking local grid conditions. Similar ongoing metrics-based research from National Renewable Energy Labs (NREL) seeks to identify key metrics based on audience and use cases to evaluate GEB performance. Hundreds of metrics are available to characterize GEBs and their impact on the grid, utility bills, and resiliency. Based on our stakeholder engagement and collaboration with utilities and researchers, we recommend the two metrics proposed in this paper to characterize GEB performance as a balance between simplicity, market-uptake potential, and comprehensiveness.

## Scale of Market Opportunity

Collectively, GEBs represent an immense opportunity for demand response through demand flexibility (DF) measures and system peak load shedding through energy efficiency (EE). Reducing peak load on the electricity grid at large will limit the need for costly transmission and distribution system expansion and upgrades, as well as limit the need for costly, rapid-response peaking plants to meet the demand during the top 1% of hours. The residential, commercial, and industrial building stock can transform the power sector by implementing EE and DF measures that limit demand and shift the remaining demand toward low-cost, low-carbon hours in an effort to accelerate system-wide decarbonization.

According to the U.S. Energy Information Administration (EIA 2022), current annual electricity generation throughout the U.S. is approximately four billion MWh and rising; current projections forecast 25% growth in in next 20 years to beyond five billion MWh per year. With the deployment of EE and DF measures (see Table 3) the commercial and residential building stock could collectively avoid 0.7 billion MWh of electricity use in 2030, or approximately 17% of the projected electricity generation in the U.S. (Langevin et al 2021). Further, based on peak load projections from NREL (2021), these measures could cut system-wide peak demand in the summer and winter by 23% and 19%, respectively in 2030. Translated to cost savings, Langevin et al (2021) estimate this collective building-grid resource to be valued at \$31 billion in 2030.

## Core Metrics to Characterize Building-Grid Integration

**Grid peak contribution (GPC)** is a measure of how much stress a building imposes on the grid. Unlike total energy use, GPC is a time-dependent measure of a building's average normalized net power demand (W/ft<sup>2</sup>) during high-priority hours. The high-priority hours are limited to just 5% of the year (438 hours) when total system load is highest<sup>1</sup>. Throughout most of the U.S., these hours are most often in summer evenings, though winter mornings and evenings also make up some of the 438 hours. The grid-delivered power to the building (i.e. net demand) during that subset of hours forms the basis for the metric. Buildings with a higher GPC, measured in Watts per square foot, create more stress for the grid, leading to greater carbon emissions, higher energy generation costs, increased generating capacity requirements, and greater risk to reliable grid operations. Measuring or calculating GPC requires hourly net demand data available via building energy modeling or hourly building metering. Users can input their demand profiles into a simple spreadsheet calculator to determine their GPC based on their local grid conditions per NREL Cambium (2021) state-by-state system load profiles. A custom system load profile can be utilized if preferred, for example distribution level system load to identify utility customers with the greatest potential to relieve local congestion. A lower GPC means a building is less burdensome to the grid by using energy outside of high-priority hours, using little energy per square foot, or both. Similar to energy use metrics, typical GPC values will vary by location, building type, operational schedule, and other factors.

$$GPC = \sum_{hour=1}^{8760} \frac{\text{Building Net Electricity Demand [W]}}{\text{Gross Conditioned Area [ft}^2\text{]}}, \text{ if } \text{Percentile}(\text{Grid Demand}) \geq .95$$

**Demand Flexibility (DF)** quantifies how much load a building can shed, much like a demand response call. In this case, DF is the average load shed over a four-hour period during the building's peak demand day and is independent of the typical (i.e. no active load shaping) hourly building load profile used to calculate GPC. The four-hour timeframe is based on existing demand response program timeframes and discussions with the GridOptimal technical advisory group. Also measured in Watts per square foot, DF is an important metric for both building owners and grid operators. Behind-the-meter energy storage, grid-connected appliances, and networked building control systems are rapidly becoming standard practice in new construction. With this infrastructure in place, utility demand response programs can leverage the building stock as a virtual battery to reduce operating costs and the use of carbon- and pollutant-intensive rapid-response generating plants such as gas turbines to meet peak loads. Buildings provide DF several ways, including: setting back HVAC setpoints, drawing upon onsite batteries, using stored thermal energy to limit chiller or boiler power, cutting power to selected plug loads, or cutting power to tank-based water heaters. Buildings with greater DF can better support their local grid by reducing their power demand with little-to-no impact to occupant comfort.

$$DF = \frac{\text{Four Hour Demand Shed Potential [W]}}{\text{Gross Conditioned Area [ft}^2\text{]}}$$

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<sup>1</sup> Though we introduce state-wide system load in this paper, the metrics may be applied at the circuit, substation, or other scale best suited to the application. Data availability may limit analysis to your balancing area or state.

Building performance and building-grid interactivity is not limited to what we capture in these two metrics. Existing metrics, including energy use intensity (kBtu/ft<sup>2</sup>), emissions intensity (kgCO<sub>2</sub>/ft<sup>2</sup>), or energy cost index (\$/ft<sup>2</sup>) provide additional context and are intentionally outside the scope of these two targeted metrics. These metrics can easily scale from a single building up to a campus or larger as needed for each stakeholder. For example, a system operator may wish to evaluate which substations are serving loads with the highest GPC in order to target retrofits and incentives in areas with the highest congestion.

These metrics provide a framework that is adaptable to other use-cases. GPC could target a different subset of hours instead of the 5% with the highest system load, such as the most carbon-intensive 10% of hours per year, or the 2% of hours with the highest energy generation cost. Similarly, for DF the four-hour window could be just one or two hours, or it could be calculated during the day when system load is highest, rather than when the building itself peaks, to better align with existing utility programs or preferences.

### Additional Methodology

To aid in metric calculations, NBI has published a spreadsheet calculator (NBI 2022) in which users can input their hourly timeseries, including demand and generation for “typical” operation, and a “demand flex” load shape wherein the building shifts energy use away from its annual peak using modeled measures (e.g. set point adjustments). The tool provides users with the timestamp for the four-hour window used in the DF calculation.

**Grid Peak Contribution (GPC).** The calculator uses average 2036-2044 state-level system load data from NREL’s Standard Scenarios Mid-Case. The forward-looking projection is to account for the long lifecycle of new construction and permanent efficiency measures.

Figure 1 highlights the top 5% of hours of grid demand. When calculating grid peak contribution, the tool averages the buildings *net* demand (W/ft<sup>2</sup>) during those hours only and ignores the rest. We use net demand to calculate the *grid-delivered* electricity consumed by the building because that is what adds to system load and therefore stress on the grid.

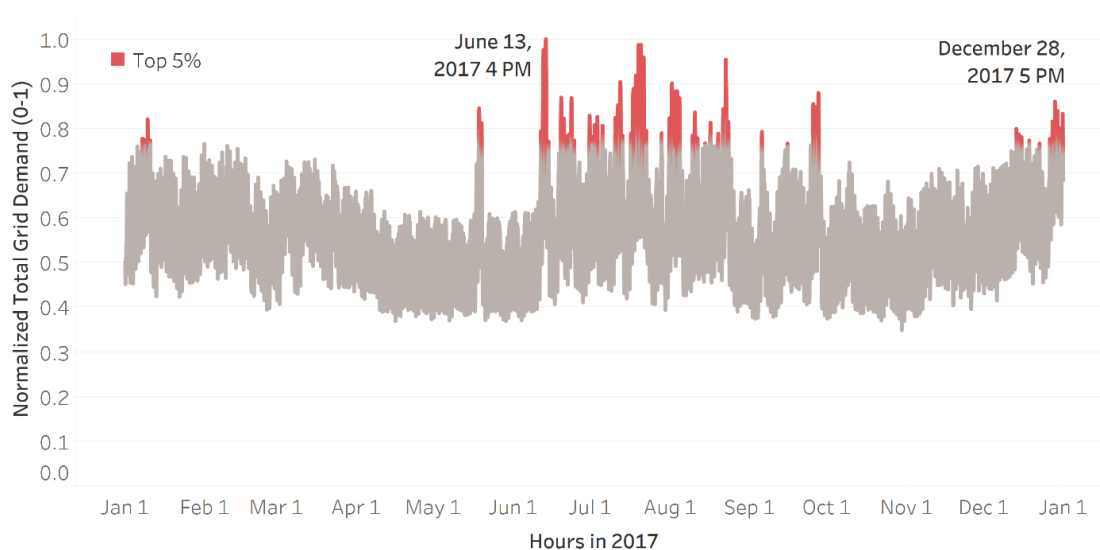


Figure 1: Example Normalized Annual System Load Highlighting “High Priority” Hours for Grid Peak Contribution Calculations. Source: New Building Institute

**Demand Flexibility (DF).** For simplicity, we evaluate a building’s demand flexibility based on a single day – when it peaks. In reality, a building’s demand flexibility potential varies throughout the year with changing heating and cooling loads, internal loads, solar availability, and other factors. Using the building’s peak day provides a standard method to compare buildings while only needing to model or calculate one day. The peak day is typically well into the summer or winter after several consecutive days of high heating or cooling loads.

Figure 2 shows a sample modeled building during its summer peak day in two operating modes – standard operations and a demand flex mode to shift load away from the contiguous four-hour peak window. The average reduction in wattage during that window forms the basis for the DF calculation. In some cases, measures may show a “rebound” before the end of the four-hour window. For example, a two-degree temperature setback may lead to a call for cooling after just an hour. In these cases, particularly in buildings with poor envelopes, a large rebound may negate or lead to a negative DF. A negative DF indicates that the building consumed more energy during the four-hour window with the active demand flexibility measure compared to the baseline case.

$$DF = \sum_{\text{hour}=1}^4 \frac{\text{Typical Bldg Net Elec. Demand [W]} - \text{"Demand Flex" Bldg Net Elec. Demand [W]}}{\text{Gross Conditioned Area [ft}^2\text{]}}$$

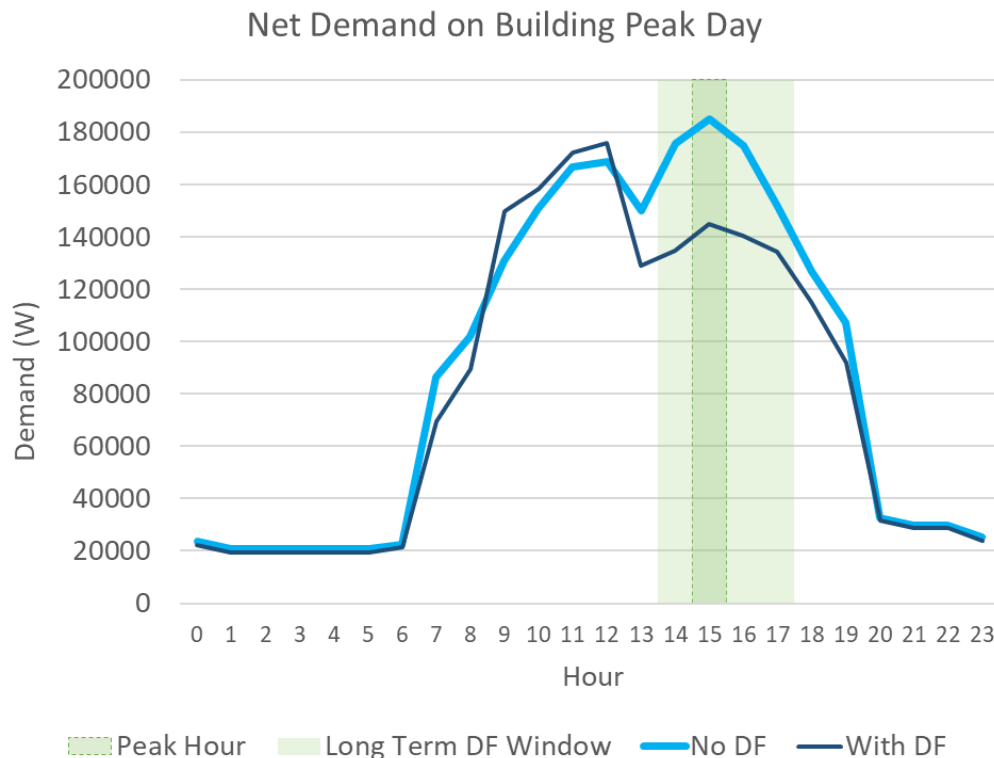


Figure 2: Sample Building Load Profile Showing Four-Hour Demand Flexibility Window, Baseline Building Performance, and Building Performance with Demand Flexibility Measures. Source: New Buildings Institute

For this sample building, the DF would be:

$$\begin{aligned}
 DF &= \frac{(175,000 + 185,000 + 174,000 + 151,000) - (134,000 + 144,000 + 140,000 + 134,000)[W]}{100,000 [ft^2]} \\
 &= \frac{133,000 [W]}{150,000 [ft^2]} = 0.89 \frac{W}{ft^2}
 \end{aligned}$$

## Potential Applications

These metrics may be used in a variety of applications, including many of the same applications that are currently common for energy efficiency metrics. Energy efficiency is often used as a proxy for other priorities, primarily cost and environmental impacts. Using these metrics in those same venues should further the achievement of those underlying goals in most, if not all, applications. A selected set (not an exhaustive list) of applications are considered here, including voluntary programs, policy, labeling/rating systems, and finance.

### Utility Program Applications

Energy efficiency incentive and technical assistance programs (usually associated with and/or implemented by a utility company: thus called “utility programs” here) are a clear application pathway for these metrics. Today’s utility programs typically offer financial incentives for the installation of energy efficient equipment via prescriptive and custom programs.

Prescriptive programs offer fixed incentives per piece of equipment (e.g., LED light fixture) or unit of qualifying hardware installed (e.g., square foot of insulation). Today’s prescriptive programs almost always base the value of incentives on the energy savings, and often also peak demand savings, associated with each measure. The GPC and DF metrics proposed here could be used to calibrate incentive levels based on the grid peak contribution and demand flexibility potential offered by specific measures in specific buildings; this is often accomplished through prototype energy modeling simulations.

Custom programs use a framework in which incentives scale with higher energy (and/or peak demand) savings. In both cases, the value of the incentive is based directly on the energy savings attainable. Custom programs could use GPC and DF to directly incentivize customers to improve their grid peak contribution or demand flexibility. These metrics could be added as a “kicker” incentive on top of existing incentives or for specific locations such as areas of high distribution grid stress, for high-priority building types whose typical load shapes are closely correlated with grid peaks, or in other applications.

Applying these metrics in utility programs would enable program designers to directly incentivize or support strategies based on the grid integration benefits they provide. Programs could broaden their scope beyond energy savings to more clearly support emissions reductions goals.

## Policy Applications

A broad range of public and private-sector policy applications exist, related to both new and existing buildings. The selected examples discussed here include building energy codes and standards, building performance standards (BPS), voluntary building labeling and rating programs, corporate sustainability goals, and financial valuation.

**Building energy codes and standards.** Energy codes and standards could adopt these metrics in performance pathways. To incentivize GEBs in building codes, alternative compliance options and credits can set targets for GPC and DF based on building typology and climate zone. This approach informed a code change proposal for the 2024 International Energy Conservation Code (IECC)<sup>2</sup> (NBI 2021). That particular 2024 IECC proposal focuses only on demand flexibility, but a similar approach could be taken focused on grid peak contribution.

**Building Performance Standards (BPS).** Building Performance Standards (BPS) are policies that require buildings to meet certain energy or climate targets. Momentum is growing across the nation for BPS, mainly at the municipal level but also in some states. In most cases, BPS are denominated in terms of site energy (EUI) but other approaches do exist. New York City’s groundbreaking Local Law 97 lays out building performance standards using a GHG emission metric (New York City 2019). Grid-interactivity based metrics such as GPC could model legislation such as Local Law 97 to set performance standards.

**Building labeling and rating systems.** Rating systems like the US Green Building Council (USGBC)’s Leadership in Energy Efficiency and Design (LEED), Green Globes, International Living Future Institute’s Living Building Challenge, and others can use these metrics to build out emerging grid-interactivity standards for new construction and existing buildings in future versions of their rating systems. Currently LEED version 4.1 includes a grid harmonization credit within the Energy and Atmosphere group (LEED 2019).

**Financial valuation.** As a means of mitigating future utility costs, corporate and municipal policies can include demand flexibility standards to ensure their buildings can successfully mitigate demand changes and generate income by participating in utility demand response programs. In addition, performance-based loan incentives may be available for high-performing and grid-integrated developments, such as the CIRRUS Low Carbon which provides preferential loan terms for buildings that meet a set of low carbon prescriptive requirements (PACE Equity).

## Early Metric Benchmarks from Simulations and Pilot Projects

As part of the GridOptimal Buildings Initiative, NBI analyzed the impact of more than 20 simulated energy efficiency (EE) and demand flexibility (DF) measures across seven prototypical buildings and 16 climate zones. We sourced data from an energy modeling analysis

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<sup>2</sup> The proposal, titled “Grid Optimal Credits CEPI-197-21,” applies to section C406 of the commercial code and would offer credits for buildings that can shed 10% (or higher credits for 20%) of the building’s peak load during its peak demand hours. In this case, the proposal considers the building’s peak demand hour, rather than the grid peak demand hour. The load shedding must be accomplished by an automated demand response or similar request from a third party such as a grid operator or aggregator. At the time of writing, the proposal was under consideration.

completed by Red Car Analytics (2019) and assessment studies from Lawrence Berkeley National Laboratory (LBNL 2021) and Langevin et al. (2021).

NBI also gathered data from pilot projects to generate GridOptimal metric scores for three buildings located in California, Vermont, and New York. The GPC and DF of select strategies and buildings are detailed below.

## Pilot Projects

Table 1 summarizes the GPC and DF of the first GridOptimal pilot project – the two-story, 15,000 square foot Sonoma Clean Power headquarters in Santa Rosa, California. For this pilot project, NBI conducted a design evaluation to optimize the GridOptimal metric scores of the proposed building while also seeking to reach zero operational carbon. This retrofit project included building electrification and a variety of energy efficiency upgrades as well as the installation of a 30-kW photovoltaic (PV) array and a 150-kWh battery. Table 1 shows a progressive improvement in GPC from 1) the baseline (existing) building to 2) the same building with energy efficiency upgrades and a battery to 3) the upgraded building plus battery with the addition of the PV array. Note that the addition of the PV array was not considered a demand flexibility strategy and thus the DF score did not change.

Table 1. Summary of GridOptimal market metric scores for Sonoma Clean Power Pilot Project

| Scenario                                     | Grid Peak Contribution (W/sf) | Demand Flexibility (W/sf) |
|----------------------------------------------|-------------------------------|---------------------------|
| Baseline building                            | 1.74                          | N/A                       |
| Energy efficiency upgrades + battery         | 1.35                          | 0.86                      |
| Energy efficiency upgrades + battery + solar | 0.66                          | 0.86                      |

For the GridOptimal pilot projects in New York and Vermont, NBI analyzed proposed thermal energy storage deployment strategies and provided recommendations to optimize the controls for marginal carbon emissions, grid load, and utility time-of-use rates or DF calls. The metric scores shown in Table 2 quantify the GPC and DF of the baseline building, and the building with a modeled thermal energy storage deployment strategy in place. For the New York building, the data only applies to the cooling system, not the whole building. This table provides a snapshot of just one deployment strategy; depending on the project goals, alternative strategies could further minimize GPC or maximize DF.

Table 2. Summary of GridOptimal market metric scores for Vermont and New York pilot projects

| Project | Building description                                  | Scenario                           | Grid Peak Contribution (W/sf) | Demand Flexibility (W/sf) |
|---------|-------------------------------------------------------|------------------------------------|-------------------------------|---------------------------|
| Vermont | 3-story, 25,000 square feet higher education building | Baseline building                  | 4.02                          | N/A                       |
|         |                                                       | Addition of thermal energy storage | 3.20                          | 0.84                      |

|          |                                                         |                                         |      |      |
|----------|---------------------------------------------------------|-----------------------------------------|------|------|
| New York | High-rise 500,000 square feet higher education building | Baseline building (cooling system only) | 0.12 | N/A  |
|          |                                                         | Addition of thermal energy storage      | 0.07 | 0.23 |

As Table 2 shows, the W/sf GPC of the New York building is much lower than the Vermont building; this is likely because the analyzed data for the New York building was only for the cooling system, not the entire building. Although the size of the Vermont and New York buildings differ as well as the scope of the data (whole building vs. cooling system only), the scores are also dependent on the deployment strategy in relation to the local grid – because GPC is calculated based on the top 5% of grid demand hours, maximizing this metric requires strategically discharging the thermal energy storage during those hours.

### Simulation analysis

LBNL (2021) conducted extensive modeling to inform the DOE’s National Roadmap for Grid-Interactive Efficient Buildings. The analysis is built upon the ASHRAE 90.1-2004 Commercial Building Prototypes (DOE). Alternative building demand scenarios were generated by applying a variety of demand flexibility and energy efficiency measures (Langevin 2021). NBI utilized these models to generate the GPC and DF values detailed below.

The results suggest that for the same measure, GPC and DF are most impacted by the climate zone the building is in, and secondarily by the building type.

shows the range of GPC results by climate zone and building type for the baseline prototypical building as compared to the same building with the most comprehensive package of demand flexibility and energy efficiency measures. A summary of the individual strategies contained in each measure package is shown in Table 3.

Across all building types, Grid Peak Contribution is generally higher in warmer climate zones. This can be attributed to the fact that most grids in the U.S. experience peak load in the summer, even in cooler climates. However, buildings in cooler climate zones generally require less cooling during these summer peak conditions than in warmer climate zones, thus contributing less to the grid peak.

While all building types clearly benefit from the DF and EE measure package, the Medium Office building type shows the greatest decrease in GPC. This is likely a function of the measures included in the packages. For example, an office building will benefit more from electronic device switching and plug load management than a retail building or warehouse.

Table 3. Summary of strategies included in the most aggressive DF measure package and the most aggressive package containing both DF and EE measures.

| DF Measure Package Strategies                                                                                                                                                                                                                                                                             | DF and EE Measure Package Strategies                                                                                                                                                                                                        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Global temperature adjustment during building peak hours</li> <li>Precooling and Preheating prior to building peak hours</li> <li>Thermal energy storage (applies only to Large Office and Large Hotel)</li> <li>Daylighting controls and light dimming</li> </ul> | <p>All DF Measures shown at left, plus the following:</p> <ul style="list-style-type: none"> <li>Envelope insulation and air sealing</li> <li>Efficient HVAC equipment</li> <li>Lighting upgrades</li> <li>Efficient electronics</li> </ul> |

- Low priority electronic device switching
- Efficient refrigeration

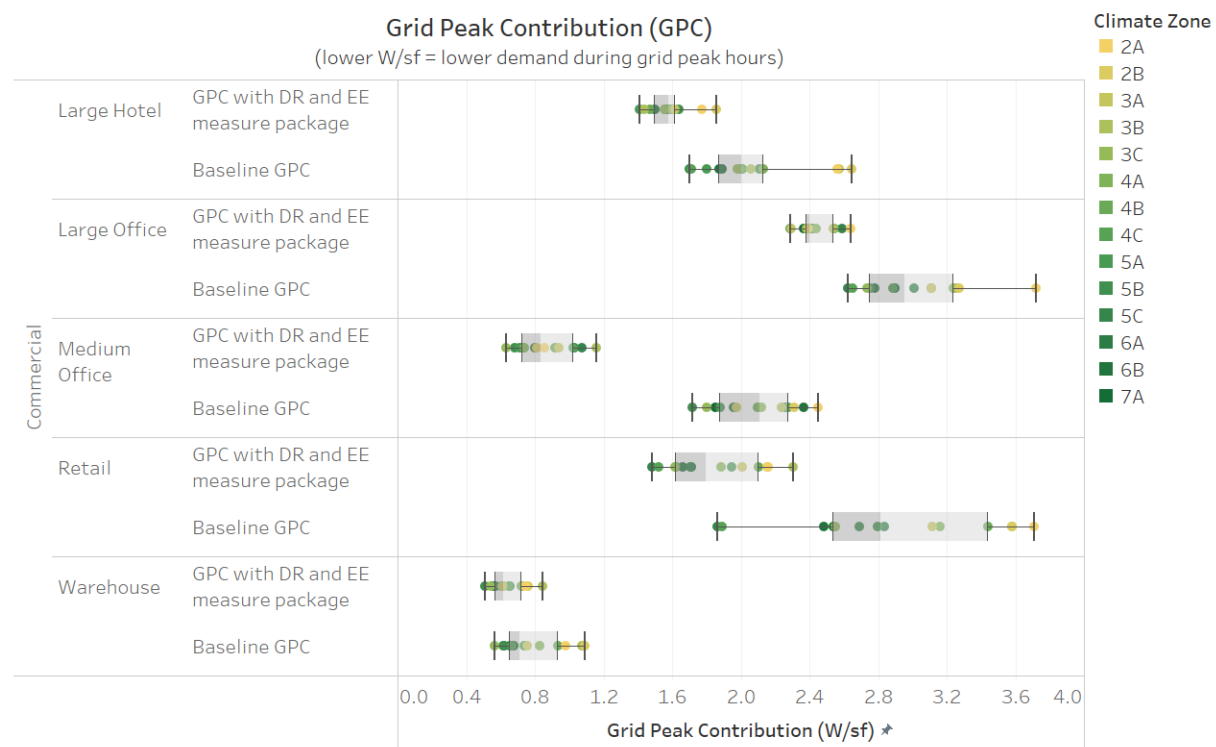


Figure 3. GPC score for five building types before and after applying the package of demand flexibility and energy efficiency measures shown in Table 3. Source: New Buildings Institute

summarizes the DF by building type and climate zone, for the most comprehensive package of demand flexibility-only measures as well as the package of both DF and EE measures. This figure highlights the ability of energy efficiency measures to act as an enabler and impact multiplier for demand flexibility; the package including energy efficiency upgrades yields consistently more demand flexibility than the package of demand flexibility strategies alone.

The DF achieved (W/sf) is consistently lower than the range of GPC shown in , but this should not be interpreted as an indicator of lower performance; these metrics are meant to be considered together when optimizing a building and not compared side-by-side.

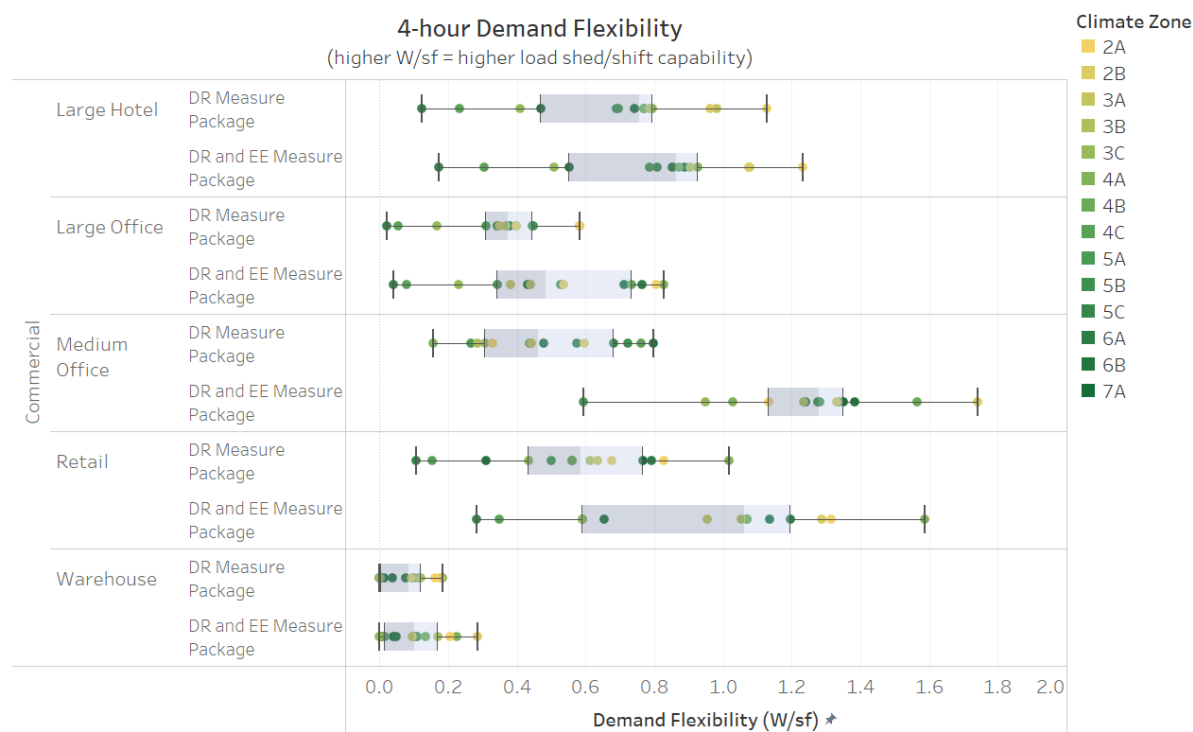


Figure 4. Demand Flexibility score for five prototypical building types with a package of demand flexibility measures vs. the same package of demand flexibility measures along with energy efficiency upgrades (see details in Table 3). Source: New Buildings Institute.

## Future Research

As GEBs continue to grow in popularity and the prevalence of advanced metering grows, abundant hourly data streams for new and existing buildings will be available for NBI and others to calculate GPC and DF performance and establish benchmarks. These benchmarks can then form a robust basis for designers and policymakers to set targets for building design and performance. In addition, further cost-benefit research is needed to quantify the potential demand response income, resiliency benefits, and avoided capacity investments that come from GEBs.

## Conclusion

This paper introduced two well-vetted metrics and a calculator to characterize building-grid interactivity. These metrics can support the implementation of GEBs in the building industry by providing a pathway to establish performance benchmarks. Early modeling studies show that GPC ranges from 4 W/ft<sup>2</sup> down to 0.5 W/ft<sup>2</sup>, while DF from a combination HVAC setpoint adjustments, plug load controls, and lighting adjustments range from just over 0 W/ft<sup>2</sup> to up to 1.5 W/ft<sup>2</sup> or more. Models also show that energy efficiency and demand flexibility work together to reduce the impact building have on system-wide peaks and that buildings have the potential, when leveraged as a collective, to curb upwards of 20% of system peaks and 15% or more of total annual energy use in 2030. Applications for these metrics include utility programs, building energy codes, building performance standards, municipal and corporate building policy, and financial market valuation.

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