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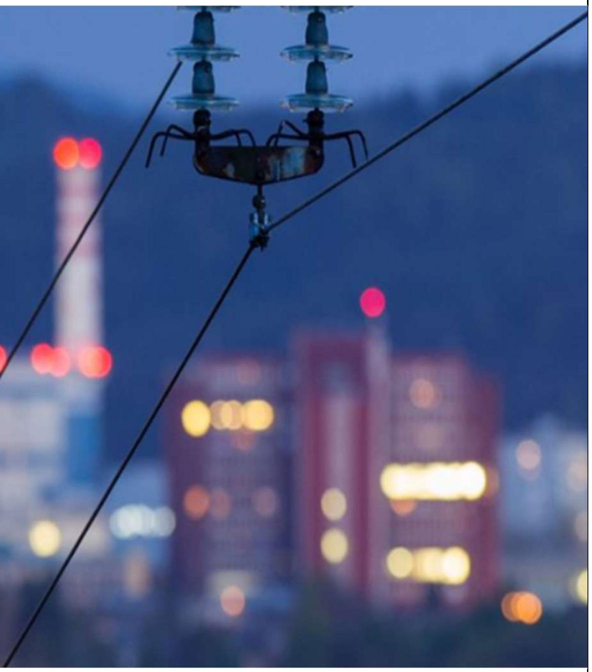

Building Energy Codes and Grid-Interactive Efficient Buildings

How building energy codes can enable a more dynamic and energy-efficient built environment

October 2021

E Franconi
M Rosenberg
R Hart

U.S. DEPARTMENT OF ENERGY
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Executive Summary

A rapid transition of the U.S. power system is underway that will reshape the operation and performance of the electric grid. Persistent growth in renewable energy resources—driven by declining costs, improved performance, and decarbonization policies[1]—is starting to noticeably impact the electricity system (GridWise Architecture Council 2015). As buildings account for over 70% of U.S. electricity use, effectively managing their loads can greatly facilitate the transition towards a clean, reliable grid. Grid-interactive efficient buildings (GEBs) combine efficiency and demand flexibility with smart technologies and communication to provide occupant comfort and productivity while serving the grid as a distributed energy resource (DER). In turn, GEBs can play a key role in enabling the affordability, reliability, and improved performance across the U.S. electric power system. Their national adoption could provide $100–200 billion in U.S. electric power system cost savings over the next two decades. The associated reduction in carbon dioxide (CO_2) emissions is estimated at 6% per year by 2030. The U.S. Department of Energy's (DOE's) national GEB vision is to triple energy efficiency and demand flexibility[2] (DF) of the buildings sector by 2030 relative to 2020 levels (DOE 2021).

Building codes represent standard design practice in the construction industry and continually evolve to include advanced technologies and innovative practices. Historically, national model energy codes establish minimum efficiency requirements for new construction.[3] Expanding codes to further support GEB capabilities is a pivotal step towards realizing demand flexibility in support of a clean grid at scale. Future building codes can include capabilities to improve interoperability between smart building systems, the grid, and renewable energy resources (Alstone et al. 2017). Energy codes can also advance the deployment of GEB technologies such as smart, connected building energy management systems, energy storage, behind-the-meter generation, and electric vehicles (EVs). Such advancements will benefit from recent DOE research focused on the development, characterization and valuation of GEB technologies.[4]

Building energy codes have the potential to advance GEB technology deployment. Market-ready capabilities are ripe for consideration, including communications and control capabilities that support DF that can be layered onto existing code requirements for GEB-relevant equipment. However, the commonly applied code development process needs to evolve to better support the inclusion of DF measures. Historically in code development, new prescriptive requirements are assessed for cost effectiveness using a flat or blended national average electricity rate, intended to broadly represent a wide range of U.S. rate structures. The convention assumes that energy efficiency provides a general reduction in overall building load shape. However, a flat rate cannot effectively value load shifting or shedding that reduces

[1] Thirty-seven states representing 80% of the U.S. population have enacted renewable portfolio standards or goals.

[2] Capability provided by DERs to reduce, shed, shift, modulate, or generate electricity; energy flexibility and load flexibility are often used interchangeably with demand flexibility.

[3] While advanced codes can be considered model codes, in this document, the term "model energy code" refers to the current published version of the International Energy Conservation Code-Residential and ASHRAE Standard 90.1, as those documents are referenced by Energy Conservation and Production Act as modified by the Energy Policy Act of 1992 as the minimum requirements for states adopting energy codes. https://www.govinfo.gov/content/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

[4] DOE Building Technology Office is sponsoring research and the development of a series of technical reports related to GEB opportunities in buildings. https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings.

building demand during high costs periods or helps manage grid supply contingency events.[5] In addition, GEB technologies are capable of providing ancillary grid services, such as fast demand response (referred to as shimmying or modulation) that occurs over minutes or seconds to smooth short-term net load changes (DOE 2021). Moving forward, a more detailed approach is needed for analyzing energy efficiency and DF impacts on building load shape and grid responsiveness when considering new code requirements.

A review of current provisions in recently published residential and commercial model energy codes[6] indicate that they include no prescriptive requirements for smart controls nor renewable energy systems.[7] Some advanced codes include more explicit GEB provisions. The California 2019 Title 24 Code (CEC 2018) has mandatory requirements for two-way data communication that adheres to the Open Automated Demand Response (OpenADR) communication protocol (OpenADR 2012). Furthermore, Title 24 includes prescriptive requirements for residential buildings for onsite solar energy systems. For commercial buildings, prescriptive requirements are specified for demand responsive thermostats, plug load controls, lighting controls, and HVAC controls. The 2018 International Green Conservation Code (ICC 2018) includes prescriptive requirements for onsite renewable energy systems and electric vehicle charging infrastructure. Its performance-based compliance path allows for renewable energy offsets, although compliance can be achieved without the offset by increasing building energy efficiency.

Future efforts to characterize, analyze, and demonstrate GEB technology cost effectiveness for consideration in codes will benefit from published research demonstrating GEB impact potential and its value to consumers. The U.S. Department of Energy's Building Technologies Office (BTO) currently funds several research activities related to the value proposition of GEBs, characterization of demand flexibility measures, and development of GEB technologies (DOE 2020).[8] Specific BTO research projects underway that can inform code development includes building end-use load profiles depicted by metered data, transactive-based controls, GEB impact analysis methods, load management operational optimization algorithms, and the building simulation models incorporating these strategies. This report includes an overview of relevant BTO research efforts to inform and guide the addition of GEB considerations in the model energy code.

Complementing DOE's research are standardization efforts for classifying and quantifying the impact of DF measures. For example, the European Union Council is funding work for the develop of a smart readiness indicator (SRI) for various building technologies (Verbeke et al. 2018). The New Buildings Institute, through its *GridOptimal* project, is developing metrics that measure and characterize a building's grid-friendly features (NBI 2019). The International Energy Agency Annex 67 is concluding a multi-year effort to evaluate GEB demand flexibility capabilities to inform building design and operational decisions (IEA 2017).

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[5] An event that is managed by a contingency plan to ensure power systems are available to provide the electricity required to operate at full capacity.

[6] In this document, the term "model energy codes" refers to the International Energy Conservation Code and ASHRAE Standard 90.1, as those documents are referenced by Energy Conservation and Production Act as modified by the Energy Policy Act 1992 as the minimum requirements for states adopting energy codes. https://www.govinfo.gov/content/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

[7] Addendum BY that adds a minimum prescriptive requirement for onsite renewable energy was approved by the ASHRAE Standards Committee on June 26, 2020.

[8] Also see the DOE webpage https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings.

Building energy codes provide a means for accelerating GEB technology adoption and achieving a clean, resilient electric grid. Acceleration efforts will benefit from research, like that described above, that targets the characterization, quantification, and optimal management of DF measures. Moving forward, the code development process must incorporate new approaches that account for the value of building efficiency and load flexibility in a more granular way. This warrants modifying code scope and the economic assessments that underlie code change proposals. In light of these considerations, enabling actions for addressing GEBs in codes include the following:

1. Expansion of the scope of energy codes and standards to cover interactions between buildings and their energy sources
2. Identification and characterization of GEB measures based on their ability to provide various grid services
3. Reflection of regional variations in the value of demand flexibility measures
4. Development of analytical methods for assessing demand flexibility value based on considerations 2 and 3 above and the acceptance of code development bodies to embrace those values.

The GEB market is still nascent. Exploring options now for incorporating GEB technologies will help reduce lost opportunities in the future. In the near term, national model energy codes can feature new prescriptive DF measures demonstrated to be cost effective following current code development methodologies. Requirements already in code that address GEB-relevant technologies (e.g., service water heating, lighting, and HVAC) can be expanded to include demand responsive control and communication capabilities. In addition, optional DF measures that are more costly can be introduced to serve early-adopter jurisdictions. In the future as the market transforms and providers serving the smart grid emerge, the market value for DF measures will increase. And as the GEB field matures, DF measure impact can be substantiated with measured data, which will also help build confidence in DF measure effectiveness and inform methods for making performance predictions. Such methods can be incorporated into the analytical frameworks and tools that currently support code advancement.

In recognition of the current status of the GEB market and in anticipation of its maturation over the next decade, a proposed progression for incorporating GEB technologies and capabilities in energy codes over time is outlined below.

1. Establish requirements for GEB readiness to ensure the supporting infrastructure, communication protocol, and centralized control capabilities are in place as needed to support their interoperation and automated response.
2. Supplement existing requirements for GEB-relevant appliances and equipment to include demand flexibility capabilities.
3. Include new prescriptive requirements for cost-effective DF measures.
4. Utilize code mechanisms[9] that offer flexibility in meeting requirements for DF capabilities.
5. Specify the most valuable and foundational DF measures as mandatory requirements.
6. Incorporate DF metrics as part of the performance-compliance path.
   a. Require projects to adhere to nominal requirements for demand flexibility.

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[9] Such as the IECC commercial code section *C406 Additional Efficiency Measures*

b. Include standardized methods for quantifying the impact of DF measures in simplified hourly performance analysis tools, such as the Total System Performance Ratio (Jonlin et al. 2018).
c. Expand modeling guidelines (e.g., ASHRAE 90.1 Appendix G) to provide standardized methods for simulating GEBs for performance compliance.

Acronyms and Abbreviations

ADR	automated demand response
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BTO	Building Technologies Office
CAISO	California Independent System Operator
CBECS	Commercial Buildings Energy Consumption Survey
CEER	Combined Energy Efficiency Ratio
CO_2	carbon dioxide
DDC	direct digital control
DER	distributed energy resource
DF	demand flexibility
DOE	U.S. Department of Energy
DR	demand response
EDR	Energy Efficiency Design Rating
EE/DR	energy efficiency/demand response
ERI	Energy Rating Index
EU	European Union
EUI	energy use intensity
EV	electric vehicle
FY	fiscal year
GEB	grid-interactive efficient building
HVAC	heating, ventilation, and air conditioning
ICT	information and communication technology
IEA	International Energy Agency
IECC	International Energy Conservation Code
IECC-R	International Energy Conservation Code for residential
IgCC	International Green Conservation Code
IoT	internet-of-things
LBNL	Lawrence Berkeley National Laboratory
MEC	model energy code
MEL	miscellaneous energy load
M&V	measurement & verification
NBI	New Buildings Institute
NIBS	National Institute of Building Sciences

NREL	National Renewable Energy Laboratory
NZEC	Net Zero Energy Coalition
OpenADR	Open Automated Demand Response
PCI	Performance Cost Index
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SRI	smart readiness indicator
SWH	Service Water Heater
TDR	Total Energy Design Rating
TDV	time-dependent value
UEF	uniform energy factor
VEN	Virtual End Note

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1.0 Introduction

This report considers the role of national model codes to promote grid-interactive efficient buildings (GEBs) as part of the modernization of the U.S. electricity grid. It introduces GEBs, describes the need to support a clean, resilient grid, and considers challenges and approaches for incorporating demand flexibility (DF) measures into national model energy code and supporting standards.

The review was conducted to inform Pacific Northwest National Laboratory (PNNL) research addressing the advancement of codes through the inclusion of advanced efficiency and DF measures. Specifically, the research involves evaluating the potential for advanced code measures to fill the energy-efficiency gap to realize net-zero-energy buildings in the U.S (Franconi et al. 2021a). A parallel research focus involves identifying DF measures currently included in building energy codes, as well as those that could be included in the future (Franconi et al. 2021b).

National model energy codes, which include the International Energy Conservation Code for residential (IECC-R) and ASHRAE Standard 90.1 for commercial, are the basis for the vast majority of U.S. state codes.[1] They are developed through national consensus processes and made available for adoption by states and local jurisdictions. Improving building energy efficiency is the current focus of their development. Recent code enhancements are improving methods to demonstrate ultra-low and net zero energy performance levels. The next wave of code advancements is anticipated to occur in conjunction with the electric grid modernization. To improve its reliability and efficiency, the electric grid is transitioning from being centralized and fossil-fuel based to being distributed and dynamic, and fully exploiting renewable energy generation (DOE 2009).

As defined by the U.S. Department of Energy (DOE) and informed by stakeholder input (DOE 2021),

> *GEBs are energy efficient buildings with smart technologies characterized by the active use of distributed energy resources (DERs) to optimize energy use for grid services, occupant needs and preferences, and cost reductions in a continuous and integrated way.*

Building energy codes can support the delivery of GEBs that promote load flexibility and responsiveness. Such DF measures are defined in California's 2019 Title 24 building energy code (CEC 2018) as the following:

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[1]In this document, the term "model energy codes" refers to the International Energy Code and ASHRAE Standard 90.1, as those documents are referenced by the Energy Conservation and Production Act as modified by the Energy Policy Act 1992 as the minimum requirements for states adopting energy codes. https://www.govinfo.gov/content/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

Measures that reduce TDV[1] energy consumption using communication and control technology to shift electricity use across hours of the day to decrease energy use on-peak or increase energy use off-peak, including but not limited to battery storage, or HVAC or water heating load shifting.

The benefits realized from GEBs vary temporally and geographically, depending on the local constraints of the grid. Accounting for these considerations in future code development requires a continuation and expansion of code-minimum energy efficiency requirements and inclusion of demand responsive and load flexibility measures while ensuring annual use and cost reductions. Also, efforts to include DF measures in codes will benefit from recent research focused on technology identification, measure characterization, and impact evaluation. Such research efforts can inform the development of a framework for considering DF measures in codes, which can take advantage of new code compliance mechanisms (such as selections of measures or measure packages that are assigned points for meeting scoring requirements).

This document reviews topics pertinent for considering GEBs in codes. Specifically, it presents the status and direction of current building energy codes, the future smart grid, high efficiency buildings, and grid-interactive buildings. The report concludes with recommendations for future code development activities to support the design of efficient, grid-interactive buildings in order to provide added value to building owners, the grid, and society.

[1] Time dependent value (TDV) is the basis for determining cost-effectiveness of energy efficiency measures for new buildings in California. TDV is based on a series of annual hourly values of electricity costs in a typical weather year. Values are developed for residential and nonresidential buildings in each of the 16 California climate zones. Retail costs are not used since these are based on averages over time periods rather than hourly differences in the cost of generation. The approach supports energy efficiency measure savings to be valued on a time-dependent basis, which better reflect the actual costs to consumers and the utility system.

2.0 Building Energy Codes

Building code development in the United States commenced over 130 years ago. First initiated in response to major fires (1886 Chicago Fire) and natural disasters (1906 San Francisco Earthquake), building codes soon after expanded because of concern for public safety and economic loss as the insurance business emerged (Rossberg and Leon 2013). During much of the 20th century, multiple organizations were responsible for developing model building codes, each tending to focus on the predominant hazards in their geographic area. In 1975, ASHRAE Standard 90, the first national energy code, was published (ASHRAE 1975).

Today's building energy codes address the design and construction of new buildings and major renovations. They focus on performance-related features that are within the scope of design and construction teams. Addressing efficiency at the time of construction offers an opportunity to influence building performance at minimal incremental cost. The impact of model energy codes on building efficiency is significant, as indicated in Figure 1. For example, ASHRAE 90.1-2010 was determined to have a nationally aggregated impact equaling 32.7% site energy savings and 29.5% energy cost savings compared to 90.1-2004, if unregulated plug and process loads (also known as miscellaneous energy loads or MELs)[1] are excluded in the percentage (Thornton et al. 2011).

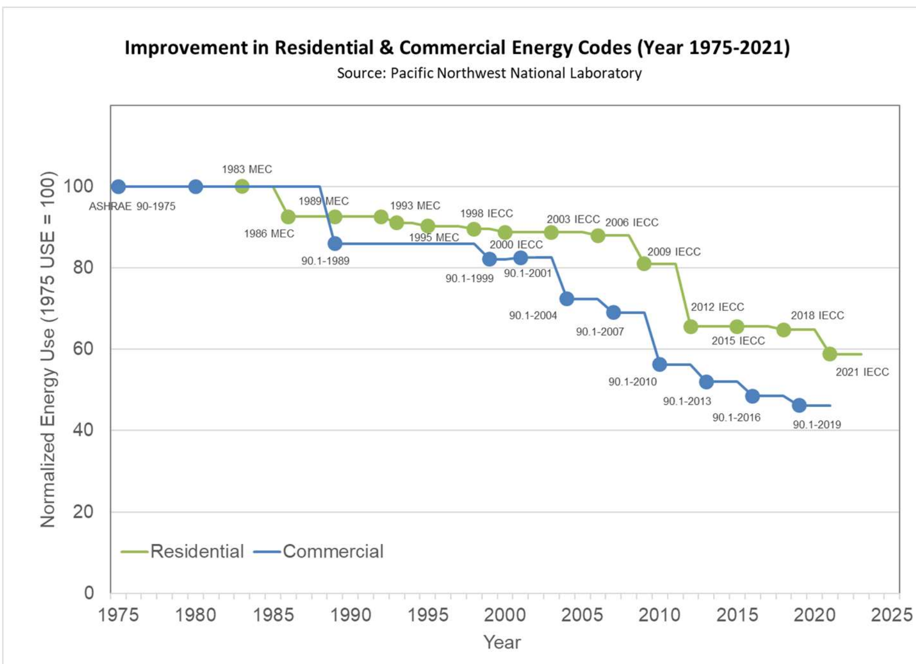

Figure 1. Model Energy Code (MEC) Efficiency Achievements

Many stakeholders[2] in the building industry have established a goal of net zero energy for new construction by 2030 (ASHRAE 2008; Mazria and Kershner 2008). As indicated in Figure 2,

[1] Generally, regulated loads include lighting, building envelope, service hot water, and HVAC, while plug, equipment and process loads have been generally unregulated, although some regulation in this area is starting.
[2] Such as the American Association of Architects, ASHRAE, States of California, Massachusetts, Minnesota, Ohio, and Vermont.

continuing the savings trajectory achieved by commercial building model codes since 2004 will fall short of reaching this 2030 goal (Franconi et al. 2021a).[1] Yet, as outlined in the 2015 Commercial Energy Codes Roadmap report (Rosenberg et al. 2015), challenges exist in using the simple prescriptive compliance path to continue to achieve aggressive efficiency improvements. For instance, as regulated loads decrease—and unregulated loads make up a larger portion of total energy use—specifications for prescriptive design solutions become more complex. This increases code development efforts and widens the potential for the different prescriptive combinations to result in different annual energy use.

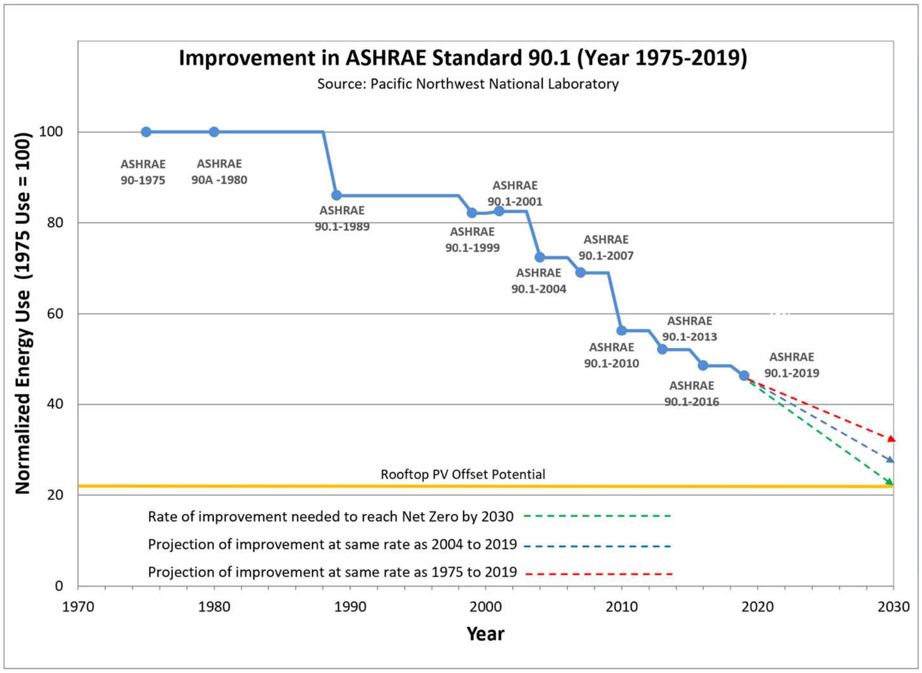

Figure 2. ASHRAE 90.1 Efficiency Projections to 2030

Reflecting on these limitations, the 2015 Commercial Energy Codes Roadmap recommends transitioning from the commonly applied prescriptive compliance path to a performance-based compliance path, which provides deeper savings and greater design flexibility. To support the transition, an additional energy efficiency credit code mechanism can be used. This approach allows design teams to choose from a number of available efficiency measures, each assigned a corresponding number of points, to achieve a desired number of total credits. The target value represents a percent decrease in total annual energy use. While this approach is most appropriate for smaller or simple buildings, it can be used as an interim method for all buildings until simple but robust tools are available to demonstrate compliance through the performance-based path, which thus far has had limited uptake due to its complexity and lack of supporting software tools (Rosenberg et al. 2015).

[1] This assumes that the annual energy use of newly constructed commercial buildings is offset by rooftop PV electricity production. The offset indicated in Figure 2 is based on published studies and code building prototype simulation analysis. For more details, see Franconi et al. (2021)a.

Recent code advancements include efforts to better align code compliance methods with clear, measurable performance goals, such as an energy use index. These outcome-based code methods expand upon design-phase compliance to also include post-occupancy actual energy use compliance. The design-phase compliance utilizes a predictive, performance-based compliance metric. The post-occupancy compliance is verified using utility billing data The post-occupancy compliance accounts for total building energy use, which recognizes integrated, low-energy-use design and operation. Also, the inclusion of a post-occupancy compliance component provide a mechanism to capture energy efficiency opportunities across the life cycle of the building (NIBS and NBI 2017). However, establishing fair and appropriate post-occupancy targets can be challenging since few buildings are typical. For predictive approaches, estimating energy use with simulation programs can be unreliable (Rosenberg et al. 2015) (due to analysis simplifications, differences in calculation algorithms, and the inevitable need to make input assumptions). Most previous attempts to use simple targets have failed (Goldstein and Eley 2014). However, the more that actual building performance data become available and are shared, the easier it will be to establish meaningful and customized targets. As simulation tools are improved for consistency and accuracy (and inputs are made less subjective), predictive performance will become more reliable and hence useful as a code compliance option pathway. More details about the benefits of outcome-based solutions and suggestions for their incorporation in codes can be found in published guidance documents (NIBS and NBI 2017).

3.0 The Future Grid

As observed in their early development and current form, building codes are adaptive. They evolve to address current concerns regarding public safety, health, and energy equity, and to guard against personal and business economic loss. Disruptive drivers affecting the utility industry today[1] provide the impetus to examine the role of building codes in this evolving energy ecosystem. For example, persistent growth in intermittent renewable energy resources (which is being driven by declining costs, improved performance, and decarbonization efforts such as the enactment of renewable energy standards)[2] is starting to noticeably impact the electricity system (GridWise Architecture Council 2015).

Historically, system operators controlled large, centralized power plants to match instantaneous demand. However, higher levels of non-controllable, variable generation sources are forcing a change in operating strategies. In 2013, the California Independent System Operator (CAISO) first published what has become known as the “duck curve” (CAISO 2016). Figure 3 shows a historical chart based on actual CAISO data, which indicates that the net load—the difference between anticipated load and expected production from distributed renewable resources—is changing as anticipated as clean grid policies are realized. It shows ramping periods getting steeper when photovoltaic (PV) resources come online and then reduce output with the diurnal solar cycle.

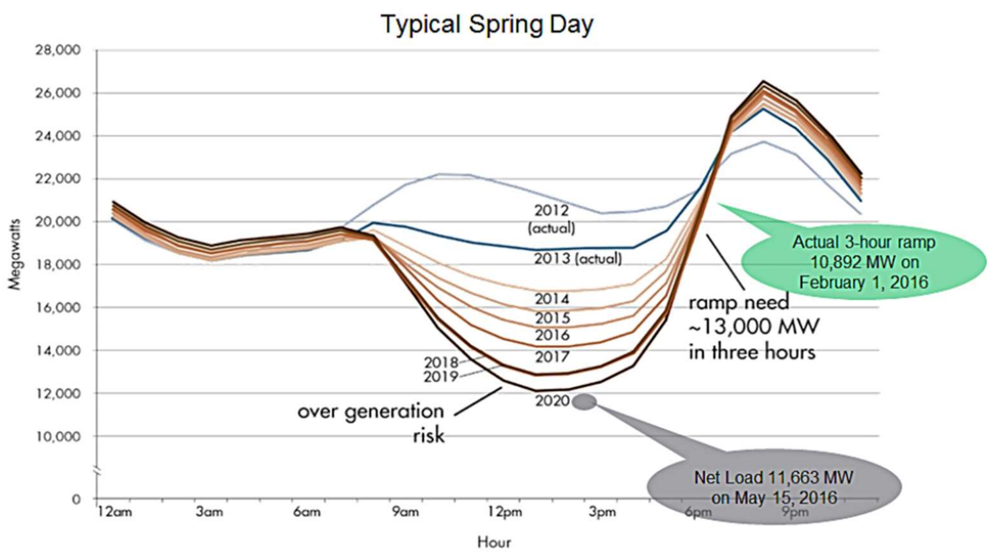

Figure 3. The CAISO Net Electricity Load Curve

[1] For example, record droughts and infestation by bark beetles have killed millions of trees, which puts utilities at increased risk of fire liability associated with downed power lines. For example, Pacific Gas and Electric filed for bankruptcy as a result of a potential liability totaling $30 billion resulting from the Tubbs Fire. Hardening the grid through multiple measures, including shutting off power in at-risk areas and serving customers with islandable microgrids, can help manage risks associated with climate events.
[2] Thirty-seven states representing 80% of the U.S. population have enacted renewable portfolio standards or goals.

Historically, demand response (DR) programs have worked well to address predictable, discrete electric peak demand events. However, as indicated in

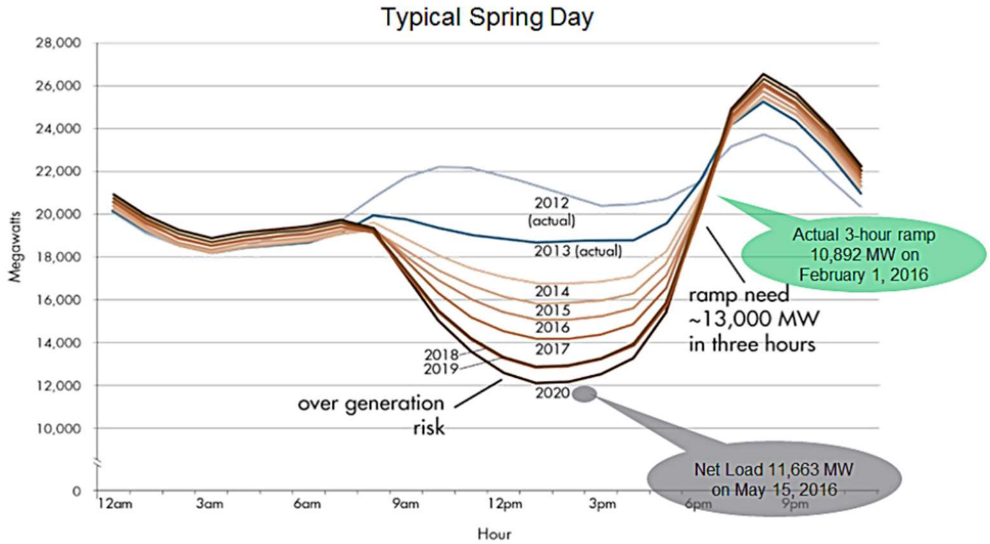

Figure 3, the power system will face operational challenges with daily short, dramatic net load swings as the grid includes a higher portion of renewable energy resources. To ensure reliability, system operators will need to manage assets more effectively to meet the various needs supporting grid resilience. Grid operations will evolve from being relatively predictable to highly dynamic (i.e., accomplished with automated operations in a distributed network). Intelligence will move from operation centers to the grid edge. Utilities and energy aggregators will become consumer service companies supporting a smart grid that delivers sustainable, economic, and secure electricity supplies (Newcomb et al. 2013).

The U.S. buildings sector accounts for 75% of U.S. electricity sales, which is nearly equally shared between residential and commercial buildings (EIA 2018). Thus, buildings (as the biggest consumers of electricity) have an important role to play in the realization of a reliable, clean electricity system. The US Department of Energy (DOE) Building Technology Office (BTO) is developing a GEB strategy targeting the optimal integration and operation of distributed energy resources (DERs) to support overall energy system operations and planning (DOE 2019). Specifically, the GEB strategy will drive towards the following:

- Dynamically managed building energy end-uses to meet grid needs and minimize electricity system costs while meeting occupant requirements,
- Integration of building DF measures with other onsite DERs—like photovoltaics, thermal and chemical energy storage, and combined heat and power, and
- Value assignment of behind-the-meter DERs—including the ability for efficiency and for DR technologies to provide grid services by location, hour, season, and year.

Targeting demand flexibility will allow buildings to response to continuously changing grid needs and price signals to support the supply-demand balance. The concept is summarized by Dyson et al. (2015, p. 5) as follows:

> *Demand flexibility uses communication and control technology to shift electricity use across hours of the day while delivering end-use services (e.g., air*

conditioning, domestic hot water, electric vehicle charging) at the same or better quality but lower cost. It does this by applying automatic control to reshape a customer's demand profile continuously in ways that either are invisible to or minimally affect the customer, and by leveraging more-granular rate structures that monetize demand flexibility's capability to reduce costs for both customers and the grid. Importantly, demand flexibility need not complicate or compromise customer experience. Technologies and business models exist today to shift load seamlessly while maintaining or even improving the quality, simplicity, choice, and value of energy services to customers.

The grid will need to become smarter to transition from being a centralized producer-controlled network to one that is less centralized and more consumer-interactive (DOE 2008). It will need to be self-healing—meaning that it will use digital components and real-time communications to continually monitor and tune grid characteristics (Amin 2015). This will require deploying and integrating new synchronized measurement technologies and sensors while incorporating system integrity protection schemes within its architecture (Amin 2015).

Achieving the smart grid supports the implementation of nuanced and effective demand-side management programs by the utility and implementation of more-informed measures by the consumer (ASHRAE 2018). Such programs and related services require devices that allow two-way communication between the utility or grid operator and the end user, including smart meters, information technology systems, building load and energy management systems, and smart end-user equipment or appliances (Lawrence et al. 2016). These smart grid features, achieved through modernizing and upgrading the existing grid infrastructure, will unleash dramatic changes in grid operation and markets. While cost estimates for improving the North American system are substantial—on the order of $400 billion over 20 years—a secure, resilient smart grid will reduce costs from outages, with savings estimated at $70 billion per year; provide sustainable jobs that pay well; and open the door to a broad range of services required across the grid (Amin 2015).

The deployment of information and communication technologies (ICTs) is key for the success of the smart grid and the building sector's ability to serve as a DER. ICT platforms will support internet-of-things (IoT) solutions—systems and devices capable of connecting with the physical environment and sharing data by connecting to the internet. Industry estimates project that the global number of devices managed by utility companies will grow from 485 million in 2013 to 1.53 billion in 2020 (Ericsson 2014). This promulgation will be spurred by the need to monitor the distribution grid to maintain its reliability and enabled by dramatic reduction in sensor costs. This transformation will impact the energy value chain for grid operators, utilities, energy service providers, and building owners. It will provide new business opportunities and retail competition. It will also provide value-add features for building owners and occupants from connected objects that provide convenience and comfort, and new data-driven services (Amin 2015).

It is envisioned that a more transactive energy ecosystem will evolve in stages, as indicated in Figure 4. The first phase of the transition is characterized by "self-optimization," which implies reducing the amount of energy needed from the grid through energy efficiency and onsite generation sources. This phase is followed by increased deployment of intelligent devices, which increases opportunities for automation (De Martini 2013). This initiates the customer "interconnection with the grid and new markets." Utilities can engage the customer DERs as "virtual power plants" to serve as active elements of the overall electric system to alleviate problems introduced by variable renewable energy supplies. At the local level, micro-grids will support "integration and balancing markets," allowing loads and DERs to be operated in a controlled, coordinated manner that may be grid-tied or islandable. Increased automation enables the implementation of agreed-upon transaction rules or smart contracts that make realizing projected demand reduction reliable. In addition, faster response times support new value streams for ancillary services that go beyond transacted energy.

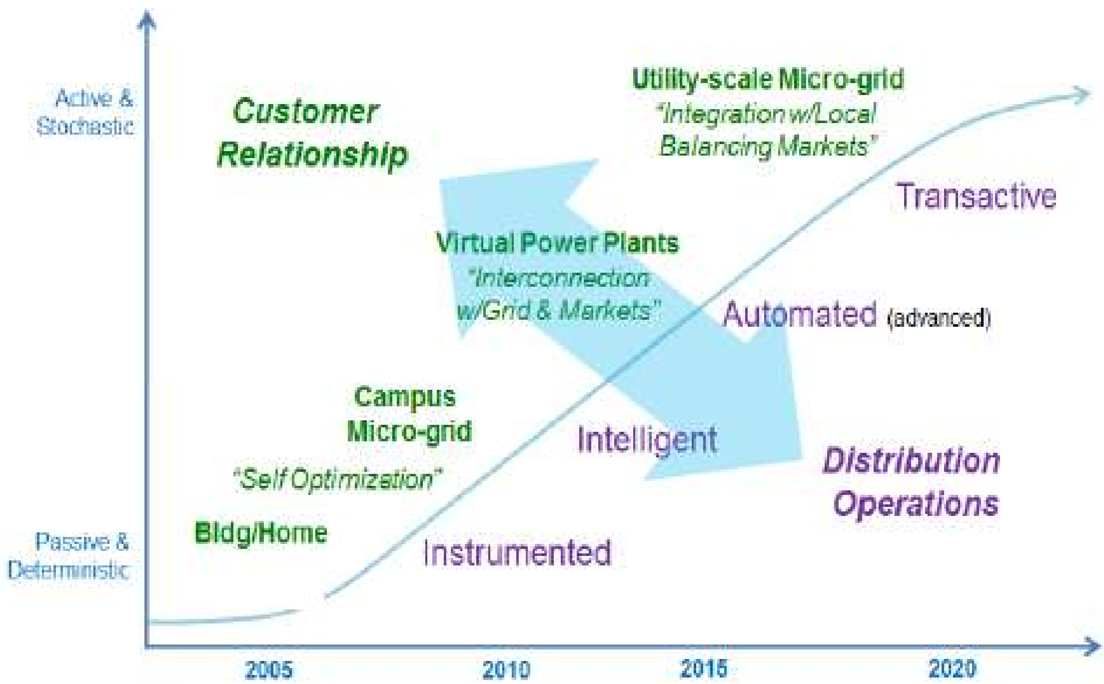

Figure 4. Stages of Adoption of Transactive Operation (De Martini 2013)

Figure 5 depicts the new grid services that buildings can provide with increasing responsiveness that results from better granularity of controls and increasing speed of automated communication (referred to as telemetry). Energy efficiency provides generally continuous service by decreasing electricity generation capacity requirements. Efficiency can be used to shape the electricity supply curve seasonally. DF measures operate across a range of timescales, depending on the end use and technology. Load shifting and shedding can impact daily behavior to mitigate supply source ramping and capture surplus renewables. Hourly responses can help manage supply contingency events[1] and support net load following. Fast DF (referred to as shimmying or modulation) occurring over minutes or seconds can support grid balancing to smooth short-term net load changes and support frequency regulation (Alstone et al. 2017).

[1] An unexpected failure or outage of a grid system component

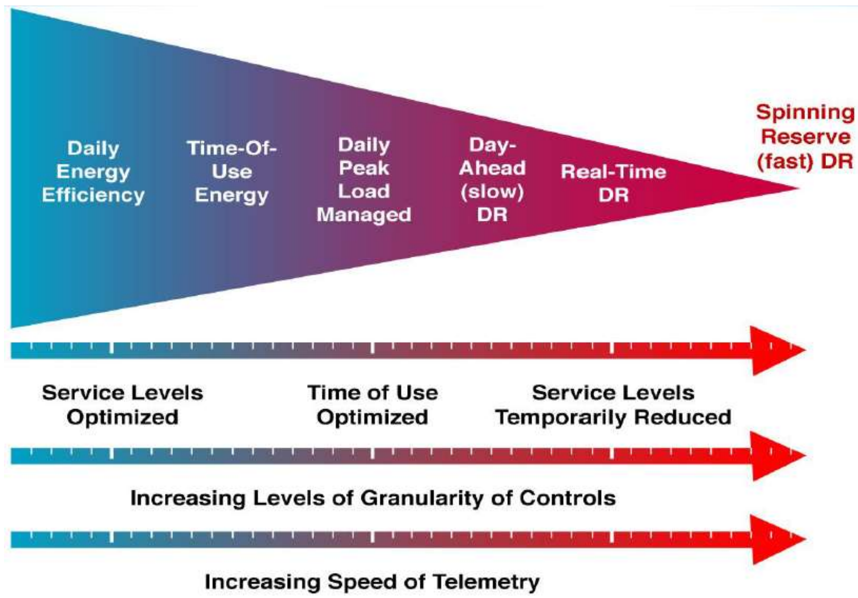

Figure 5. Realizing New Grid Services with Improved Building Responsiveness (Piette 2019)

The value of grid services is time-dependent and varies regionally and geographically. It is dependent on seasonal system peaks, coincidence factors, and diversity factors, which influence the time of peak and off-peak periods and the avoided costs associated with demand savings (Mims et al. 2017). Distribution system constraints can also impact the locational value of efficiency and the value of DR services. From a building owner perspective, DR value is linked to utility rates, DR program incentives, aggregator service contracts, and/or penalties for exceeding peak thresholds. Thus, an important consideration for building owner investments in flexible load technologies is their ability to deliver grid services and the associated local value.

PNNL research on the characteristics and qualities of transactive energy systems includes the valuation of the commodity. The work concludes that careful representation for valuation is required regarding 1) the operational objectives of individual grid services and 2) how systems will change behavior in response to value representation. PNNL estimated the potential value of engaging real-time flexible loads in residential and commercial buildings to provide grid services. The value refers to the cost to provide these services through alternative means today. It captures the utility infrastructure cost as well as the operational cost savings for buildings. Based on the analysis, the estimated building-sector load flexibility savings totals $22 billion per year and accounts for four value streams for grid services as described in Table 1 (Hammerstrom et al. 2016).

Table 1. Estimated National Value of Residential and Commercial Grid Services

Value Stream	Description	Residential ($B/yr)	Commercial ($B/yr)	Total ($B/yr)
Peak Capacity	Reduction of marginal construction costs due to displaced generation, transmission, and distribution capacity from peak load reduction	8.8	8.0	16.8
Wholesale Production	Displacement of wholesale energy costs by shifting flexible building loads	2.7	1.0	3.7
Regulation	Management of short-term imbalances between supply and demand than can cause system frequency to deviate from 60 Hz			0.3
Spinning Reserves	Connected capacity that can deliver energy in 10 minutes and run for at least 2 hours			1.2
			Total	22.1

A recently published DOE report establishes a roadmap for the national adoption of GEBs, which is a key strategy for enabling the affordability, reliability, and improved performance across the U.S. electric power system (DOE 2021). The report estimates their potential value to range between $100–200 billion in U.S. electric power system cost savings over the next two decades. The associated reduction in carbon dioxide (CO_2) emissions is estimated at 6% per year by 2030. DOE's national GEB vision is to triple energy efficiency and demand flexibility of the buildings sector by 2030 relative to 2020 levels. The report makes 14 recommendations for overcoming technical and market barriers, which form the 4 pillars of roadmap actions, namely: 1) advancing GEBs through research and development; 2) enhancing the value of GEB to consumers and utilities; 3) empowering GEB users, installers, and operators; and 4) supporting GEB deployment through Federal, state, and local policies and programs.

4.0 Overview of Industry Efforts Supporting GEBs

Future efforts to characterize, analyze, and demonstrate GEB technology cost effectiveness for consideration in energy codes will benefit from published research that demonstrates DF impact potential and its value to consumers. The DOE BTO currently funds several research activities related to the value proposition of GEB.[1] In addition, DF-related studies sponsored by the European Union (EU) are nearing completion, and new industry efforts supporting its standardization are gaining interest and gathering momentum. This section describes several key projects tackling topics of high relevance to code development that can be draw upon to inform DF measure characterization and impact assessment methods.

4.1 DOE BTO Research

BTO is supporting GEB research to investigate, integrate, and validate dynamic energy-efficient technologies, techniques, tools, and services for both existing and new residential and commercial buildings. BTO activities can be categorized in four focus areas (DOE 2020):

1. Value proposition for GEBs
2. Building technologies for flexible loads
3. Optimization of building systems and across buildings for flexible loads
4. Validation and verification of building performance for grid services.

It is anticipated that the projects addressing the value proposition for GEBs will provide metrics, analytical inputs, and new methods to help demonstrate the value of GEB measures for codes. Four examples of projects producing work products of interest in this area are described below.

End Use Load Shapes (NREL, LBNL, ANL)[2] – End use load profiles will be developed from U.S. building survey data and used in calibrated prototype building models to estimate energy efficiency / demand response (EE/DR) savings for GEB technologies. The end use and occupancy schedules used in the code prototype models can be informed by such end use load profiles that represent new buildings. The methods followed to customize the stock models based on measured energy use data could also be adopted by codes to improve regional, state, or county analysis. Ultimately, the stock models and code prototype models could merge into a universal set of models, although issues regarding EnergyPlus and OpenStudio capability and ongoing model maintenance need to be resolved.

Time-Sensitive Valuation (LBNL)[3] – This study documents the time-varying energy and demand impacts of efficiency measures in multiple geographic regions. While results are presented from the utility perspective, understanding the EE/DR relationship of measures and the variation regionally will provide insights for considering these measures in codes. It will also inform the need for better geographic resolution in prototype building simulation analysis for code development.

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[1] See the DOE Grid-Interactive Efficient Buildings webpage at https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings.

[2] Retrieved on July 14, 2021 from https://www.nrel.gov/buildings/end-use-load-profiles.html

[3] Retrieved on July 14, 2021 from https://emp.lbl.gov/projects/time-value-efficiency

Framework and Methodology to Define Flexible Loads in Buildings (LBNL)[1] – This project will create a framework and methodology that defines buildings' grid flexibility across end uses and location using a bottom-up approach. The insights gained can inform new code options addressing GEB measures, and potentially their qualitative and/or quantitative rating.

GEB Technical Reports (Navigant, NREL)[2] – A series of grid-interactive efficient building technical reports will describe flexibility opportunities of building loads by technology area (HVAC, lighting, envelope, sensors/controls/analytics) for grid services. The reports will provide information key for understanding the most promising GEB measures and associated controls to consider in codes.

Connected Lighting Systems Potential to Provide Grid Services (PNNL)[3] – This research will help increase the likelihood that emerging grid-connected products and integrated systems will result in energy savings, service improvements, and added value for owners and occupants. This work will help inform the development of code requirements that address effective new and needed features for interoperability and grid integration.

4.2 Smart Readiness Indicator for Buildings

The Energy Performance of Buildings Directive is published by the European Union Council to support EU resiliency targets achieving low- and no-emissions buildings by 2050. It includes the development of a smart readiness indicator (SRI) intended to accelerate investments of smart technologies in buildings. The 2018 SRI study report provides a definition of SRI, its methodological framework, and the definition of smart services (Verbeke et al. 2018).

The SRI is intended to raise awareness, motivate consumers, and support uptake of smart technologies. Its aim is to also improve policy linkages between energy, buildings, and ICT, which will better position the building sector to integrate with future energy systems and markets. To meet these goals, the SRI will measure three key readiness functionalities:

1. Adapting to the needs of the occupant
2. Facilitating maintenance and efficient operation
3. Adapting in response to signals from the energy grid.

The proposed methodology is a qualitative assessment based on an inventory of smart-ready services present in a building. The assessment procedure involves evaluation of the degree of smartness that each service can implement, referred to as the functionality level. The services are organized by domain (e.g., heating, cooling, lighting, electric car charging) and by impact (e.g., energy savings, load flexibility, improved comfort, etc.). Numerical points are assigned to each service at each functionality level. The overall SRI score is based on the ratio of the building score to the maximum sum of service points.

The SRI methodology is linked to a Smart Ready Services Catalogue that lists relevant building services and describes their main expected impacts. Many of the services are based on international technical standards (Verbeke et al. 2018). The catalogue includes 10 domains:

[1] Retrieved on July 14, 2021 from https://www.energy.gov/sites/prod/files/2019/05/f62/bto-peer-2019-grid-interactive-efficient-buildings-strategy.pdf
[2] Retrieved on July 14, 2021 from https://www.energy.gov/eere/buildings/downloads/bto-peer-review-2019-grid-interactive-efficient-buildings
[3] Retrieved on July 14, 2021 from https://www.energy.gov/eere/ssl/connected-lighting-systems

heating, cooling, service hot water, controlled ventilation, lighting, dynamic building envelope, onsite renewable energy systems, demand-side management, electric vehicle charging, and monitoring and control. The SRI methodology is flexible. It is intended to be used for building design and after occupancy. Weightings can be assigned to domains and impact criteria to reflect their importance to the overall aggregated impact score.

The Smart Ready Services Catalogue provides a starting point for characterizing DF measures and assigning owner benefits and grid services. It provides a framework for considering the smartness of controls across energy end-use services aligned with impact criteria. The information can be used to qualitatively inform the development of optional prescriptive requirements for codes. In addition, the SRI directive considers the ability to inspect implemented services. Inspections and actions to facilitate (e.g., labeling) are also of interest for demonstrating code compliance. Potentially, the catalogue scoring system could be adopted by codes or referenced as an approved external standard. Developing such an American National Standards Institute (ANSI) approved[1] standard could be helpful for advancing the GEB market. Once developed, it would be straightforward to reference in codes along with an associated requirement for a achieving building demand flexibility score. Alternatively, energy codes could specify individual demand flexibility measures.

4.3 GridOptimal

Launched in early 2018, the *GridOptimal* project is a collaboration between New Buildings Institute (NBI) and the U.S. Green Buildings Council with support from utilities and other organizations. The effort aims to develop strategies, metrics, and pilot projects to advance better integration of building demand flexibility with grid operation. Planned tools and resources to be developed as part of *GridOptimal* include a metric and rating tool, non-wires alternative application guide, utility program criteria, and model code criteria.

The activities planned for *GridOptimal* development include (NBI 2019):

- Bringing together key stakeholders and experts to develop standards and metrics
- Establishing a framework for the rating system
- Developing the rating system, which will reference existing standards
- Identifying pilot projects and participants
- Outlining incentive programs and financing mechanisms
- Providing educational guidance.

Initial concepts for the *GridOptimal* framework involve the definition of GEB technology categories important for ascertaining their ability to provide grid services and associated value. Identified attribute categories include static, flexible, and dispatchable. Service dimensions include capacity, duration, time of use, and response time. Additional features for indicating technology response characteristics include generation, storage, direct or indirect control, and contractual agreements. Measures or building features would be evaluated based on these interactions and associated impacts.

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[1] If a code or standard references an external document as a normative requirement, the document is typically required to be ANSI approved.

The creation of the rating system will be informed by building simulation performance modeling. The analysis inputs and outputs will help quantify metrics and their value in identifying opportunity, which will help prioritize needed input characterizations and design solutions. Through impact testing using building simulation analysis, a better understanding of the following is anticipated (NBI 2019):

- The need for metered-based performance analysis
- The building modeling software methodology
  - Characteristics of building load shapes
  - Variations in building load shapes by building type
  - Insights into asset-based ratings
- The utility-based data for each service territory
  - Critical constraints and opportunities
  - Prioritizing parameters and scenarios.

Recently, NBI and its contractor completed initial modeling studies to investigate how select GEB measures benefit load shifting in different parts of the country. The analysis assessed the impact of 11 measures in 5 package combinations for a medium office building in 3 locations. For the code-compliant office, the analysis determined the peak power reduction for the packages, with reductions ranging from 29% to 61% for Austin, TX; 26% to 57% for Burlington, VT; and 18% to 44% for San Francisco, CA (NBI 2019). The results indicate the potential value of GEB measures to reduce and shift load and address short-term grid constraints.

The *GridOptimal* work is well-aligned with the objectives for considering GEB measures in codes. The recognized requirements for standardizing input assumptions and modeling methodology are also highly relevant.

4.4 IEA Annex 67

The International Energy Agency (IEA) Energy in Buildings and Community Program is contributing Annex 67, Energy Flexibility in Buildings (Energy Flexibility), to the European Smart Buildings Initiative. The 5-year project, which concludes in 2019, has deliverables that address the energy flexibility standard definition, control strategies, documented business cases, and results from demonstrations.

Energy Flexibility recognizes three distinct capabilities: a building that can 1) manage itself, 2) interact with its users, and 3) take part in DR. The SRI framework, described above, evaluates these capabilities based on a qualitative approach. The Energy Flexibility methodology is based on quantitative and physical indicators. Its intention is to support design and operation decision-making in response to market signals for buildings and clusters of buildings (IEA 2017). A quantitative approach also recognizes that impact is not just about the technologies in a building. It depends on the way technologies are used, controlled, and interact with the energy network, the occupants, and climate conditions.

Energy Flexibility advocates for consistency in definitions and methodology for determination of metric and impact values in order to harmonize approaches and increase comparability in different studies. Figure 6 provides an example of Energy Flexibility metrics that can be easily communicated, interpreted, and derived in a standardized way to characterize the system. The graph indicates the building's response to a penalty signal (such as cost). The metrics identified include those related to the following:

- Capacity—the maximum response (∆), the amount of energy shifted (A), the rebound effect (B)
- Time—time elapsed after the signal until the response starts (τ), time elapsed from the response start to maximum response (α), duration of the response (β)
- Penalty signal—electrical cost.

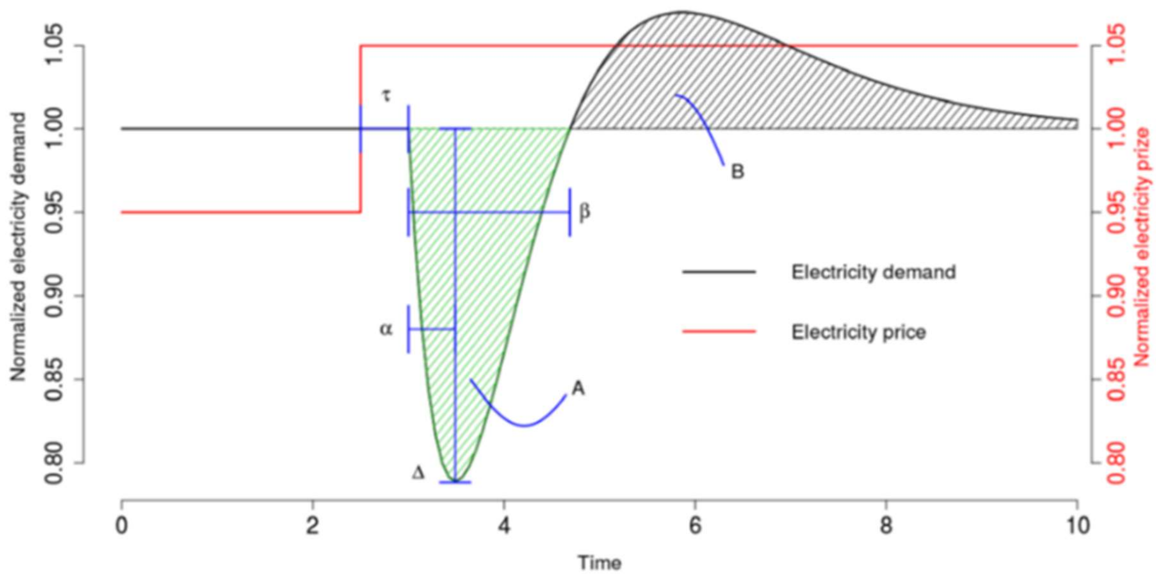

Figure 6. IEA Annex 67 Example of Energy Flexibility Metrics (IEA 2017)

In addition to the metrics characterized above, the study identifies several levels of metrics indicative of energy flexibility based on a review of recent publications. Some of these new key performance indicators, defined at the building level, include flexibility factor, self-consumption factor, self-generation factor, available structural storage capacity, storage efficiency, shifting efficiency, and power shifting efficiency.

The Energy Flexibility effort includes various research projects associated with analysis, development, and testing of energy flexibility in buildings. Specific tasks include the following:

- Simulation of energy flexibility in single buildings and clusters of buildings
- Applied control strategies and development of new strategies and algorithms
- Laboratory testing of components, systems, and algorithms
- Investigation of barriers and motivation of users based on case studies.

The Energy Flexibility research into available and needed control strategies is highly relevant for code development. For example, information about effective strategies and their supporting software and hardware requirements for deploying load flexibility can inform code provisions that specify control requirements and system operation. In addition, exploring the range of simulation modeling approaches and their associated strengths and weaknesses can inform methods applied in modeling GEB measures for code development.

4.5 Measures Supporting GEB

Demand flexibility is defined as the capability provided by DERs to reduce, shed, shift, modulate or generate electricity. Energy flexibility and load flexibility are often used interchangeably with demand flexibility (DOE 2021). A key task for addressing GEB capabilities with energy codes is to develop an inventory of DF measures for potential consideration in code development. The inventory can include qualitative and quantitative characterizations of DF measure impact based on potential market value, published research, or performance analysis. A high-level review of DF measures, which were captured from a sample of research studies, is provided below to introduce the topic.

Assessing DF measures and their associated operating strategies involves considering the coordinated, simultaneous operation of distributed energy generation, flexible building loads, and energy storage. Their interaction and impact on the building load shape are depicted in Figure 7. As indicated in the figure, energy efficiency measures lower the overall building load shape, which can reduce peak loads, flatten the load curve, and decrease the building load factor. Energy storage (including thermal, chemical, and electric vehicle) and load-shifting measures can change the building peak to be non-coincident with the electricity system peak or to coincide with peak renewable energy generation. Such dynamic measures can be deployed with automated demand response (ADR) in reaction to a DR event, utility price signal, energy use threshold, or utility time-of-use rate price increase.

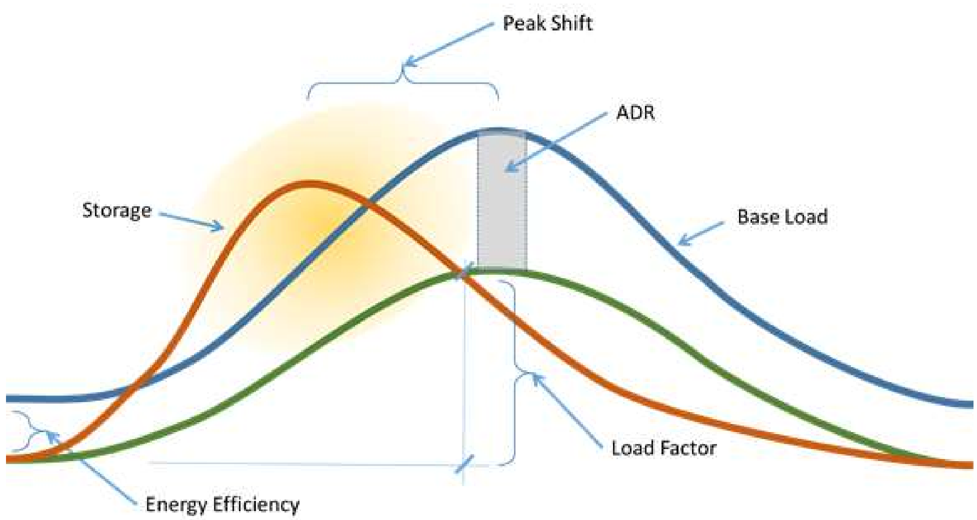

Figure 7. GEB Measures Impact on Building Electric Load Shape (Graphic Courtesy of NBI)

A 2017 PNNL study indicates the savings potential associated with control measures for reducing energy and peak demand in commercial buildings (Fernandez et al. 2017). The study simulated sensor and controls measures in 9 commercial prototype buildings in 16 climates and extended the savings to represent 51% of the total U.S. commercial building stock consuming 57% of the commercial energy. Of the 37 control measures evaluated, 9 were each capable of reducing peak demand by 3% in at least one building type and 4 achieved over 10% savings. Figure 8 presents the demand savings for six individual DF measures and two packages of measures during critical peak pricing events. The reactive package can be implemented immediately upon initiation of the critical peak pricing event. The predictive package can prepare for the event by pre-cooling the building's interior spaces and thermal mass in advance. Applying each DF package across all building types and climates resulted in ~19% peak demand reduction. In addition, the study estimated the energy savings resulting from the 37 control measures applied across buildings and climates to total 1.32 quads of site energy or 2.74 quads of primary energy (Fernandez et al. 2017). Therefore, IoT technologies that benefit load shedding and shifting can also result in significant reduction in overall energy use when also supporting automated fault detection and diagnosis.

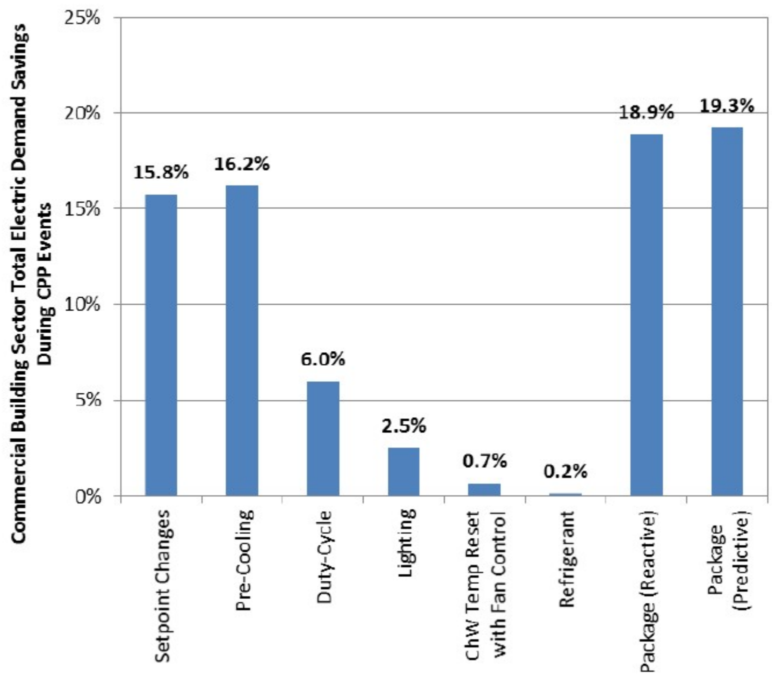

Figure 8. Aggregate National Savings for Demand Flexibility Measures and Packages (Fernandez et al. 2017)

A 2017 Lawrence Berkeley National Laboratory (LBNL) study evaluated the 2025 California automated DR potential (Alstone et al. 2017). The evaluation focused on two existing DF products (load shifting and load shedding) and two products designed to meet future needs (bi-directional load shifting and fast bi-directional load shifting for ancillary services). The measures modeled in the residential and commercial sectors are presented in Table 2.

Table 2. California DR Potential Study: End Uses and DF Measures

Sector	End use	DF Measures
All	Battery-electric and plug-in hybrid vehicles	Level 1 and level 2 charging interruption
	Behind-the-meter batteries	Automated DR
Residential	Air conditioning	Direct load control and smart communicating thermostats
	Pool pumps	Direct load control
Commercial	HVAC	Depending on size – energy management system automated DR, direct load control, and/or smart thermostats
	Lighting	A range of luminaire level, zonal, and standard control options
	Refrigerated warehouse	Automated DR

5.0 GEB Considerations in Current Codes

The GEB research topics and DF-related industry applications described in Section 4.0 establish the latest thinking on GEBs. In this section, we consider how these efforts can inform the incorporation of GEB provisions in codes, as well as the opportunities and challenges to do so. Specifically, the inclusion of GEBs in codes requires several important GEB attributes (DOE 2019) to be addressed, namely the following:

- Energy efficiency
- Smart and connected—with advanced controls, sensors, and communication technologies
- Self-diagnosing for improved operation
- Optimized to manage and integrate multiple flexibility measures and distributed energy resources.

A review of current model code and advanced code requirements was conducted to evaluate the present status of such GEB considerations in codes.

5.1 Model Energy Codes

The U.S. model codes are the 2021 IECC (ICC 2021) for residential buildings and ASHRAE Standard 90.1-2019 (ASHRAE 2019) for commercial buildings.[1] Traditionally, model code requirements target energy conservation. Yet model code requirements also include automated controls that support improved equipment integration, part-load performance, and overall efficient operation. However, model codes do not currently include prescriptive measures that involve grid-connected communication or controls for demand flexibility, or requirements for onsite renewable energy systems. To address these limitations, current automated control requirements can be expanded to include grid interaction and DR. The code sections that include requirements for automated control are described below to highlight these opportunities.

As indicated in **Error! Reference source not found.**, the 2021 IECC Residential (IECC-R) does not include any prescriptive compliance measures that address demand flexibility or onsite renewable energy systems. There are four mentions of active controls or timers. For performance-based compliance, the Energy Rating Index (ERI) path is available, which provides compliance flexibility by allowing some prescriptive requirement trade-offs. The ERI method does not consider onsite power production from renewables. While the original method does consider energy from electric vehicle (EV) charging, it is excluded in the IECC-R application, which occludes adding EV charging controls.

[1] The 2021 IECC commercial provisions include a compliance option that references ASHRAE 90.1-2019.

Table 3. Automated Controls and Renewable Energy Considerations Addressed in IECC 2021 Residential

Category	Code Section	GEB-Related Requirement	Section Summary
Envelope-Prescriptive Requirement	R402.3.2	Dynamic glazing	Provides an exception to the prescriptive glazing U-factor requirements allowing the use of dynamic glazing. *Note that there are no requirements connecting this element to any communications or control provisions.*
Systems-Prescriptive Requirement	R403.1.1	Programmable thermostat	Requires HVAC thermostats to be capable of controlling space temperature between 55 and 85 °F and have the ability to schedule settings by day and time of day. *Note that there are no requirements connecting this element to any communications or control provisions.*
Systems-Prescriptive Requirement	R403.2	Boiler temperature reset	Requires hot water boilers to be capable of automatically adjusting water temperature supplied in response to a change in heat load accomplished by outdoor reset, indoor reset, or water temperature sensing. *Note that there are no requirements connecting this element to any communications or control provisions.*
Systems-Prescriptive Requirement	R403.8	Systems serving multiple dwelling units	Provides that systems serving more than one dwelling unit comply with commercial provisions in Section C403 and C404 of the IECC. Hence, *any GEB-related provisions in those sections would apply.*
Systems-Prescriptive Requirement	R403.10.2	Time switches	Provides that pool heaters and pump motors be controlled by switches with preset schedules. *Note that there are no requirements connecting this element to any communications or control provisions.*
Performance-Based Compliance	R406.3	Energy Rating Index and EV controls	Allows compliance by means of an Energy Rating Index defined similarly to RESNET's Home Energy Rating system (RESNET/ICC 301) but excluding consideration of energy for EV charging. *Hence, the ERI path as currently designed would not be amendable to inclusion of EV charging controls.*
Performance-Based Compliance	R406.4	Energy Rating Index and onsite renewable energy	Specifies ERI thresholds by climate zone. Where onsite renewable energy (generation) is included in the ERI calculation, the home is required to meet the IECC's mandatory provisions and the building thermal envelope provisions of the 2015 IECC. *The footnote holding this provision is the only place in the code that mentions onsite generation.*
Optional appendices	RB	Solar Ready	Includes solar-ready specifications to provide pathways for connections and adequate structural capacity of roof systems to accommodate solar systems.
Optional appendices	RC	Zero Energy Residential Building	Provides requirements intended to result in net zero energy consumption over the course of a year; replaces section R401.2. It sets a ERI zero energy target as well as a maximum ERI index without renewable energy offsets included.

As noted in Table 3, two new appendices included in the 2021 IECC-R address requirements for low-energy buildings. Appendix RB lists solar-ready provisions for non-shaded buildings without a permanently installed onsite renewable energy system. Appendix RC Zero Energy Residential provides a net zero energy code option and is based on the ERI compliance path found in Section R406 of the standard. It sets an ERI value aligned with a highly efficient performance level. The remaining energy use is offset by renewable energy production.

GEB-related provisions and potential leverage points for including grid-interactive controls in ASHRAE Standard 90.1-2019 (which includes all building types except for low-rise residential) are summarized in **Error! Reference source not found.**. The list includes an efficiency requirement for grid-connected service hot-water heaters and current provisions for active controls related to HVAC, lighting, power, service water heating, and elevators. Requirements for whole building metering are also specified. The list is extensive. Thus, adding automated DR requirements as an incremental capability may be feasible at nominal cost for many components and systems with active controls already regulated in current code.

Table 4. Automated Controls in ASHRAE Standard 90.1-2019

System	Subsection Label	Requirement Type	GEB-Related and Active Control Requirements
HVAC	6.4.3.3.2	Mandatory	Thermostat setback
	6.4.3.3.3	Mandatory	Optimal start controls
	6.4.3.3.5	Mandatory	Guestroom thermostat and ventilation control
	6.4.3.4.2	Mandatory	Unoccupied space damper control
	6.4.3.4.5	Mandatory	Parking garage fan controls
	6.4.3.5	Mandatory	Heat pump supplementary heat control
	6.4.3.7	Mandatory	Snow and ice-melting system control
	6.4.3.8	Mandatory	Demand control ventilation
	6.4.3.8	Mandatory	Adjustable airflow control
	6.4.3.9	Mandatory	Vestibule heating controls
	6.4.3.12	Mandatory	DX economizer fault detection
	6.5.1.1.3	Prescriptive	Economizer high-limit shutoff control
	6.5.2.1	Prescriptive	Thermostatic zone control
	6.5.2.1, 6.5.2.2	Prescriptive	Air and water distribution system control
	6.5.2.4.1	Prescriptive	Humidity system control
	6.5.3.2.1	Prescriptive	Low cooling/ventilation load fan control
	6.5.3.3	Prescriptive	Dynamic ventilation reset for MZ systems
	6.5.3.5	Prescriptive	MZ HVAC system supply air temperature reset
	6.5.3.8	Prescriptive	Ventilation control for occupied-standby mode
	6.5.4.3.1	Prescriptive	Multiple chiller flow reduction
	6.5.4.3.2	Prescriptive	Multiple boiler flow reduction
	6.5.4.5.1	Prescriptive	WSHP two-position valve
	6.5.5.2.1	Prescriptive	Cooling tower variable speed control
	6.5.8.1	Prescriptive	Outdoor radiant heating

System	Subsection Label	Requirement Type	GEB-Related and Active Control Requirements
	6.5.10	Prescriptive	Open door mechanical system disable
SWH	7.4.2 and Table F-2	Mandatory	Efficiency requirements for grid-enabled water heaters
Lighting	9.4.1.1e, 9.4.1.1f	Mandatory	Daylighting control
	9.4.1.1g, 9.4.1.1h	Mandatory	Occupancy sensor control
	9.4.1.1i	Mandatory	Automatic time switch control
	9.4.1.1j	Mandatory	Shutoff during non-business hours
	9.4.1.3a	Mandatory	Display lighting control
	9.4.1.3b	Mandatory	Guestroom lighting control
	9.4.1.3c	Mandatory	Task lighting control
	9.4.1.4	Mandatory	Exterior lighting control
Power	8.4.3.1	Mandatory	Building electrical sub-metering
	8.4.2	Mandatory	Plug load controls
Other	10.4.2	Mandatory	SWH pressure boosting pumps
	10.4.5.1	Mandatory	Whole building metering
	10.4.3.3	Mandatory	Elevators standby mode

An addendum that includes GEB measures has been proposed to ASHRAE 90.1-2019. Addendum AP includes additional efficiency requirements. Its objective is to increase building performance requirements while providing flexibility to building owners and designers to meet the requirements. Efficiency credit targets are specified by climate zone for different building occupancy categories. The targets are achieved by incorporating sufficient measures, each with assigned point values. One of the categories of measures is load management, which includes requirements for connected communication and seven strategies that support demand flexibility.

The point system approach, which also includes an onsite renewable energy generation option, indicates increasing levels of performance while providing flexibility in the choice of technologies that best serve the project attributes. Also, not all point-system measures or packages need to demonstrate cost effectiveness since multiple options are available. Thus, this code section can readily accommodate new GEB technologies, DR controls, and interoperability requirements in the future.

The framework is similar to Section C406 included in the 2021 IECC-C (ICC 2021), but it does not include load management measures. However, since it references ASHRAE 90.1, it is anticipated that these measures will be included in the next IECC code cycle. The 2021 IECC-C code provides code language for zero energy commercial building through optional appendix CC. The option requires performance-based designs to offset building energy use with renewable energy production offsets. The building energy use intensity is specified by building type and climate zone in a look-up table. Renewable offsets can be provided from onsite or off-site production. Off-site production is derated based on a procurement factor, which varies based on type of off-site procurement (e.g., community solar, green retail tariff, unbundled renewable energy credits).

5.2 Advanced Codes

To assess the current status of grid-interactive and distributed energy resource requirements in advanced energy codes, two sets of codes were reviewed, compared, and summarized, namely: California Title 24 2019 Part 6 and the 2018 International Green Conservation Code (2018 IgCC) (ICC 2018). GEB considerations in the Title 24 2019 residential code are described in **Error! Reference source not found.**. GEB considerations in the Title 24 2019 and the IgCC 2018 commercial codes are described in **Error! Reference source not found.**. It is worth noting that the IgCC is powered by ASHRAE Standard 189.1 (i.e., the 2018 IgCC references ASHRAE Standard.189.1-2017). In addition, ASHRAE Standard 189.1 is an overlay on Standard 90.1 (e.g., 189.1-2017 references 90.1-2016). Thus, every mandatory GEB-related requirement found in 90.1 will be adopted in the 189.1 release that follows 2 years later.

Table 5. Title 24 2019 GEB Measures for Low-Rise Residential Buildings

GEB Measure	Subsection Label	Requirement Type	Overview
Demand responsive controls: protocols	110.12.a	Mandatory	All low-rise residential demand responsive controls shall be certified as either OpenADR Virtual End Node (VEN) or as being capable of responding automatically to a DR signal from a certified OpenADR VEN.
Energy Efficiency and PV/Demand Flexibility Design	150.1.b.1	Performance Compliance	For new constructions following a performance compliance approach, the design shall separately comply with the Energy Efficiency Design Rating (EDR) and the Total Energy Design Rating (TDR). The TDR is the EDR minus the PV/flexibility design rating, which captures the PV system, battery storage system, precooling strategy, and other demand responsive measures.
Solar ready buildings: solar zone	110.10.b.1.A	Mandatory	Residences without PV system installed shall have a have a minimum 250 ft^2 solar zone on the roof
	110.10.b.1.B	Mandatory	Exceptions to solar zone include: solar thermal existence, DR thermostats, complying with additional measures including EnergyStar dishwasher and refrigerator, whole house fan or Type 2 EV charger, DR home automation system, grey water system, or rainwater catchment.
Solar water heating for multiple dwelling units	150.1.c.8.B.iii	Prescriptive	Solar water heating systems must be installed in low-rise residential buildings with multiple dwelling units.
Community shared solar electric generation system or battery storage system	150.1.b.1	Performance Compliance	Performance Standards—community shared solar electric generation or battery storage systems serve as an alternate compliance option to partially or totally meet onsite solar electric generation and/or battery storage requirements required by Section 150.1(b)1.

GEB Measure	Subsection Label	Requirement Type	Overview
Solar ready buildings: interconnection pathways	110.10.c	Mandatory	Construction documents shall indicate the location reserved for inverters and metering equipment and a pathway reserved for the electrical inter-connection. Single-family with central water heating will have a pathway indicated for solar zone plumbing.
Solar ready buildings: documentation	110.10.d	Mandatory	Documentation indicating the information for solar ready area, reserved space, and interconnection pathway shall be provided.
Solar ready buildings: electrical panel	110.10.e	Mandatory	Single-family residences without PV installed shall have electric service of 200 amps and reserved space for a double-pole circuit breaker designated for future solar electric installation.

Table 6. Title 24 2019 and IgCC 2018 GEB Measures for Non-Residential, High Rise Residential, Hotel, and Motel Buildings

GEB Measure	Code	Subsection Label	Requirement Type	Overview
		Building		
Demand responsive controls: protocols	Title-24 2019	110.12.a	Mandatory	For all buildings, except for healthcare, demand responsive controls shall be certified as either OpenADR Virtual End Node (VEN) or as being capable of responding automatically to a DR signal from a certified OpenADR VEN.
Energy use measurement	IgCC 2018	1001.3.2 (10.3.2)	Mandatory	The building operation plan shall specify procedures needed to comply with requirements outlined for initial measurement & verification (M&V), track and assess energy consumption, track energy performance, assess energy performance, and document energy performance.
Energy use measurement with remote communication capability	IgCC 2018	701.3.3 (7.3.3)	Mandatory	Measurement devices with remote communication capability to the data acquisition system shall be provided to collect and report energy consumption data for each energy supply source and subsystems that exceed the specified thresholds.
Solar ready buildings: production requirement	IgCC 2018	701.4.1.1 (7.4.1.1)	Prescriptive	Building projects shall contain onsite renewable energy systems that provide not less than 6.0 kBtu/ft^2 (20 kWh/m^2) for single-story buildings and 10.0 kBtu/ft^2 (32 kWh/m^2) x the gross roof area for all other buildings.
		701.4.1.1.2 (7.4.1.1.2)	Prescriptive	Onsite renewable energy production requirements are reduced by ~30% for building projects that comply with additional equipment, SWH, and ENERGYSTAR® efficiency requirements.
Solar ready buildings: solar zone	IgCC 2018	701.3.2 (7.3.2)	Mandatory	Infrastructure must be allocated for renewable energy systems to produce the annual energy production requirements specified.
	Title-24 2019	110.10.b	Mandatory	Solar zone area space allocation exceptions apply including for low-rise and high-rise multifamily buildings with DR thermostats.
				Nonresidential buildings excluding healthcare, hotel/motel, and high-rise multifamily buildings without PV system installed shall have a have a total solar ready area no less than 15% of the total roof area.

GEB Measure	Code	Subsection Label	Requirement Type	Overview
Solar ready buildings: interconnection pathways	IgCC 2018	701.3.2 (7.3.2)	Mandatory	Space must be allocated for renewable energy systems to produce the annual energy production requirements specified based for the building.
	Title-24 2019	110.10.c	Mandatory	Low-rise residential, hotel/motel, and high-rise multifamily buildings with 10 stories or fewer, or nonresidential buildings of 3 stories or fewer without PV system installed shall have a have a total area no less than 15% of the total roof area.
Solar ready buildings: documentation	Title-24 2019	110.10.d	Mandatory	Documentation indicating the information for solar ready area, reserved space, and interconnection pathway shall be provided.
Electric-vehicle charging infrastructure	IgCC 2018	501.3.7.3.b	Mandatory	For buildings with greater than 100 occupants, install 2 or more electric-vehicle charging stations.
Power				
Electric power metering	Title-24 2019	130.5.a	Mandatory	Table 130.5-A specifies the minimum requirements for permanent metering of electrical service or feeder.
Electric power separation	Title-24 2019	130.5.b	Mandatory	Electric power distribution system requirements for separation of electrical circuits by end use for electrical energy monitoring.
Electric power circuit controls for receptables	Title-24 2019	130.5.d	Mandatory	Both controlled and uncontrolled 120-volt receptacles shall be provided in office areas, lobbies, conference rooms, kitchen areas in office spaces, copy rooms, and hotel/motel guest rooms.
HVAC				
Demand responsive controls: HVAC	IgCC 2018	701.3.4.1 (7.3.4.1) 701.3.4.2 (7.3.4.2)	Mandatory	The building controls shall be designed with automated DR infrastructure capable of automatically implementing load adjustments to the HVAC (system zone set points and VSD equipment).
		701.4.3.4 (7.4.3.4)	Prescriptive	Exceptions to economizer requirements include choosing the renewable approach and meeting additional cooling equipment efficiency requirements.
		Table B101.4 (table B-4, footnote b)	Prescriptive	Room air conditioners connected to utility programs are allowed a lower Combined Energy Efficiency Ratio (CEER) value if in compliance with and certified per EnergyStar version 4.0 for connected equipment.
	Title-24 2019	110.12.b	Mandatory	HVAC systems with direct digital control to the zone level shall be programmed to allow centralized demand shed for non-critical

GEB Measure	Code	Subsection Label	Requirement Type	Overview
				zones to remotely adjust setpoint temperatures for automatic demand shed control.
		141.0.b.2.E.i	Prescriptive	For renovation projects, all newly installed HVAC systems require demand responsive thermostats.
SHW				
Demand responsive controls: SWH	IgCC 2018	Table B101.8 (TableB-8)	Prescriptive	The uniform energy factors (UEFs) listed for electric-resistance grid-enabled water heaters supersede ASHRAE Standard 90.1 that mandates heat-pump water heaters for >75 gal storage.
Service hot water energy supply	Title-24 2019	110.3.c.5	Mandatory	New state buildings shall derive their service water heating from a system that provides at least 60% of the energy needed from site solar or recovered energy.
Lighting				
Demand responsive controls: lighting	IgCC 2018	701.3.4.3 (7.3.4.3)	Mandatory	The building controls shall be designed with automated DR infrastructure capable of automatically implementing load adjustments to a centrally controlled lighting systems, excluding daylight-controlled areas.
	Title-24 2019	110.12.c	Mandatory	For nonresidential buildings >10,000 ft^2, lighting controls shall be capable of automatically reducing lighting by a minimum of 15% relative to installed lighting power in response to a DR signal.
		110.12.d	Mandatory	Controls for an electronic messaging center with power >15 kW shall be capable of reducing lighting power by a minimum of 30% when receiving a DR signal.
		140.6.a.2.k	Prescriptive	For buildings less than 10,000 ft^2 meeting DR control requirements, lighting wattage qualify for a power density adjustment factor equaling 0.05 for DR control per Table 140.6-A.
Lighting control interactions, including DR, requirements	Title-24 2019	130.1.f	Mandatory	Multi-level lighting control shall permit demand responsive controls to adjust lighting during a DR event and return it to level set by multilevel control after the event.

It is worth noting that the performance approach in the 2018 IgCC (and ASHRAE 189.1-2017) includes two separate performance metrics—one based on annual energy costs and one for annual carbon emissions. The performance cost index (PCI) target is defined similarly to that described in Appendix G of ASHRAE Standard 90.1-2016. However, the credit for renewable energy is based on costs after adjustment for production offset determined on an hourly basis. Also, the Building Performance Factor used in the calculation is lower than for ASHRAE 90.1, which increases the 189.1 performance requirements. In addition, the IgCC requires that the proposed design PCI, without consideration of renewables, exceed the requirements of the ASHRAE 90.1 baseline PCI. The second performance-path compliance requires that the carbon dioxide equivalent (CO_2e)[1] determined for the proposed-building annual energy use be equal to or less than that of the baseline building. The carbon equivalent value is determined based on predicted energy consumption and CO_2e emission factors specified by energy source.

As indicated in the tables, some key GEB considerations that are required in the advanced code but not in the current model code include the following:

- Adherence of DR controls to the OpenADR (OpenADR 2012) communication protocols (Title 24-R, Title-24-C)
- Demand responsive (DR) thermostats (Title 24-C)
- DR lighting controls (Title 24-C)
- DR HVAC controls (Title 24-C, IgCC)
- Prescriptive requirement for onsite renewable energy systems (Title 24-R, IgCC)
- Solar-ready requirements for buildings that do not install PV systems (IgCC, Title 24-R)
- Electric vehicle charging requirements (IgCC).

[1] A carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases on the basis of their global warming potential expressed in terms of the equivalent amount of carbon dioxide with the same global warming

6.0 GEB Considerations in Future Code Development

The approach taken to incorporate GEB considerations in energy code can reflect agreed-upon strategies to achieve intended objectives. Based on the defining attributes of GEBs and approaches being applied by research and industry to achieve a clean, resilient grid (Verbeke et al. 2018; IEA 2017, GridWise Architecture Council 2015; Mims et al. 2017; Eley et al. 2011), the following strategies should be considered in future code development:

1. Maintain a baseline efficiency that reflects cost-effective measures.
2. Address demand flexibility and PV self-utilization.
3. Move towards a clean energy emissions metric.
4. Account for the time-sensitive-value of efficiency, demand flexibility, and onsite renewable energy generation.
5. Consider ancillary grid services, such as short-term ramping and frequency regulation.

This study recognizes the implementation of these strategies will require overcoming challenges stemming from the traditional focus on energy efficiency in code development. For example, increases in efficiency achieved in past code cycles have been justified by trading off increases in first costs for long-term utility bill savings. Yet due to the nascent state of grid-modernization efforts, the market for demand flexibility and grid services is just emerging. In addition, there is a wide range of utility electricity rates and demand prices offered across the United States, which results in variations in customer motivation for load management and GEB technology cost effectiveness.

Regardless of current market signals, the need remains for a clean grid, as well as the incorporation of GEB technologies in buildings. Until strong market signals exist, GEB requirements may need to be regarded similarly to life-safety code requirements, where relaxed cost effectiveness criteria can be justified and tied to the greater societal good. Energy codes offer an important policy lever and can play a key role in obtaining these objectives. However, to do so effectively, questions need to be answered concerning the determination of GEB impact and its valuation in code development. Specifically, how much load reduction and grid services can DF technologies provide? What are the associated control, communication, and transactional requirements? What is the locational value of GEB services? Can the value be recognized within the current code development process? If not, how can the process evolve to improve its valuation?

Code development is an applied and not fundamental research program. Thus, answers to these questions and supporting methods will evolve alongside topical GEB research investigating its impact and quantifying grid value. In the short-term, broad assessments and existing code mechanisms can be utilized. For example, lower cost demand flexibility measures can be considered, including the specification of communication protocol requirements and dynamic equipment controls for GEB-relevant technologies already addressed in energy codes and standards. Additional ideas and needs for considering GEBs in codes are discussed in more detail in the following subsections.

6.1 A Path Forward

In order to consider GEB technologies and strategies in energy codes, the value of demand flexibility measures needs to be recognized. To support this, the code development process must incorporate new approaches that account for the value of building efficiency and load flexibility in a more granular way. This warrants modifying code scope and the economic assessments that underlie code change proposals. More details describing approaches for establishing DF value and its reflection in energy codes are presented in Appendix A. Overall recommendations considering GEBs in codes include the following.

1. Expansion of the scope of energy codes and standards to capture interactions of buildings and their energy sources
2. Identification and characterization of DF measures based on their ability to provide various grid services, potentially based on an ANSI standard that provides a classification schema
3. Reflection of geographic variations in the value of efficiency and load flexibility measures
4. Incorporation of analytical methods that can assess DF measure value based on considerations 2 and 3 above and the acceptance of the methods by the code development bodies.

The GEB market is still nascent and exploring options now for incorporating GEB technologies will help reduce lost opportunities in the future. In the near term, national model energy codes can feature new prescriptive DF measures demonstrated to be cost effective following current code development methodologies. Requirements already in code that address GEB-relevant technologies (e.g., service water heating, lighting, and HVAC) can be expanded to include demand responsive control and communication capabilities. In addition, optional DF measures that are more costly can be introduced to serve early-adopter jurisdictions. In the future as the market transforms and providers serving the smart grid emerge, the market value for demand flexibility measures will increase. And as the GEB field matures, DF measure impact can be substantiated with measured data, which will also help build confidence in their effectiveness and inform methods for making performance predictions.

In recognition of the current status of the GEB market and in anticipation of it maturation over the next decade, a proposed progression for incorporating DF measures in codes over time is outlined below.

1. Establish requirements for GEB readiness to ensure the supporting infrastructure, communication protocol, and centralized control capabilities are in place as needed to support building automated DR.
2. Supplement existing requirements for GEB-relevant appliances and equipment to include DR capabilities.
3. Include new prescriptive requirements for cost-effective DF measures.
4. Utilize code mechanisms[1] that offer flexibility in meeting requirements for DF capabilities.
5. Specify the most valuable and foundational DF measures as mandatory requirements.
6. Incorporate DF metrics as part of the performance-compliance path.
   d. Require projects to adhere to nominal requirements for demand flexibility.

[1] Such as the IECC commercial code, section *C406 Additional Efficiency Measures* (IECC 2018),

e. Include standardized methods for quantifying the impact of DF measures in simplified hourly performance analysis tools, such as the Total System Performance Ratio (Jonlin et al. 2018).

f. Expand modeling guidelines (e.g., ASHRAE 90.1 Appendix G) to provide standardized methods for simulating GEBs for performance compliance.

The staged progression outlined above will require new, more sophisticated performance analysis methods be applied in support of code development. The new methods can be incorporated into the PNNL code prototype modeling framework and other analytical tools that support code advancement. It is envisioned that assessments supporting GEBs in codes will bring into play a range of options for qualitatively and quantitatively assessing GEB value. Such approaches are described below:

1. A GEB rating based on a qualitative assessment developed from engineering judgement
2. A GEB rating based on a quasi-quantitative assessment informed by GEB measure characterization and limited prototype modeling
3. A GEB performance assessment conducted using PNNL prototype building model simulation analysis and “rules” that dictate GEB technology and building operation in response to critical peak pricing
4. A GEB performance assessment conducted using enhanced PNNL prototype building simulation operational optimization analysis to represent supervisory control
5. The development of code development guidelines and user tools to support performing standardized DF impact analysis that accounts for regional variations in demand flexibility value.

6.2 Next Steps

The path forward for considering GEBs in energy codes will require getting stakeholder agreement on the underlying strategies to be incorporated into future code. Supporting efforts can address current challenges for effectively valuing DF measures in the code development process. GEB-in-codes activities can roll out as a staged progression that initially addresses DF measures deemed to be cost effective today. Increased emphasis of GEBs in energy code will evolve as the market matures. The progression can be aided by GEB performance assessment studies that account for the time-sensitive value and regional variations in DF measure value.

Based on these considerations and additional insights gained from this study, recommendations for progressively addressing GEB capabilities in energy codes include the following.

- Expand the scope of model energy codes and standards to cover the effective interaction of buildings with their sources of energy.
- Identify the most promising and impactful DF measures:
  - Review market-ready and near-market-ready GEB technologies for residential and commercial buildings.
  - Use published research and supporting data to characterize the needs of the future grid and the value of services provided by GEB measures.
  - Qualitatively characterize GEB measures to indicate their relative impact and ability to provide various grid services.

- Consider new approaches for performing cost-effectiveness analysis for code development in order to better assess the value of DF.
- Expand current methods used to inform code development to include demand flexibility considerations
  - Develop/expand the residential/commercial energy code roadmaps to include GEB considerations.
  - Prioritize measures to analyze based on their anticipated value and ease of implementation.
  - Leverage existing and investigate new compliance mechanisms that support including GEB capabilities and DF measures in national model codes.
  - Utilize the PNNL code prototypes modeling capabilities and other analytical tools to inform new GEB-related requirements.

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Appendix A – GEBs in Energy Codes: Approaches and Resources

Table A-1. Approaches and Resources for Considering GEB Measures in Codes

Item	Issue	Description	Potential Approach	Related BTO Research	Additional Resources
1	Demonstrating cost effectiveness	General	- Consider the time-sensitive value of efficiency and DF - Consider the societal value of DF measures - Include demand flexibility and other GEB-related measures through optional compliance mechanisms	- National GEB potential (LBNL, NREL) -Portfolio Analysis Across Commercial Buildings (various) - Impact of DR on Building EE Metrics (SLAC) -Virtual Batteries (PNNL) -Framework and Methodology to Define Flexible Loads in Buildings (LBNL)	-IECC Standard 2018 (Commercial) Section C406 -ASHRAE 90.1-2019 Addendum AP -2021 WA state energy code
2	Demonstrating cost effectiveness	Flat national utility rate used in code development	- Apply the ASHRAE TOU rate in GEB-related proposed measures - Account for the regional variations in TOU and demand rates	-Time Sensitive Valuation (LBNL) -System-Level Assessment of EE&DR (LBNL) -Framework and Methodology to Define Flexible Loads in Buildings (LBNL)	
3	Demonstrating cost effectiveness	Utility rates may not reflect the value of grid services or decarbonization	- Account for the regional variations in value of GEBs to the grid - Consider the societal value of DF measures - Define GEB-related performance-based compliance metrics	-Time Sensitive Valuation (LBNL) -System-Level Assessment of EE&DR (LBNL)	-WattTime; NREL Cambium tool -California Title-24 TDV method -ZERO Code California TDS method -Locational Value of DERs (LBNL for SPIA) - NBI GridOptimal Metrics -EU Sustainable Building Index -IEA Annex 67

Item	Issue	Description	Potential Approach	Related BTO Research	Additional Resources
4	Demonstrating cost effectiveness	GEB "readiness" requirements can incur costs but don't guarantee savings	- Layer on DF requirements to GEB-relevant technologies with active controls already addressed in codes. - Make requirements optional through an IECC appendix or Additional Efficiency Measures.	-See item 1, 8, and 9	
5	Demonstrating cost effectiveness	Modelers may not characterize GEB measures or their impact on operating schedule in a consistent manner	- Require GEB-related credits be met through the Additional Efficiency Measures for prescriptive and performance-based compliance. -Incorporate DF measures into simplified performance-based compliance tools. -Develop standardized procedures for modeling DF measures.	-End Use Load Shapes (NREL/LBNL) -System Level Assessment of EE&DR (LBNL) - ASHRAE Standard 90.1-2019 Addendum AP -2021 Washington State Energy Code	
6	Identifying and Characterizing GEB Measures	Identify GEB measures	-Initially focus on GEB-relevant technologies with control specifications already existing in codes. -Draw on research studies that identify GEB measures . -Draw on BECP expertise. -Draw on advanced standards and codes, as well as standards' committee member expertise. -Identify and prioritize GEB measures for codes.	-GEB Technical Reports (Navigant/NREL) -National GEB Report (Navigant/NREL) -Virtual Batteries (PNNL)	-Code GEB measure review in this report

Item	Issue	Description	Potential Approach	Related BTO Research	Additional Resources
7	Identifying and Characterizing GEB Measures	Understand GEB measure value for load shifting and ancillary grid services	-Draw on research studies and industry activities that characterize and/or evaluate the impacts of GEB measures. -Confer with grid experts to assign value based on grid services. -Engage grid services stakeholders to reveal their needs and balancing strategies.	-Time Sensitive Valuation (LBNL) -GEB Technical Reports (Navigant/NREL) -System-Level Assessment of EE&DR (LBNL) -CUBE via Multi-Scale Metrics (LLNL)	-Locational Value of DERs (LBNL for SPIA)
8	Differentiating grid needs locally, regionally, and nationally	DF and DERs provide different value based on specific grid constraints, which vary geographically	-Draw on research findings that characterizes grid net supply load shape and associated metrics. -Draw on data sources that quantify current and projected source carbon based on generation sources. -Characterize several standard grid supply side shapes to use to inform code development.	-See Item 7	
9	Evaluating GEB impact for code development	Improve methods for accounting for GEB measure cost effectiveness	- Prioritize importance of considerations outlined above based on published data. -Inform approach by performing sensitivity studies using PNNL code prototype models and other tools.	-See Item 1	-See Item 1

Item	Issue	Description	Potential Approach	Related BTO Research	Additional Resources
10	Evaluating GEB impact for code development	Progressively increase the level of complexity in evaluating GEB measure	-Initially evaluate impact based on qualitative then quantitative rating systems. -Evaluate impact using PNNL code prototypes and rule-based operating response to various TOU /critical peak pricing rate structures. -Incorporate metrics and data into code evaluation methods and user tools to value high first-cost GEB measures taking into account regional variations grid service needs.	- See item 1 -Time Sensitive Valuation (LBNL) -Impact of DR on Building EE Metrics (SLAC) -Hierarchical Model-Free Transactive Control of Building Loads (ORNL) -Comprehensive pliant permissive priority optimization (PNNL) -Spawn of EnergyPlus (LBNL) - GridOptimal (NBI)	-See Item 1

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