Codes for Loads: Bringing Energy Codes into the 21st Century with Time-of-Use Efficiency

Jim Edelson
Member ASHRAE

Alexi Miller, PE
Member ASHRAE

Kevin Carbonnier, PhD

ABSTRACT

Buildings are becoming more efficient and more renewable energy is coming online every day. These trends are being driven by market forces, as well as aggressive climate and energy efficiency policies, in jurisdictions across North America. Major changes to the grid will occur, and in some places already are occurring, due to major changes to the energy supply mix (mainly, more wind and solar energy). Because wind and solar are intermittent resources (and their supply-side generation profiles are often not easily aligned with demand-side load profiles), building-grid harmonization is becoming more important on both sides of the meter. The specific operational needs of the grid, and the emissions impact of energy consumption, vary increasingly by location, season, and time of day. In general, it is becoming clear that buildings have an important, and growing, role in catalyzing the clean, reliable, affordable, and safe operation of the electricity grid. Energy codes and building standards have an important role in ensuring that buildings help, rather than impede, building-grid harmonization.

This paper examines a selection of energy conservation measures that shape, shift, or otherwise modify the building's demand profile to support building-grid harmonization. This set of measures is used to demonsrate how energy conservation codes can begin to incorporate these additional grid-based values into energy code scopes and metrics.

The paper builds out a framework to ensure that energy codes can consider building-grid harmonization benefits in a productive manner based on five principles for code applications to grid integration measures. Guided by these principles, the paper explains the conceptual framework, including a formula for calculating total design load credits in a building, and identifies specific opportunities for code compliance enhancements. For example, energy modeling could support a sensitivity analysis to identify specific high-priority, high-impact code modification/update options (e.g. equipment, physical features of buildings) that could be used to develop a matrix of credits that could be traded in the code. Performance-based pathways are also considered. The paper discusses ways in which load management measures can be commissioned and verified to ensure predicted performance. Finally, the paper discusses recommended research and next steps. The foundational analysis and code framework laid out in this paper will help codes to remain relevant and impactful as building-grid interactions, and the grid itself, continue to evolve.

INTRODUCTION

Since their inception in the 1970s and 1980s, energy codes have been a critical regulatory and market-signal-sending mechanism advancing the energy-efficiency of the built environment. Energy codes have been remarkably successful at bringing higher-performance building technologies and practices to scale. Over the first 20 years of the US Department of Energy (DOE) Building Energy Codes Program, building energy codes have saved home and business owners more than $44 billion, representing 4.2 quads of primary energy (ASE 2017). The improvements in building performance from continued advancements in energy codes will continue to save consumers billions of dollars – and will continue

Jim Edelson is the Director of Codes and Policy at New Buildings Institute (NBI), Portland, Oregon. **Alexi Miller** is a Senior Project Manager at NBI. **Kevin Carbonnier** is a Project Manager at NBI.

to benefit society by reducing greenhouse gas (GHG) emissions and other pollution impacts associated with electricity generation and onsite fossil fuel consumption.

Energy codes were adopted in the United States in the 1970s and 1980s, after the OPEC oil embargo of 1973-1974, as a way to insulate American society from excessive reliance on oil imports. Today, the situation is different. In mid-2018 the US became the world's largest crude oil producer, surpassing Saudi Arabia and Russia. It is no longer all about running out of oil. Many jurisdictions are now using energy codes as a primary tool to manage and minimize GHG emissions within their communities.

At the same time, the accelerating transition in many electricity grids away from large centralized thermal (especially coal-fired) generating stations and toward both centralized and distributed renewable energy generation is changing the grid in unprecedented ways. The role of buildings in a changing grid paradigm is evolving, and energy codes must change with the times to maximize their benefits and remain relevant.

This paper builds on concepts introduced in two prior papers: "Taking the (Fuel) Blinders off Energy Codes Part 1" (Miller and Edelson 2018) and "Taking the (Fuel) Blinders off Energy Codes Part 2: Metrics and Mechanics in the Modern Era" (Miller and Edelson 2019). The 2018 paper discusses the need for a carbon metric in energy codes, discusses the concept of emissions efficiency (Dennis, Colburn, and Lazar 2016), and introduces a range of foundational considerations. The 2019 paper builds on that foundation and proposes a specific metric: the Carbon Intensity Index (CII). This metric defines a building's normalized annual greenhouse gas emissions impact.

> *Energy codes need to adapt to the reality that specific fuels used to power buildings, and their specific emission characteristics, can be as critical as total energy use. The declared intent of energy codes is falling further out of alignment with climate policy.* (Miller and Edelson 2018)
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> *With residential and commercial building energy codes, a policy tool already exists that can be modestly reoriented to achieve additional meaningful reductions in carbon emissions. The use of a carbon metric will modernize these building energy codes to better meet today's policy goals.* (Miller and Edelson 2019)

The Nexus of Greenhouse Gas Emissions and Time of Use Efficiency

The climate crisis is driving jurisdictions across the country to implement policies calling for decarbonization of the electricity grid. This is transforming the electricity sector, at unprecedented rates in many places, and is driving a range of new challenges for grid operation. Buildings can, and should, play a critical role in catalyzing the transformation of the electricity grid. However, as more intermittent renewables such as wind and solar come onto the electric grid, the variability in carbon emissions impacts varies more across regions and from one hour to another throughout the year. Therefore, it is becoming increasingly important to move beyond annual nationwide averages and undertake a more precise and nuanced accounting of building operational GHG emissions. It is now incumbent upon policymakers seeking to minimize GHG emissions in buildings, including those involved with the development and implementation of energy codes, to consider not how much energy is used in buildings (i.e. efficiency) but also the grid interaction implications of that energy use.

The concept of **time-of-use efficiency** is useful as a way to consider the granular GHG, source energy, and cost impacts of energy efficiency measures at the building scale. The following section discusses a range of specific pathways by which energy codes can enhance building-grid integration by encouraging designers, owners, and other building industry stakeholders to consider time-of-use energy efficiency.

THE SCALE OF POTENTIAL IMPACTS

Time-of-use efficiency is applicable and deployable in nearly all building types and climates with few exceptions. To varying degrees, buildings can delay or front-load energy use within a typical daily use pattern. Some buildings already shift energy demand with the use of thermal and electrical storage, most often with the goal of avoiding utility demand changes or favoring hours when electricity prices are lower (St. John 2017). Moving forward, operational and design strategies can encourage buildings to use energy during opportune hours to support grid operation, increase renewable energy consumption, and avoid emissions from generation plants running on more polluting energy sources. This section will cover a brief overview of existing research into time-of-use efficiency and the potential impacts of various analyzed measures at the building scale.

Brief Overview of Existing Work

A time-of-use efficiency pilot project achieved peak demand reduction with the implementation of several energy conservation measures. These measures, including temporary set point adjustments, pre-conditioning, lighting reductions, and energy storage showed an aggregate potential of peak demand reduction of over 10% compared to baseline operating conditions.

Working with and advising the design team, NBI provided feedback on the performance of various iterations of the building design with regards to temporal energy demand in the context of the California Independent System Operator (CAISO) grid region. The team identified priority hours for the grid based on peak system demand, significant ramp rates (change in demand), and above-average marginal emissions rates. The design team then worked on energy savings solutions and design modifications in order to reduce or shift energy demand during these priority hours.

In a separate project, associated with the GridOptimal Buildings Initiative, NBI worked with an energy modeling team (Red Car Analytics) to explore the energy demand savings potential of two offices in three different climate zones. The analysis assessed the energy flexibility and load modification potential of a variety of individual demand response measures and packages, including interior shading, electrochromic glazing, lighting demand response, additional thermal mass, grid-integrated appliances, pre-cooling, pre-heating, and expanded thermal comfort ranges. This proof-of-concept analysis highlighted the feasibility of shifting and shedding building energy demand during system peak hours with little to no impact on occupant comfort.

Potential Impact of Measures

Based on conservative estimates of the potential impact of load shifting and mitigation due to time-of-use efficiency, the overall impact on the market may be significant, with benefits expanding beyond energy and cost. Results from the aforementioned existing work in the field indicate that building demand reduction of 5% or greater (per measure) during system peak hours is achievable with a variety of measures, including pre-cooling, temperature setbacks, grid-integrated appliances, lighting reduction, pre-cooling, automated blinds, and energy storage (both thermal and electrical). For the three modeled climate zones (2A, 3C, 6A), the largest peak savings were consistently found in the hot humid climate of zone 2A.

Evaluated measures included some passive design elements (e.g. enhanced thermal mass), some active dispatchable resources (e.g. dimmable lighting controls), and some energy storage measures (e.g. behind-the-meter battery systems). When measures were combined into packages, peak demand reductions up to 40% were observed. On an individual-measure basis, the savings were of course lower and varied significantly. Automated shading, which has little to no impact on occupants, could save up to 10% in peak energy demand during the summer season. Modest changes to the indoor environment with pre-cooling and temperature setbacks of up to a few degrees Fahrenheit could reduce peak demand by 5-15%. The study did not find appreciable peak demand reduction from pre-heating the building in cold climates. Lastly, reduced lighting levels were able to reduce peak demand by 0-9%. In cold climates, lighting reduction did not save peak demand due to the need for additional heating. However, in the warmer climates, lighting reductions during the summer also reduced cooling demand, resulting in greater energy demand reductions. Energy storage is a very effective (though currently relatively expensive) option to shave peak energy demand without impacting occupants-and can be sized and scaled to reduce peak demand as needed to meet a project's goals or utility's needs. The peak demand reduction hours at the building from these measures are commonly coincident with peak demand on the grid, further enhancing the time-of-use value of these savings. (GridOptimal 2019).

ENERGY CODE PATHWAYS AND POSSIBILITIES

Recognizing the objective above of integrating buildings in an advantageous way with the electricity grid (the scope of this paper is for electric grids only, but similar concepts could be applied to natural gas and other fuel supply systems), this chapter explores how building codes can impact the design and commissioning of features that support this objective. The US Department of Energy (DOE) is using the term Grid-integrated Efficient Buildings (GEB) to connote an additional objective that would supplement, and complement, the objective of energy efficiency in buildings. This term will be used as the general term in this paper when referring to specific measure impacts, and the term "grid integration" will be used when referring more broadly to dynamic building-grid interactions.

Five Principles for Code Applications to Grid Integration Measures

The recommendations for code development later in this paper provide general best practice principles for the expansion of the intent and role of energy codes and standards to address grid integration. Design and development of code metrics and measures to encourage grid integration should embrace the following five principles:

1. Measures that are required in support of grid integration should also attempt to increase the **energy efficiency** of a building. To the extent that there is an energy penalty (e.g. battery round-trip efficiency), the additional energy consumption should be minimized to the extent possible.
2. GEB measures in code should **send explicit signals** that support enhanced grid integration. The measures should be as granular, both temporally and geographically, as possible to provide the most accurate inputs for design decisions that properly impact the relation to the grid in which the building situated. This impetus for granularity must be balanced by the complexity of specifying code requirements in both time and geographic dimensions.
3. The first instances of GEB measures in energy codes should be focused on **new construction.** This use-case provides the best opportunities for applying these new types of measures and presents code developers less variability in baseline conditions. Existing building codes do not have the same uniformity in underlying conditions. This complicates predicting how much load-shifting capacity could be provided by each strategy.
4. The **title, purpose, and scopes** (TPS) of energy codes should be clear that GEB measures fall within the scope of model and local energy codes. As of the time of this publication, both ASHRAE Standard 90.1 and IECC were considering TPS revisions that would accomplish this clarification of scope.
5. In national model codes and standards such as the International Energy Conservation Code (IECC) and ASHRAE Standard 90.1, sections that target GEB measures should be mandatory only in grid regions or service territories where there is specific value in managing time-of-use characteristics of a building's energy demand. This may be done by including the sections in an **informative appendix** that a jurisdiction has the option of adopting, or by prefacing each grid integration section such that it is contingent on the availability of a utility demand management price signal or rate.

Conceptual Framework for Crediting Grid Integration in Building Energy Codes

Within the bounds of maintaining reasonable code usability, the grid integration credit received in code should be proportional to the level of services and support provided to the grid. The value of GEB measures and strategies to the grid can vary significantly based on factors including the certainty of the load modification impacts (from the perspective of the grid operator or utility), frequency with which the GEB measure may be deployed, lead time required, degree of alignment between building load modification and grid conditions and needs, location of the building on the grid itself, and other factors. The authors propose the following three GEB measure categories to provide a conceptual framework that may be used to recognize the differing values of GEB measures to the grid:

1.	Passive Design Elements	(e.g. exterior shading for solar heat gain control)
2.	Active Dispatchable Resources	(e.g. Demand Response (DR) HVAC controls)
3.	Customer-Controlled Demand Flexibility Resources	(e.g. battery entirely controlled by customer)

This differentiation in the certainty, frequency, etc. of a measure classified in this way can be reflected in the following formula. The generalized formula for total design load credits is as follows:

Formula 1: Total Design Load Credit = $P * G_p * t_p \;+\; D * G_d * t_d \;+\; F * G_f * t_f$

P = Load Modification Capacity of **Passive Design Elements** vs. baseline, in kW

D = Load Modification Capacity of **Active Dispatchable Resources** vs. baseline, in kW

F = Load Modification Capacity of **Customer-Controlled Demand Flexibility Resources** vs. baseline, in kW

G_p, G_d, G_f = Grid value factors(per hour or other interval), reflecting the relative value to the grid (specific to location or service territory) of GEB measure categories

t_p, t_d, t_f = Duration of load shift in hours (or other interval)

Assigning Values to Load Order

The fixed factors ($G_p/G_d/G_f$) play a significant role in the calculation of total design load credits, but substantial groundwork remains to be done before these factors may be defined. A variety of considerations must be factored into the analysis. In today's market, while momentum is building toward time of use rate structures, many energy consumers (both residential and commercial) still purchase electricity based on temporally flat rate structures. The market for DR is reasonably mature in some parts of North America, but the market for deep, holistic load modification in building design and operation (as discussed in the "Potential Impact of Measures" section above) is nascent to nonexistent.

In an immature market, such as today's, higher weight might be placed on passive design elements (that is, a higher value for G_p would be assigned in Formula 1) because the capacity to engage active dispatchable resources relies on communications technology that may not yet be in place. Similarly, while energy storage deployments are growing fast for both market and policy reasons, the market is still small compared with its potential to provide grid services, and in many cases the controls technology is not yet deployed (and may not yet be developed) to enable batteries to serve as load modification resources in support of grid operational and capacity goals.

In a more mature market, in which communications infrastructure, rates, incentives, and other conditions are in place to ensure that active dispatchable resources may be fully implemented and applied, higher weight might be placed on active dispatchable resources (that is, a higher value for G_f would be assigned in Formula 1). The assignation of values for factors G_p, G_d, and G_f for code purposes should be subject to a comprehensive analysis for each region, service territory, or distribution grid location, and these values will need to be recalibrated at regular intervals as technology and markets evolve. Alternately, these factors may be defaulted to national or regional averages, as is currently done for emission factors in 2018 IgCC and for fuel costs in ASHRAE Standard 90.1.

Prescriptive Code Applications of Load Credits

Once a suite of grid integration measures is identified and its grid-integration capability is quantified, the energy code can apply a variety of existing code mechanisms, or reformulations of these mechanisms, to load credits to foster more grid-integrated buildings. This section will discuss three prescriptive approaches in particular, and then performance path approaches in general.

In existing code language, some basic requirements already exist related to specific communication capacities that allow flexible loads to respond to grid signals. An example of this type of measure is found in Section 701 of the 2018 IgCC based on language developed for ASHRAE 189.1-2017 (IgCC 2018):

> *(7.3.4) Automated Demand Response. Building projects shall contain automatic control systems that have the capability to reduce building equipment loads to lower electric peak demand of the building. The building controls shall be designed with automated demand-response (DR) infrastructure capable of receiving DR requests from the utility, electrical system operator, or third-party DR program provider and automatically implementing load adjustments to the HVAC and lighting systems.*

A straightforward approach, though it is limited and may be potentially problematic in some regards, would be to add **additional efficiency packages in Section 406 of the IECC**: This approach applies some value to grid integration measures by allowing them to be applied in Section 406 of the IECC-Additional Efficiency Package Options. One drawback of this approach is that a grid integration measure could be used to trade off against energy efficiency options. Proposal CE 238-19 for the 2021 IECC uses this approach (CE 238-19):

> *C406.1 Requirements. Buildings shall comply with one or more of the following:*
> *1. More efficient HVAC performance in accordance with Section C406.2.*
> *2. Reduced lighting power in accordance with Section C406.3.*
> *3. Enhanced lighting controls in accordance with Section C406.4.*
> *4. On-site supply of renewable energy in accordance with Section C406.5.*
> *5. Provision of a dedicated outdoor air system for certain HVAC equipment in accordance with Section C406.6.*
> *6. High-efficiency service water heating in accordance with Section C406.7.*
> *7. Enhanced envelope performance in accordance with Section C406.8.*
> *8. Reduced air infiltration in accordance with Section C406.9.*
> *9. Provision of an electrical energy storage system (EESS) controlled via an energy management system that shall be programmed to shift a portion of the building load from on-peak to off-peak, in accordance with Section C406.10.*
>
> (Proposed additional text is underlined.)

The authors feel that the best approach would be to set a **minimum level of load credits**, based on a quantitative research into load modification impacts in buildings, applied systematically. This approach applies the load credit calculations directly in a new requirement for a minimum level of load credits as calculated in Formula 1. If the load credit requirement were included in an informative appendix, each adopting jurisdiction could determine the level of grid-integration capacity needed for their evolving grids. Alternatively, as with emission factors and energy cost, national average values could be provided in the model codes and standards.

Performance Code Applications of Load Credits

The performance approach is well suited for the application of load credits in energy codes. Each building project undergoing an energy simulation develops an 8760 hourly schedule for the building performance in energy use. The 8760 hourly schedules lend themselves to hourly adjustments for incorporating and valuing the delivery of grid-integration benefits - even if that level of information is not currently applied in commonly use software.

As described above, modeling software can layer grid resources into its calculation and quantify the energy shifting capacity that can be contributed by a building's design. It can quantify passive design elements, active dispatchable resources, and storage devices, including electric vehicles if so equipped. Pacific Northwest National Laboratories (PNNL) is using its analytical resources to build modeling infrastructure to enable the inclusion of grid integration measures in energy code performance paths. It is undertaking feasibility and scoping investigations to understand how energy models can inform codes that support grid integration in buildings, as described in its scope (Franconi 2019):

Feasibility Study: *Identify advanced measures necessary to enable low- and zero-energy buildings that may be feasible for implementation in future codes.*

1. *Identify advanced technologies and measures*
2. *Modify the PNNL prototype models to incorporate the advanced measures*
3. *Assess the impact of the measures on EUI and potential cost -effectiveness.*

Considerations in Codes: *Identify GEB measures. Develop, test, and prioritize assessment methods to inform future code development.*

1. *Conduct a scoping study to understand GEB value and potential GEB measures which could be considered in current future codes*
2. *Identify and characterize GEB measures based on their ability to provide various grid services*
3. *Evaluate select GEB measures using the PNNL code prototype models*
    a. *Develop metrics to quantify impact on demand reduction*
    b. *Investigate the effect of valuation methods, which take into account time of day and geographic differences, in evaluating impact*

Code-required Commissioning of Grid-Integrated Measures:

Both the IECC and ASHRAE Standard 90.1 have requirements for commissioning or functional testing of many building systems. The equipment now required to be commissioned or tested includes HVAC systems and controls, lighting systems and controls, and hot water systems. As the systems become more complex and increasingly driven by more extensive control mechanisms to deliver better energy performance, the role of commissioning and testing in codes has grown.

It is critical that equipment that passively or actively delivers some kind of grid integration service be installed correctly and then commissioned. This will ensure that its design intent is realized in actual building operation. This is particularly true for the kinds of equipment that may only sporadically be called upon for a grid response. However, the commissioning documentation and functional performance testing found in current codes should be readily applicable to grid-integrated devices with only minor modifications.

RECOMMENDED AND RELATED RESEARCH

The recommendations and potential pathways laid out in this paper are only the beginning. More research will be needed to understand how buildings actually perform and what the potential savings are from various GEB or load-modification measures. It will be important to develop and agree upon estimates of GEB measure impacts in order to be able to stipulate energy load shifting capacities in energy codes. In parallel, it will also be important to perform research to understand the details of grid conditions in which buildings are operated. The development of data libraries for both GEB measure impacts and grid conditions will be foundational to this effort.

CONCLUSION

Our buildings are increasingly becoming the operational nexus for where work, domicile, and transportation interacts with the networks that deliver the energy that powers these activities. As the climate crisis drives a growing number of policies that necessitate the use of clean and emissions-free electricity (with some building processes that will likely tap GHG-free natural gas), buildings need to play a critical role in being able to help manage the transition to more variable sources of electricity, such as wind and solar. Concepts and mechanisms are now at hand to make this possible in energy code development today.

Energy codes not only have played a significant role in making homes and buildings more energy efficient, they have saved Americans billions of dollars on their fuel bills (ASE 2017). Energy codes also have driven down costs for increasingly efficient designs and equipment which has led to better performing homes and buildings across the country – even for those not subject to better energy codes (Zakarian et al. 2014). It is now time to harness the effectiveness of energy codes to ensure homes and buildings are equipped with the capacity to integrate their energy use (and onsite renewable generation) with the rapidly increasing supply of variable renewable energy coming from the grid. It is time to tap the scale of impact that energy codes have already demonstrated to prepare buildings and the grid for a rapid transition to 100%, or nearly 100%, renewable supplies of power across broad swaths of America.

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