Zero Net Energy Buildings and the Grid

The Future of Low Energy Building-Grid Interactions

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ABSTRACT

As zero net energy (ZNE) and other low-energy buildings become increasingly common, it is important to consider how different ZNE strategies can interact with local electricity grids. The electricity grid was built as a one-way street, with energy flowing from the power plant to buildings. But widely distributed renewable energy systems and other cutting-edge building technologies will change that equation as the grid transitions to a transactive energy framework with integrated demand-side management. Demand response (DR) technologies and grid-sensitive design features in ZNE buildings will be critical to enabling the successful integration of these facilities into the grid at a large scale.

The paper describes three tiers of DR and renewable energy technology integration in commercial buildings:

1. *Conventional buildings with one-way energy flows or conventional net metering*
2. *Moderately responsive buildings with interactive demand response capacity*
3. *Fully grid-integrated buildings with active and passive efficiency and demand response features, often with onsite renewable energy*

This third tier represents the buildings of the future. These buildings integrate grid-sensitive design features, fully dispatchable DR across major end-uses in the building, and carefully designed and installed renewable energy technologies that are intended to improve the relationship between the building and the electricity grid. These buildings, whether operating at a ZNE level or not, must be explicitly designed with both active and passive features and technologies to optimize the interactions between buildings and the utility grid. Passive design strategies such as building orientation, daylighting, and passive space conditioning, are the foundational step and should be implemented as much as practicable. Active strategies such as night ventilation, thermal storage, or DR will also be instrumental and can allow buildings to be used when necessary as storage for the grid. Renewable energy systems should be carefully chosen and designed to interact well with the grid.

The paper differentiates between renewable-oriented and efficiency-oriented ZNE building typologies and discusses their impacts. The paper presents a framework for employing design strategies and measures that ensure buildings of the future can benefit from, and support, the grid modernization efforts that will occur throughout the life of the buildings. Finally, policy recommendations to improve future building-grid interactions are offered.

INTRODUCTION

Policies, programs and market developments have dramatically changed the prospects for Zero Net Energy (ZNE) buildings over the past decade. There is burgeoning market interest in ZNE, and policies and programs can foster and grow that interest through leadership, direct support, and the reduction of risks and uncertainties.

Actual ZNE construction to date is still relatively new, and only a small percentage of building construction now has a goal of ZNE. However, efforts are increasing, with a doubling in the number of commercial ZNE buildings over the last few years (NBI 2014). ZNE homes and buildings have been designed and constructed by a growing number of design teams and builders and are spread throughout a number of climate zones and political jurisdictions, including (in North America) 39 US states, three Canadian provinces, and the District of Columbia.

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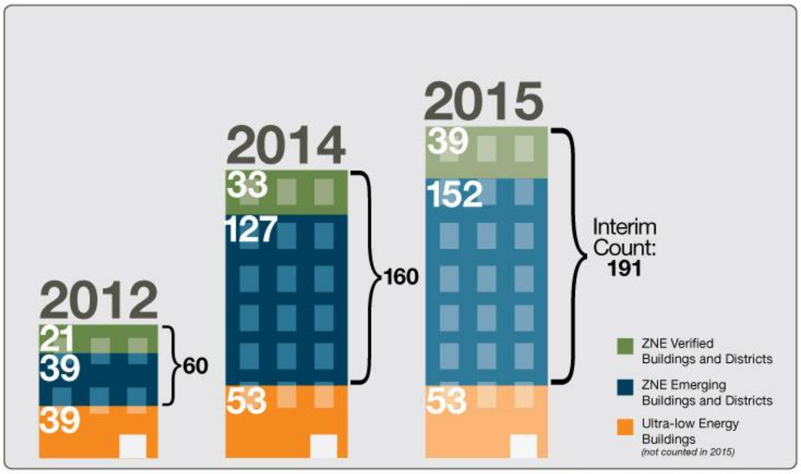

Figure 1 Growth in ZNE projects from 2012 to 2015 (NBI)

ZNE buildings have now passed the "proof of concept" stage, with more ZNE buildings being constructed as well as larger and more complex buildings. One important question now is how to garner the significant benefits of rapidly increasing the numbers of ZNE homes and buildings through policies and programs while adding to the stability, rather than the instability, of the energy delivery systems throughout North America.

The analysis and recommendations below depict a pathway for best advancing ZNE buildings in light of their impacts on the grid. Almost all existing ZNE policies follow from broader climate or energy policies enacted by state legislatures, governors, mayors and city councils, but usually with regard only to energy consumption, not considering the impact on the grids. California is a notable exception, with its value of energy (Time Dependent Valuation-TDV) dependent on the time-of-day use; but even there, the extreme patterns of consumption in ZNE buildings are not fully considered.

The US Department of Energy, states and local governments can all contribute to the development of a Path to ZNE that considers development of a ZNE building stock that works well for the energy delivery infrastructure. Utilities and program administrators can operate successful ZNE pilots with this purpose in mind. Even building codes are at the early stages of considering changes that could better support ZNE in the future and can also be guided with this same dual objective (energy and grid) in mind.

This paper first frames the ZNE building impact in a general sense and then describes the different impacts of "Renewable-oriented" versus "Efficiency-oriented" ZNE buildings. A synthesis and set of technical recommendations are then presented, including examples of where and how the various strategies may be optimal. The paper concludes by exploring potential policy research and policy development avenues. We hope this paper provides useful information to expand the role of ZNE buildings in achieving carbon and efficiency policy goals while also working to help the grid smoothly integrate distributed energy generation and very low-energy buildings.

TWO TYPOLOGIES FOR ZERO NET ENERGY BUILDINGS

As zero net energy buildings become increasingly common, it is important to consider how different ZNE strategies can interact with local electricity grids. Although a building may generate enough renewable energy onsite to offset the imported energy used over the course of the year, at any particular time it is very unlikely that the generation is actually equivalent to the usage. Integrating demand response (DR) technologies and grid-sensitive design features into ZNE buildings is critical to enabling the large-scale integration of these facilities. This paper will examine the two major typologies in ZNE buildings as they relate to the grid.

To understand the relationship of buildings to the grid in general, three tiers of DR and renewable energy technology integration in buildings can be identified:

Tier 1. Conventional buildings with one-way energy flows or conventional net metering: These buildings comprise the great majority of buildings and have no DR technologies, grid-sensitive design features, or other smart features. These buildings may be equipped with renewable energy sources such as PV panels, but the panels are typically designed for maximum annual production, and the building imports energy as needed throughout the day and year.

Tier 2. Moderately responsive buildings with some DR capacity: These buildings have some DR technology installed, typically associated with discrete end-uses. For example, there may be controllers installed on heating, ventilation, and cooling (HVAC) or lighting equipment to allow the building to participate in demand response programs through load aggregators by shedding load at specific times based on automated instructions from a third party.

Tier 3. Fully grid-integrated buildings: These buildings are carefully designed, and interactions with the electricity grid have been considered during the design process. The buildings integrate grid-sensitive design features, fully dispatchable DR across all major end-uses in the building, and carefully designed and installed renewable energy technologies that are intended to facilitate a positive relationship between the building and the electricity grid.

These three tiers of DR and renewable energy integration can play out differently in various applications. However, within the generic category of ZNE buildings there are two fundamental typologies: **Renewable-Oriented** ZNE buildings and **Efficiency-Oriented** ZNE buildings. The different features commonly seen in these two approaches interact differently with the grid, and each approach offers its own opportunities and challenges.

Features of Renewable-Oriented ZNE Buildings

Renewable-oriented ZNE buildings may be designed as such or may be a conventional (Tier 1 or 2 in the above list) building retrofitted with significant renewable energy generation. These buildings, of course, generate as much energy onsite as they consume on an annual basis. The path to achieving this goal involves more active strategies as well as more renewable generation to account for a higher energy usage relative to efficiency-oriented ZNE buildings. These buildings are generally more likely to exhibit both high peak usage and high peak generation.

Renewable-oriented ZNE buildings typically have higher overall energy usage when compared to their efficiency-oriented peers. (When compared with a run-of-the-mill building, these buildings clearly stand out as energy efficient and high performing.) To compensate for their higher energy usage, these buildings tend to have more renewable energy generation capacity installed onsite.

These buildings are likely to fall into Tier 1 or Tier 2 of the above list: net-metered buildings, which may be moderately responsive with some DR capability. In order to optimize the impacts these buildings have on the electricity grid, more active strategies are needed. For example, active DR strategies, like those often delivered by an Energy Services Company (ESCO) or a DR aggregator, may be implemented so that the building can respond to specific load shedding or curtailment events by adjusting the operation of its mechanical systems. Other active systems such as night ventilation or thermal storage are well suited to improve the grid-sensitivity of these buildings.

The load shape impacts of these buildings and their renewable energy systems can be very significant. Jim Lazar published a paper in January 2014 titled "Teaching the 'Duck' to Fly" in which he discusses the impacts of increasing renewable energy generation on California's energy grid and outlines ten strategies that can significantly ameliorate the potential problems these changes will pose (Lazar 2014). Figure 1 shows the predicted load shape on an illustrative day in southern California in 2020. (Lazar notes: "this illustrative day is a light load; a heavy renewable energy generation day such as one that might be experienced in the spring or fall and is not intended to represent a 'normal' or 'summer peak' day. It is selected to illustrate the opportunities available to meet a challenging situation." That is, this represents something of an extreme case at this point in time and for the near future.)

The blue line shows the total load on the system. The red line, often called the "Duck Curve," shows what could happen if the state achieves its Renewable Portfolio Standard (RPS) goals in 2020 without careful consideration of how to accommodate renewable energy's impact on the load shape. A renewable-oriented ZNE building will be more likely to exacerbate the swings within the duck curve, without incorporating significant DR capabilities.

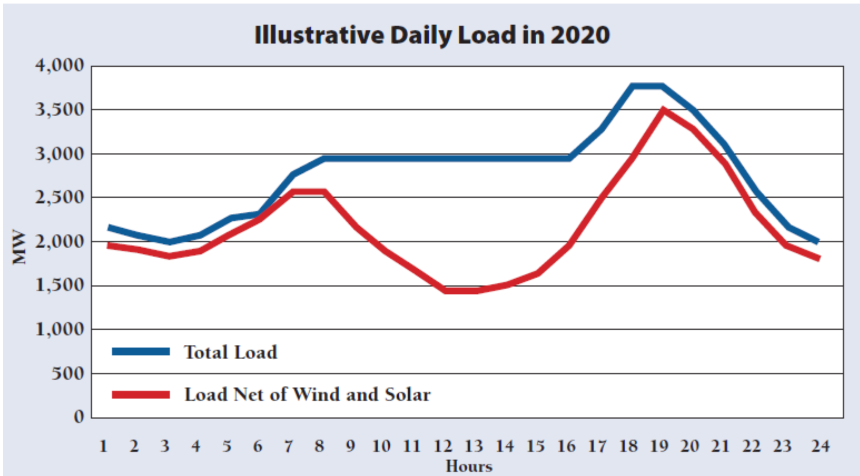

Figure 2 The Sitting Duck: CA loadshape on an illustrative day in 2020 before and after renewables (Lazar).

Features of Efficiency-Oriented ZNE Buildings

Efficiency-oriented ZNE buildings are typically designed from the ground up to be as efficient as possible and include only enough onsite renewable energy generation to cover the minimal needs of the building. These buildings are likely to fall within Tier 2 or Tier 3 of the above list (moderately or fully grid-integrated buildings) and are generally more energy efficient than their renewable-oriented peers. The integrated design process common in these buildings offers opportunities to ensure that grid-sensitive design elements are incorporated.

Passive design strategies tend to play a bigger role in efficiency-oriented ZNE buildings than in renewable-oriented ZNE buildings. These design strategies are grid-sensitive and by definition do not require intervention by a third party such as a building operator or ESCO. Some examples of passive design strategies often employed in these buildings are daylighting, building orientation, high insulation levels, and passive heating and cooling. That is not to say that efficiency-oriented ZNE buildings cannot make use of active strategies. Buildings in this category, and those in Tier 3 in general, are good candidates for DR strategies such as load curtailment and for active load management strategies such as thermal storage. These strategies are generally implemented in the building at the design stage.

One benefit of incorporating grid-sensitive design strategies into buildings such as these is that the building becomes significantly more independent and reliable. The degree of independence depends on the particular energy efficiency and demand response strategies employed, but for the most part, a building with passive technologies implemented will be better able to withstand extreme events (such as a power outage) and will be inherently better suited to respond to price signals such as those sent by time-of-use energy pricing.

The grid impacts of efficiency-oriented ZNE buildings can be ameliorated in large part by grid-sensitive design strategies and operational choices. The effects of these strategies and choices can flatten out the load shape significantly and can help reduce the peak demand issues illustrated in Figure 1 above (the Sitting Duck). Figure 2 shows the predicted load shape on an illustrative day in California in 2020–just as Figure 1–both before (red) and after (green) the adoption of Lazar's ten recommended strategies. In this case, the duck has taken flight (resulting in significantly lower peak demand and less dramatic ramping rates), with positive impacts for the utilities and society as a whole. (The ten strategies recommended by Lazar include strategies at the utility-wide scale as well as the building level. Nonetheless, the impact of grid-sensitive building design has effects similar to these.)

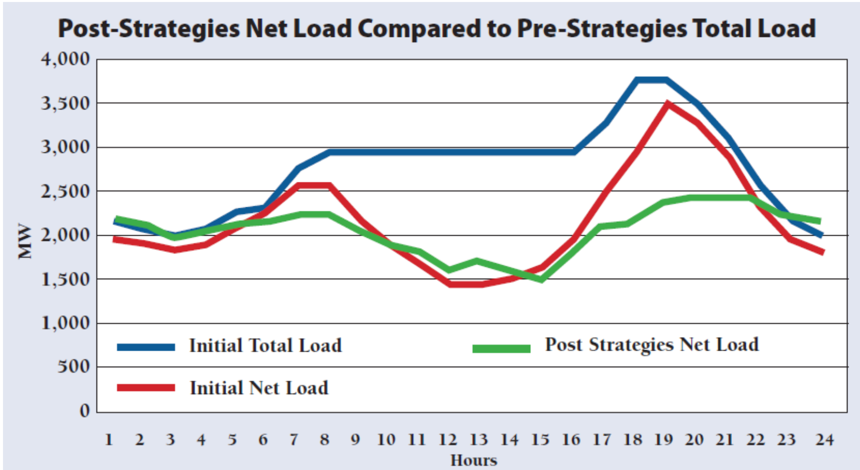

Figure 3 The Flying Duck: The impact of multiple strategies on an illustrative day's load shape in 2020 (Lazar).

How Can These Two ZNE Building Typologies Coexist?

There is space for both renewable-oriented ZNE buildings and efficiency-oriented ZNE buildings. Because of the different effects the two design approaches can have on the grid, it is important to work with the design community to consider grid impacts at the design stage and with building operators to manage building loads intelligently. Passive design strategies should be installed in as many buildings as appropriate, but in some cases design priorities may preclude these strategies. In existing building renovations there may be additional limitations imposed by the existing facility. In these cases, active DR strategies and active design strategies are called for.

Utilities, regulators, and other third party players can play a significant role in guiding the adoption of strategies in this arena. By implementing market strategies such as time of use pricing the utility can send signals to designers, building owners, and other stakeholders that considering the grid impacts of their buildings is important. Similarly, incentivizing grid-sensitive design strategies and active management strategies can encourage those involved with high-performance buildings to use these tools to their full potential.

DESIGNING THE GRID-INTEGRATED BUILDINGS OF THE FUTURE

The most appropriate strategies and technologies to be applied in the intelligent, grid-integrated, high-performance buildings of the future will be different for every building. Traditional design considerations will continue to be relevant: climate, building use type, orientation constraints, local building codes, and so on. But new design considerations, for instance, grid-scale effects such as peak load conditions, are becoming more prominent and will directly impact building design, especially at ZNE levels. These considerations are already appearing in certain energy metrics: the prime example is California's Time Dependent Valuation energy methodology. These considerations can vary significantly by climate and based on local grid conditions as shown in Table 1.

Table 1. Five Representative Cities

City	Location	Climate Zone	Building Design Considerations
Atlanta, Georgia	34°N, 84°W	3A	High heat & humidity: cooling-related active DR strategies
Los Angeles, California	34°N, 118°W	3B	Hot dry summers & mild winters: passive design, natural ventilation; High summer peak load drives active DR strategies on wide scale
Seattle, Washington	48°N, 122°W	4C	Mild marine climate: passive design can minimize HVAC loads
Boston, Massachusetts	42°N, 71°W	5A	Humid summers & cold winters: thermal storage, passive design
Minneapolis, Minnesota	42°N, 88°W	6A	Humid summers & cold winters: heating & cooling season peaks

Passive design strategies were used for thousands of years and are once more a critical part of high-performance building design. Concepts like careful orientation of the building, placement of fenestration to balance thermal effects with daylighting capability, passive HVAC design enabling the use of natural ventilation and free heating and cooling, and use of building elements such as overhangs and exterior fins can all make a significant difference in a building's load profile. Many passive elements can be considered built-in demand response.

These passive strategies offer built-in demand response: they are always on. Passive design strategies can be considered in mid-term (day-ahead scale) load planning at the utility level. Utilities or ESCOs can use predicted and actual demand effects of passive strategies to help control and shape building load profiles.

Active design strategies have more recently become an important piece of the utility or ESCO's demand-response toolkit. Some of these strategies are well established. For example, curtailment of interruptible loads has been used for years to reduce peak loads and the contracts can be structured in various ways (optional, compulsory, or a combination). Generally, today these demand-response resources in buildings are HVAC, lighting, or process loads, and curtailment is administered on a short-term (minutes to hours) basis. Newer strategies are becoming more common, such as thermal storage tanks that allow a building to precool a reservoir of water or ice overnight in preparation for a peak cooling day. Night ventilation can also be considered an active strategy when used to reduce daytime HVAC energy requirements.

Unlike a passive design strategy, an active design strategy must be initiated before it will provide benefits to the building or the grid. This requires some degree of intervention from a building manager or other user. This intervention may, however, be automated.

The increasing adoption of these and other passive and active strategies will be key pieces of the transition from simple widget-based energy efficiency efforts to an intelligent building-grid interface within an interactive distribution network (sometimes implemented as Transactive Energy or Integrated Demand Side Management). This transition relies on diverse drivers on both sides of the Grid Edge as shown below.

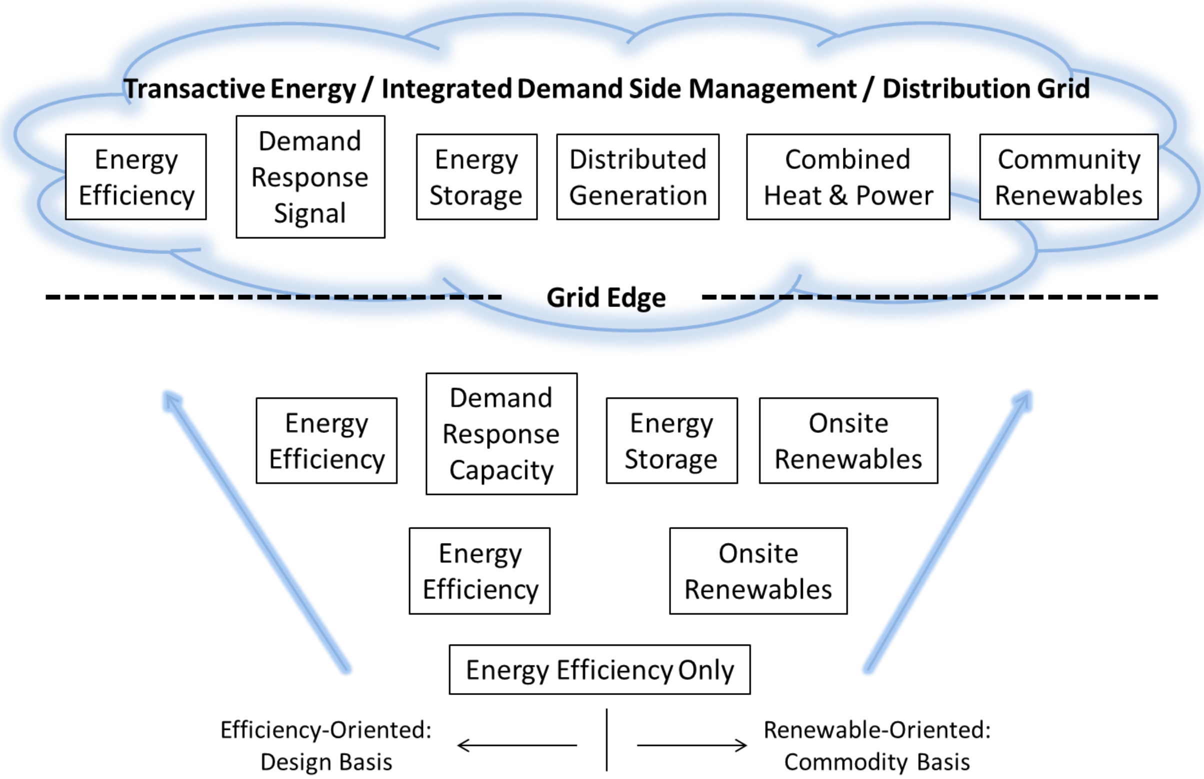

Figure 4 Moving building performance strategies from simple building systems to full grid integration.

Emerging technologies will change how buildings look and how they interact with the grid in the future. Customized strategies will be needed – no two buildings are exactly alike, and fine-tuning building performance will require consideration of many factors, though guidelines can establish the strategies and techniques likely to be available for individual sites. The emerging strategies discussed below are not an exhaustive list, and more strategies and technologies will doubtless emerge in the future.

- Buildings as Batteries: Buildings may be connected to the power grid and controlled in such a way that the building may be controlled to some extent by the utility or an ESCO. If a peak demand period is anticipated, the building may be able to respond before the demand strikes, for example by precooling the space or by curtailing certain loads. Buildings may also have the capacity to provide dispatchable generation onsite through backup generators or fuel cells. Finally, building-scale batteries have arrived on the market and will be increasingly common as battery prices drop.
- Microgrid Networks: By building networks connecting buildings within a relatively small geographical area to each other, small-scale power grids can enhance reliability, reduce peak demand, and provide ancillary benefits (e.g., frequency regulation) for areas with high concentrations of critical loads. One demonstration microgrid with centralized battery backup has been built in the Salem, Oregon, area (BPA 2014).
- Plug Loads: Connected devices offer the opportunity to both track and control energy use at the appliance or device level. As buildings trim their heating, ventilating, cooling, lighting, and water heating energy use, plug loads are becoming a major issue. The Internet of Things will enhance the ability of buildings to control these unregulated loads. However, this same proliferation of connected devices can cause a proliferation of communications protocols and information overload to the end user if standards do not emerge in the near-term.

> *As the more permanent subcomponents of a building continue to improve in efficiency (envelope, HVAC, and lighting), the remaining plug loads are becoming a larger and larger portion of the overall load. In this "stress test" of Zero Net Energy design objectives, reducing the plug loads often proved critical to meeting the overall energy use targets. That is also the experience of most architects and engineers working on Zero Net Energy projects. (Arup 2012)*

- Plug-In Electric Vehicles: Electric cars whose batteries can be connected to the grid when the vehicle is not in use offer a host of benefits. Sufficiently large numbers of electric cars could be used to provide grid services including peak load shaving and frequency regulation. Through energy price arbitrage, the owners can benefit as their batteries are discharged during peak hours (and charged during off-peak hours). At this time, the number of electric cars is not sufficient to provide these grid-scale benefits; however, the infrastructure is being built, and the major auto manufacturers are either currently selling or are planning to sell mass-market electric cars in the next few years.

The role of renewable energy generation in the grid-connected buildings of the future may look significantly different than it does today. Distributed renewable generation resources are rapidly scaling up from low levels of penetration to much higher levels, driven by factors including regulatory or legislative targets, direct and indirect incentives, energy price increases, customer preference, corporate sustainability policies, and ZNE buildings targets. Most importantly, significant cost reductions have already driven much more rapid uptake in onsite solar installations.

As solar resources become commonplace building features, strategies will emerge to manage their integration into the grid. Strategies like east-west solar panel orientation or tracking arrays controlled by the utility can ensure that photovoltaics generate power more closely matched with peak load conditions. South-facing solar panels produce the most power when the sun is directly overhead, whereas west-oriented panels will produce more power in the afternoon hours when load tends to increase. Utilities may want to consider incentivizing strategies that improve the generation profile of distributed renewable generation.

The balance of renewable generation resources and efficiency improvements is shifting now and will continue to do so as the price of renewable energy generating technology drops. It will likely continue to get cheaper to build renewable-oriented ZNE buildings. Electric utilities and other grid stakeholders should consider their incentive structures and their ZNE deployment priorities to manage the balance between efficiency and renewable resources and how the design of both affects grid management.

Grid resiliency is a top-tier concern of electric utilities and other entities whose work relates to the grid. ZNE and other buildings incorporating advanced demand response, whether active or passive, can play a role in supporting increased grid reliability. These buildings can help manage staged outages and can smooth the restart process after an outage. As buildings are increasingly connected in new and intelligent ways to the grid, opportunities will be present to enhance resiliency by building these capacities. The time to take advantage of these benefits is upon us.

POLICY AND THE FUTURE OF GRID-INTEGRATED BUILDINGS

Potential wide swings in levels of energy production and consumption in ZNE buildings highlight the importance of understanding the issues that these buildings will present to the continent's energy grids. With the realization that the two typologies of ZNE buildings—renewable oriented and efficiency oriented—both present distinct threats and opportunities to the grid, it is critical that policies for ZNE design and construction account for the impacts on the grid and be developed in such a way that optimizes the ZNE building as a grid resource.

A systematic evaluation is currently needed to understand how current policies such as energy codes, utility incentive programs, and appliance standards impact a ZNE building's interaction with the grid. Most, if not all, of these policies have not yet learned how to "teach the duck to fly." Once building features are set in the design and construction phase, there is little option to influence most of the major building systems for decades to come. Therefore, it is in design/construction phase codes and programs for ZNE buildings that changes need to be made to account for impacts on the grid – with the knowledge that the renewable-oriented and efficiency-oriented typologies for ZNE buildings can make this possible.

A major transformation of the grid by distributed and local renewable energy is underway. The market forces behind the growth of renewables and other grid impacts, such as electric vehicles, are significant and moving rapidly. While power generation will be changing rapidly, the number of buildings that generate as much energy as they use will grow rapidly as well. How this next generation of buildings interacts with the grid will be either supportive of grid stabilization or be an additional force exacerbating uneven grid delivery patterns. And how the policies for these ZNE buildings roll out across the continent will be a critical factor in determining the monetary and environmental costs of supplying our future energy needs.

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