Energy Codes for Ultra-Low-Energy Buildings: A Critical Pathway to Zero Net Energy Buildings

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Executive Summary

A number of high-profile public and private goals have been announced calling for a full transition to zero net energy (ZNE) construction for new residential and commercial buildings by 2030. By establishing minimum requirements for the energy performance of new construction and major renovations, building energy codes can evolve to ensure that most homes and buildings are built to perform as ZNE by 2030.

The recent growth in ZNE construction in the residential and commercial sectors shows the feasibility of technologies and construction practices that can deliver zero net energy buildings. While we have many of the technologies and techniques needed to build these buildings now, additional work is necessary to bring ZNE construction to scale and make it standard practice. Economies of scale, more efficient and effective construction practices and techniques, and innovative technologies can lower the cost of ZNE buildings. These advances will make it easier to achieve ZNE in production-scale building and ensure that these buildings deliver in performance what they promise in design.

Building energy codes set a minimum baseline for the energy efficiency of new construction and major renovations. In the United States, the major model energy codes are updated every three years. Each three-year revision presents an opportunity to lock in energy efficiency gains as new technologies and practices are proven, and a chance to amend code implementation and compliance strategies to better align with ZNE goals. Thus codes can serve to ratchet up buildings' energy performance and increase the likelihood of achieving 2030 goals for ZNE buildings. Figure ES1 shows the efficiency gains from each code cycle since the first national model codes were adopted in 1980.

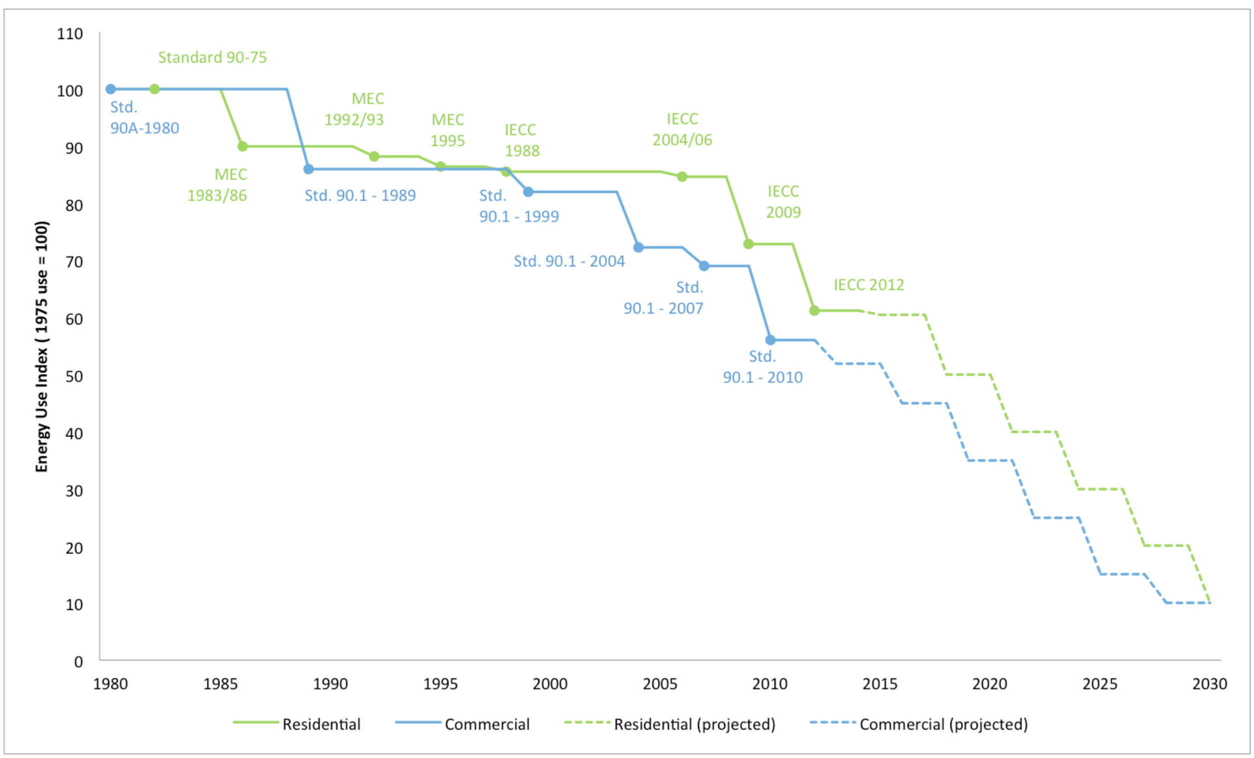

Figure ES1. History of U.S. building codes, 1980–2012. *Source:* Data from U.S. DOE Building Codes Program.

Given the current design and structure of our building codes, it will be challenging to use recent code improvements as a basis for achieving greater energy efficiency and, ultimately, ultra-low-energy code requirements. The largest obstacles to zero net energy in current codes include:

- The limited set of regulated end uses covered by code, primarily envelope materials, heating and cooling equipment (HVAC), water heating, and lighting
- Diminishing opportunities for energy savings in a number of regulated equipment types
- Federal preemption of code requirements for equipment efficiency in products covered under the federal appliance standards program
- Reliance on prescriptive requirements and/or performance methods based largely on the modeling of building design
- A lack of mechanisms to account for or address building operations and maintenance

Effective codes for ZNE buildings will **capture savings across all building energy end uses**, including ever-increasing plug and process loads, by emphasizing whole-building energy use rather than improvements to specific regulated end uses. Even as they recognize advances in individual equipment and component efficiency, codes must **address the larger potential energy savings available in systems**. For example, they should shift from chiller efficiency requirements to HVAC system efficiency that includes not only the chiller but also the associated pumps, fans, and so on.

In addition, to reach ZNE goals, it is not enough for buildings to meet stringent efficiency targets on paper or in computer models; they must **meet stringent efficiency targets in actual ongoing operation**. Today's codes govern building design and, to a degree, system and component efficiency, but not building energy use. Outcome-based codes address this disconnect by establishing performance targets tied to actual performance outcomes. The 2015 International Green Construction Code incorporates a version of this compliance approach; this code could provide early experience and lessons on implementation of an outcome-based code prior to wide adoption.

Numerous studies have demonstrated the impact of building operators and occupants on building energy consumption. To ensure post-occupancy ZNE performance, building energy codes need to **consider the impact of building occupants and operators on building energy use**. While research and case studies demonstrate the feasibility of low-energy design and construction, we need more data on the operational requirements to achieve actual ZNE performance in building operation. Finally, codes should be designed to **anticipate the future** by allowing for relatively straightforward retrofits or equipment replacements to obviate some of the built-in obsolescence in legacy construction. Another way to anticipate the future is to ensure the persistence of high-efficiency performance in building components and installed systems.

Getting building energy codes to ZNE by 2030 will be challenging, but much can be done to ease the transition and increase the likelihood of achieving this goal. Complementary policies, targeted research, market transformation and related activities, and the coordination of efforts and advocacy can establish the foundation for ZNE while providing energy savings and related benefits in the interim.

COMPLEMENTARY POLICIES

Federal, state, and local energy efficiency policies can help make the transition to ZNE codes. They can increase our understanding of building energy performance, increase demand for more energy-efficient homes and buildings, grow market capacity for high-efficiency construction, and introduce more certainty to market actors about future code requirements. A strong suite of policies can pave the way for the aggressive code changes that are needed. Key policies include the following.

Building labeling, rating, and disclosure policies are a new way to gather actual building energy-use data on a statistically significant set of buildings representing a number of building types and uses. These data are crucial to developing performance targets for outcome-based energy codes. Rating and labeling programs such as the Home Energy Rating System (HERS) and ASHRAE's Building Energy Quotient (bEQ) As Designed label can communicate information on expected building energy use based on well-vetted and robust rating methods.

Public-sector leadership leverages the unique role of the public sector in researching, developing, and deploying new technologies and practices that have significant social benefits. In the buildings sector, government agencies at all levels have taken the lead in demonstrating sustainable building practices, energy-efficient procurement, building benchmarking, and to a lesser extent, advanced building operations and maintenance.

Stretch codes, green codes, and beyond-code guidelines represent code requirements more stringent than state-level codes, which are generally based on the national model codes. States may allow local jurisdictions to adopt more stringent stretch codes as an alternative to code. These advanced codes can serve as a proof of concept for new code requirements or alternative compliance mechanisms. In recent years, states and cities have adopted some novel approaches, using codes to encourage innovative building practices and to pave the way for next-generation building technologies.

RESEARCH NEEDS

We can identify an initial set of research needs and priorities to help reach the goal of ZNE by 2030. Then, moving beyond these initial steps, a comprehensive research agenda that prioritizes needs and coordinates efforts would be valuable. Initial research needs include the following.

Gathering data on how energy is dissipated in buildings will be critical to devising better building codes and achieving ZNE building operation. Larger scale metering and submetering data from a broader set of buildings—facilitated by new information and communications technologies—would inform our understanding of whole-building and system-level energy flows and the most effective ways of reducing buildings' energy consumption.

Technology research and development efforts are needed to increase energy savings and lower the cost of efficiency improvements in building components and systems. The tools, technologies, and practices for constructing ZNE homes and buildings are available off the shelf today; what is missing are the techniques and economics to rapidly scale up these technologies and practices into mainstream construction.

Research into the human dimensions of energy use can help determine the best ways to reliably engage occupants as part of a building's operating and control strategies.

MARKET TRANSFORMATION AND RELATED ACTIVITIES

Efficiency programs can play a central role in sparking demand and building the infrastructure for ultra-low-energy construction. As more ZNE buildings are completed, we will have better information on the most effective technical approaches and the cost of various design strategies. We can use this information to determine the most cost-effective approaches; then, where superior technical approaches have been overlooked because of high cost, market transformation programs can bring costs down. While the most obvious opportunities come from new construction programs, other programs in an administrator's portfolio can also help accelerate the transition to ZNE construction.

COORDINATION AND ADVOCACY EFFORTS

Progress on these strategies will require greater coordination among the energy efficiency community and allied stakeholders. California's efforts to meet 2020 ZNE goals for residential new construction provide an informative example of state and utility efforts to coordinate research, efficiency programs, codes, and standards to support the transition to ZNE buildings. A well-coordinated advocacy effort will also be required. Key areas of focus include the development of appropriate cost-effectiveness methodologies, coordinated advocacy in support of model code development, and stronger code compliance and enforcement efforts. We will also need to leverage federal support for ZNE goals, work to ensure that appliance standards keep pace with code, and pursue options to differentiate between the new construction and replacement markets.

Introduction

A number of high-profile public and private goals have been announced calling for a full transition to zero net energy (ZNE) construction for new residential and commercial buildings by 2030. Zero net energy buildings reduce the energy demand and environmental impact of the building sector—currently responsible for roughly 40% of U.S. energy consumption—through energy efficiency and onsite (or near-site) use of renewable energy sources. By establishing minimum requirements for the energy performance of new construction and major renovations, building energy codes can evolve to ensure that homes and buildings are built to perform as ZNE in 2030. For this to happen, what must building energy codes require in terms of energy performance? This paper presents a summary of the technical, institutional, design, and policy opportunities and barriers to the development of zero net energy codes in time for their adoption in 2030. We discuss the ongoing needs for research, coordination, market transformation, and advocacy efforts to meet this goal, as well as code development milestones for the intervening code cycles.

The recent growth in ZNE construction in both the residential and commercial sectors demonstrates the feasibility of the technologies and construction practices that can deliver zero net energy buildings. New Buildings Institute has documented a total of 160 ZNE commercial buildings and districts in North America (either completed or in some stage of design, planning, or construction) and another 53 buildings with very low energy use intensities comparable to those of ZNE buildings (NBI 2014).[1] This is up from 60 ZNE projects and 39 low-energy (or zero net–capable) buildings documented in a 2012 study. The number of ZNE and low-energy homes is somewhat harder to ascertain, but a review of the literature and case studies suggests that the number of homes exceeds that of commercial buildings.

A recent study commissioned by the California investor-owned utilities found "that ZNE buildings will be technically feasible for much of California's new construction market in 2020" (Arup et al. 2012). While we have many of the technologies and techniques needed to build these buildings now, additional work is needed to bring ZNE construction to scale and make it standard construction practice. Economies of scale, more efficient and effective construction practices and techniques, new approaches, and innovative technologies can all lower the cost of ultra-low-energy and ZNE buildings while also making it easier to achieve in production-scale building and ensuring that these buildings deliver in performance what they promise in design.

Building energy codes set a minimum baseline for the energy efficiency of new construction and major renovations. In the United States, the major model energy codes are updated every three years. Each three-year revision presents an opportunity to lock in energy efficiency gains as new technologies and practices are proven and to amend code implementation and compliance strategies to meet evolving needs for fulfilling ZNE goals.

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[1] Of the 160 ZNE buildings identified, 33 have been verified to perform as ZNE over the course of a year of operation. The remaining 127 have made public commitments to achieving ZNE, but do not yet have documented ZNE performance (NBI 2014).

In this way, codes can ratchet up buildings energy performance and increase the likelihood of achieving 2030 goals for ZNE buildings.

Terminology

For our purposes, how are we defining ZNE?

In the buildings sector, "zero net energy" is a broad term generally understood to mean a home or commercial building that on average produces as much energy as it uses, achieved through energy efficiency and renewable technologies. Beyond this very general definition, a number of more specific definitions and terms have been put forth to better capture the specifics of how ZNE performance is achieved and measured.[2] These specific definitions reflect the differences in priorities and perspectives among the diverse set of parties interested in ZNE buildings—for example, emphasis on demand-side versus supply-side technologies or a focus on onsite energy use versus carbon emissions—and can have an impact on design decisions (Torcellini et al. 2006). Table 1 summarizes common terms related to zero net energy.

Table 1. Zero net energy terms and definitions

Term	Definition
Net zero site energy	A building that produces as much energy as it uses in a year, when accounted for at the site
Net zero source energy	A building that produces as much energy as it uses in a year, as measured at the source (i.e., accounting for energy used to generate and deliver the energy to the site)
Net zero energy equivalent, or off-site zero energy	A building that produces as much energy as it uses in a year, with consideration of off-site renewable energy sources
Net zero energy emissions, or zero carbon	A building that produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources
Net zero energy ready, net zero capable, or ultra-low energy	A highly efficient building that could meet its energy needs with the addition of onsite renewables

Source: Torcellini et al. 2006; NBI 2014

Common to these definitions is the recognition that the critical path to ZNE starts with reduction of building energy loads by means of energy efficiency. In some cases, this primary role for energy efficiency is made explicit with specific energy efficiency targets (e.g., the 2030 Challenge). Over time, California has refined its definitions of terms related to

[2] The National Institute of Building Sciences has undertaken a project to establish common national definitions for zero energy buildings terms and metrics; the initial results of their effort will be available for public review in late 2014 and final definitions and metrics are slated for publication in 2015.

ZNE buildings to recognize that ZNE buildings must meet energy use intensity (EUI) levels reflecting the best practices for highly efficient buildings (CEC and CPUC 2013).

Given ACEEE's focus on and expertise in building energy efficiency, this report focuses on the use of energy-efficient technologies and practices to achieve high-performing, ultra-low-energy (ULE) buildings that can meet a broad range of ZNE definitions depending on the needs and goals of the specific project and how owners choose to meet the remaining energy supply needs. This approach is also in keeping with this paper's emphasis on building energy codes, which primarily focus on building construction techniques and systems that govern and drive energy consumption rather than on the incorporation of onsite energy production systems (with some limited exceptions that we will address in later sections).[3]

To this end, we focus on possible ULE building codes in the future that:

- Emphasize energy efficiency improvements to allow for simple, cost-effective renewables or limited grid power/gas to meet remaining building energy needs (70–90% energy efficiency improvement relative to 2004 model codes)
- Apply to a single building or facility such as that covered by energy codes rather than to larger installations, campuses, or communities[4]
- Fairly address source impacts for any energy delivered to the site
- Have readily measureable and verifiable energy performance
- Provide confidence that the building will perform at a zero net level over time (i.e., zero net performance, not just zero net design)

The State of Ultra-Low and Zero Net Energy Construction

The number of ZNE and ULE buildings constructed to date represents a very small, albeit growing, fraction of the new construction market. Early efforts to design and build such high-performance homes and buildings as one-off demonstration projects have evolved as production builders and large-portfolio property owners are increasingly interested in constructing community-scale pilots and building prototypes to guide them in the shift toward ZNE.

The hundreds of ULE and ZNE buildings in operation today demonstrate how existing building materials and systems coupled with advanced design strategies and scrupulous construction practices can deliver extraordinary energy efficiency and provide insights into which strategies are most effective in achieving ULE performance in actual building operation. They also provide lessons on the areas where improvements in technical

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[3] This is not to say that future building codes will not incorporate provisions addressing onsite renewables and related systems.

[4] While this paper focuses on individual buildings, ZNE campuses, communities, and other groupings of buildings will be critical to meeting ZNE goals on average across the building stock. It is unlikely that all building types will meet ZNE or ULE criteria due to configuration and the presence of energy-intensive process loads; at the same time, other buildings will operate as net-positive energy. Methods for applying ULE/ZNE metrics on average will allow for coordination between buildings and building owners and will be an important part of future code development.

performance, construction quality, efficiency, and cost are needed to make ULE construction mainstream. While successful projects rely on a diverse set of technology and equipment choices, almost all demonstrate the importance of prioritizing energy efficiency from the initial design phase to meet ZNE goals, and the critical role of a rigorous integrated design approach.

Research and on-the-ground experience with energy-efficient building design, construction, and retrofit have resulted in an accepted rubric for prioritizing energy efficiency strategies and the introduction of renewables in project design and implementation. Table 2 provides a simplified view of the critical design steps and sample technology options for each stage in the process. Focusing first on reducing building energy demands and meeting major building functions with the highest-efficiency systems available reduces the amount of renewable energy needed to serve core building energy needs. This enables the flexibility that would be required for the building to continue to operate as ZNE if its use changed over time (e.g., from general retail to grocery) or occupants introduced new end uses to the building (e.g., home office, home medical equipment, and so on).

This rubric provides a good framework for examining progress toward achieving ultra-low-energy building performance in terms of advances in technologies and practices as well as improvements in cost effectiveness.

Table 2. Zero net energy design steps

Design step	Sample technology options
1. Reduce building energy loads with improved envelopes and the use of passive systems	Superinsulation, daylighting, exterior shading, natural ventilation
2. Install high-efficiency systems to address primary building energy loads	Heating, ventilation, and air-conditioning systems (including distribution), water heating, appliances/equipment
3. Install systems to manage building energy loads with effective control strategies and other mechanisms	Energy management systems, plug-load control strategies, feedback to users and occupants
4. Incorporate energy recovery mechanisms to minimize energy losses	Energy recovery ventilation, heat-pump water heaters
5. Use renewables to meet remaining building loads	Rooftop and other photovoltaic energy systems
6. Monitor and manage building energy use post-occupancy	Monitoring-based commissioning, occupant engagement

Source: Arup et al. 2012; NBI 2014

HOMES

Analyses of the technical potential for ULE and ZNE homes have found that ZNE construction is technically feasible now and will be for the majority of California's residential construction by 2020 (Arup et al. 2012). Nationally, experience with ultra-low-energy construction (e.g., off-grid homes, homes built to Passive House standards, and others) demonstrates that ZNE-capable homes can and are being built across the country.

Commitments by leading production builders provide further proof that ZNE homes can be built in diverse climates not just as one-off custom projects, but at scale.[5] Figure 1 compares the performance of existing homes with that of typical new- construction homes, homes meeting upcoming code requirements, and ULE homes (including Passive House and DOE Zero Energy Ready Homes).

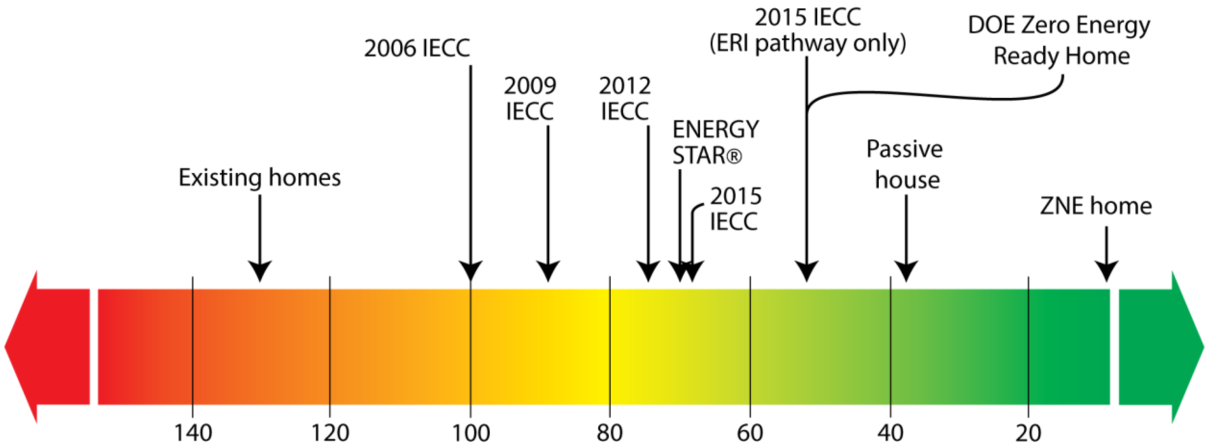

Figure 1. Comparison of home energy performance. The Home Energy Rating System (HERS) Index uses the 2006 International Energy Conservation Code (IECC) as the reference home (i.e., 2006 IECC = 100). *Source:* EIA 2013.

The strategies outlined below should provide a pathway to ZNE for most residential buildings. The one exception is high-rise multifamily buildings, which face the challenge of procuring sufficient renewables to meet building energy demands, primarily due to the limited roof area for installation of solar. Still, these buildings can achieve levels of ultra-low-energy performance similar to those of other residential building types (single-family and low-rise multifamily) and take advantage of community-scale renewable energy assets to operate as ZNE buildings.

Energy Efficiency Strategies

In accordance with the design steps outlined in table 2, this section highlights the advances in residential energy efficiency that offer the greatest promise for achieving the ultra-low-energy performance needed for ZNE operation and draws attention to areas where additional research and development are needed. Figure 2 breaks down energy consumption by end use for U.S. homes on average compared to conventional recent construction.

[5] Meritage Homes (2013) and KB Home (2011) are among the production builders that are offering or have announced plans to offer ZNE homes in the markets they serve nationwide.

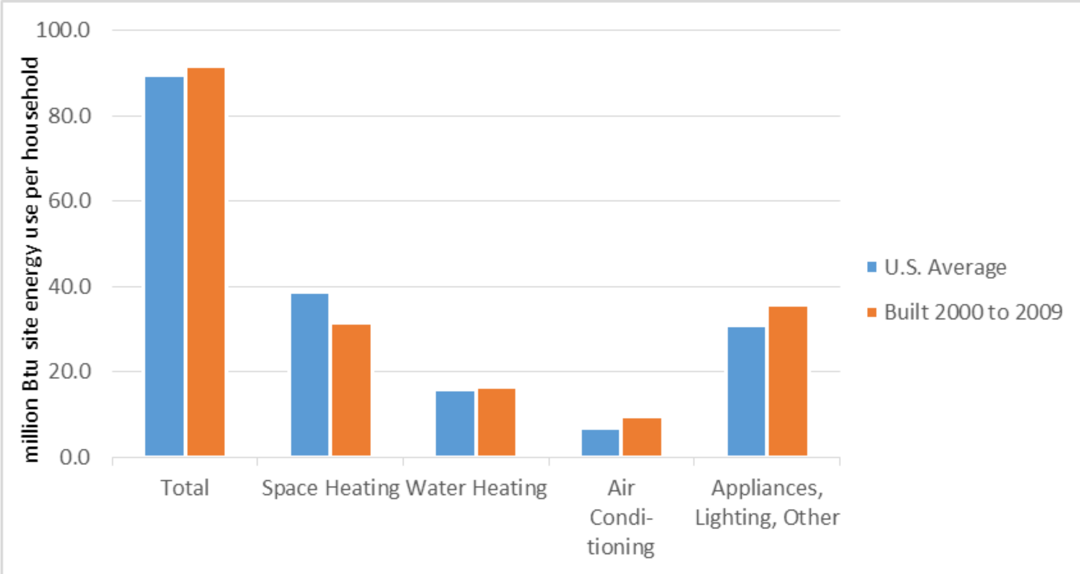

Figure 2. Energy consumption by end use in homes. *Source:* EIA 2013.

REDUCE LOADS In all but the mildest climates, space conditioning (heating and cooling) loads dominate residential energy consumption. Consideration of building orientation and incorporation of shading can optimize passive heating and cooling opportunities. By improving building envelopes, incorporating passive systems, and minimizing internal heat loads, heating and cooling requirements can be reduced and, in some cases, even eliminated during much of the year. As the first step in designing low-energy buildings, airtight construction techniques, advanced framing and wall assemblies, superinsulation, and high-efficiency glazing and doors have been primary targets of research and demonstration efforts.

Building energy codes and beyond-code programs emphasize the performance of the building thermal envelope, and recent improvements in materials and techniques have driven advances in code requirements and beyond-code labeling and recognition programs (see table 3). Homes built to the DOE Zero Energy Ready Home (ZERH) specification (formerly Builders Challenge) and the Passive House Institute U.S. certification (PHIUS+) incorporate materials and techniques that deliver thermal envelopes capable of ULE performance in all U.S. climates. Scaling up this level of construction will require an emphasis on builder and contractor training and the development of techniques that can simplify high-quality installation and reduce errors. One promising option for further investigation is greater use of prefabricated wall assemblies.

Table 3. Requirements for building envelope components

2006 IECC	2009 IECC	2012 IECC	2015 IECC	ENERGY STAR® 3.0	DOE ZERH
Airtightness (ACH_{50})*					
None	≤7.0	≤3.0 to ≤5.0	≤3.0 to ≤5.0	≤3.0 to ≤6.0	≤1.5 to ≤3.0
Duct leakage (CFM_{25}/100 ft^2 conditioned floor area)					
None	Total ≤12 *or* leakage to outdoors ≤8	Total ≤ 4; blower door verified	Total ≤ 4; blower door verified	Total ≤6 *or* leakage to outdoors ≤4	All ducts within thermal and air barrier boundary
Insulation, ceiling					
R-30 to R-49	R-30 to R-49	R-30 to R-49	R-30 to R-49	2009 IECC	2012 IECC
Insulation, wall (wood frame)					
R-13 to R-21	R-13 to R-21	R-13 to R-20+5 *or* R-13+10	R-13 to R-20+5 *or* R-13+10	2009 IECC	2012 IECC
Insulation, floor					
R-13 to R-30	R-13 to R-30	R-13 to R-38	R-13 to R-38	2009 IECC	2012 IECC
Insulation, basement wall					
R-0 to R-10/13	R-0 to R-15/19	R-0 to R-15/19	R-0 to R-15/19	2009 IECC	2012 IECC
Windows, U-factor					
1.20 to 0.35	1.20 to 0.35	NR to 0.32	NR to 0.32	0.60 to 0.30	0.40 to 0.27
Windows, SHGC					
NR to 0.40	NR to 0.30	NR to 0.25	NR to 0.25	NR to 0.30	NR to 0.25
Skylights, U-factor					
0.60 to 0.75	0.60 to 0.75	0.55 to 0.75	0.55 to 0.75	0.55 to 0.70	ENERGY STAR

*PHIUS+ requires ≤0.6 air changes per hour (ACH) in all but the hottest climates.

INSTALL HIGH-EFFICIENCY SYSTEMS Space conditioning systems well suited to meeting the needs of ultra-low-energy homes include high-efficiency radiant heating, ductless heat pumps, geothermal heat pumps, and high-efficiency combination water heaters. With careful system design, conventional ducted systems (e.g., high-efficiency condensing furnaces, central air-conditioners, and air-source heat pumps) can also meet ultra-low-energy specifications. Ducted central heating and cooling systems require special attention in ULE homes, given widespread issues with duct leakage and thermal losses as conditioned air travels through the ducts. To address these issues, ductwork must be installed in conditioned space. Studies suggest that relocating ducts to conditioned space (or shifting to ductless systems) yields HVAC savings on the order of 30% (Arup et al. 2012).

Oversizing of conventional single-stage heating and cooling equipment has long been a major source of energy waste; new multistage or variable-speed systems help relieve the oversizing penalty. Finding high-efficiency, small-capacity systems to serve low-load homes is a challenge for ULE construction. Low-energy homes can have heating loads of 5,000 British thermal units (Btu) per square foot or less, yet few systems are available to serve such low loads. For example, conventional heat pumps with a capacity below 1.5 tons (18,000 Btu) are rare; even among the ductless minisplit systems popular for high-efficiency homes, it is hard to find units below 1 ton. Research, product development, and market transformation programs are needed to build market channels for this equipment.

In the United States, interest in and experience with ULE homes has been concentrated in colder climates as well as in milder regions such as California and the Pacific Northwest. As interest in ULE homes grows in hot and humid climates, new techniques, new products, and new program requirements are emerging. One notable example is the evolution of Passive House concepts originally developed in northern Europe, without consideration of the types of hot-and-dry and hot-and-humid climates found in the United States. New products and updated equipment designs for the unique needs of these climates include evaporative cooling systems, split-coil dehumidifiers, conditioning energy recovery ventilators (ERVs), and systems with separate sensors and controls for relative humidity and temperature. Near-term emerging options for these climates include demand control ventilation, systems that can operate in dehumidify-only mode, and ERVs with higher latent load (dehumidification) efficiency.

Minimizing water heating loads requires attention to plumbing layouts and water use efficiency as well as installation of high-efficiency water heating equipment. Typical plumbing layouts result in significant energy loss in long pipe runs between the water heater tank and point-of-use outlets. Structured plumbing is the best solution for new construction (Klein 2008). For ULE houses, multiple hot-water sources will compete. High-efficiency integrated gas heat and hot-water appliances can be a good option, particularly in cold climates with high domestic hot-water use. Present cost trends for photovoltaic (PV) systems may actually favor PV-sourced heat pump water heaters, and even some point-of-use resistance hot water for seldom-used fixtures. Solar thermal is also an option. Deciding on solar thermal over other technologies will depend on the level of PV desired or required for the project and other project goals regarding reduction of fossil fuels that may preclude or favor gas water heating.

While lighting is a moderate energy end use in conventional homes, it accounts for a much larger proportion of electricity use in low-load homes. Inefficient lighting is not only a source of energy waste, it can also contribute to significant internal heat loads. Efficient lighting (typically CFLs) has become commonplace in energy-efficient new construction, but opportunities for achieving further and potentially more persistent savings remain. Advances in LED technology continue to yield improved efficacy and product performance. In new construction, use of dedicated LED fixtures can reduce energy use and optimize fixture optical performance. As LED performance continues to improve toward projected luminaire efficacy levels of 200 lumens per watt (lpw) by 2020 (DOE 2013a), savings relative to CFLs (60 lpw) and linear fluorescents (90 lpw) are clear.

MANAGE BUILDING ENERGY LOADS In order to achieve ULE operation, occupants need the tools to effectively manage home energy loads. Climate controls (e.g., programmable thermostats) are one well-known mechanism for managing space conditioning loads to increase occupant comfort and optimize energy efficiency. There is also a growing market for occupancy sensors and dimmers for residential lighting. Plug loads represent the fastest-growing energy end use in the residential sector. Vast improvements in the efficiency of major appliances have been offset somewhat by the demand for larger appliances with more features, growing product saturation, and the proliferation of new plug-load devices. As a result of these trends, plug-load management is a key challenge in achieving ZNE.

If plug loads are not adequately accounted for during design and construction, it may be difficult to meet energy efficiency and ZNE goals post-occupancy. New tools for understanding and managing home energy loads, including plug loads, are proliferating in the market; these include smart power strips and home energy management devices and software. The California ZNE feasibility study assumed that a 20% reduction in residential plug loads is possible by 2020 through selection of high-efficiency equipment and industry-wide improvements in plug-load efficiency (Arup et al. 2012).

INCORPORATE ENERGY RECOVERY MECHANISMS Tight, well-insulated thermal envelopes reduce heating and cooling loads, but also require increased attention to proper ventilation and moisture control. Whole-house mechanical ventilation is used to maintain adequate fresh air exchange in compliance with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.2, and is a requirement for DOE ZERH- and PHIUS+-certified homes. Heat recovery ventilators (HRVs) and ERVs provide fresh air while transferring sensible heat loads into supply or exhaust air depending on the season; in humid climates, ERVs can be used to transfer latent heat from supply air into the exhaust air, reducing the load on the air-conditioner or dehumidifier. When properly installed, these systems save more energy through reduced heating and cooling demands than the energy they require to operate and also provide non-energy benefits including improved air quality. However, they are significantly more expensive than conventional exhaust ventilation systems and may not be cost effective in milder climates at current equipment prices. Other energy recovery devices include desuperheaters (to capture waste heat from space cooling for use in water heating) and drain water heat recovery systems (to capture the energy embedded in heated water).

MONITOR AND MANAGE POST-OCCUPANCY ENERGY USE Once the home is occupied, residents need to monitor and manage their energy use to achieve ULE performance. This requires actively tracking energy use and modifying use of the home or relying on energy management systems or control devices as outlined above. A Passive House case study from Massachusetts (Holladay 2012) shows that this is an issue even for energy-aware homeowners. Significant plug loads—consumer electronics, a second refrigerator, and a dehumidifier, among others—led to much higher demands than expected (a continuous draw of 1,061 watts instead of the 621 watts expected). These plug loads, combined with unanticipated levels of lighting use and the increased air-conditioning needed to serve the internal cooling load resulted in overall electricity use higher than that of the average home.

Cost Effectiveness

Demonstrating cost effectiveness is critical to ensuring large-scale market acceptance of new energy efficiency technologies. In the case of new homes, it is equally important to keep incremental costs low to attract the interest of builders as well as home buyers who may not fully understand, appreciate, or trust that an ultra-efficient home can translate into a lower cost of ownership despite higher upfront costs. A California study found a 45–60% reduction in EUI for modeled single-family homes built to ZNE relative to a 2013 Title 24 baseline home and a 42–50% reduction for low-rise multifamily buildings (Arup 2012). Net life cycle costs were negative (i.e., energy bill savings exceeded additional upfront costs) for all of the modeled examples, even with the cost of rooftop solar included.[6]

Experience to date reveals the importance of a design-stage focus to achieving ULE/ZNE goals. Additional time and resources invested during the design stage can yield significant cost savings in other areas, thereby offsetting higher upfront design and construction costs. For example, projects designed to meet very tight envelope and high insulation targets may require greater investments in design, construction, and materials, but these costs can be recouped through elimination of ductwork, HVAC downsizing, and so forth. Going forward, the cost of such custom approaches will drop as they become the basis for production-scale building.

Investments in energy efficiency reduce the amount of renewables required for a ZNE home and, in many cases, are significantly less expensive than investments in solar PV. A study conducted for the California Energy Commission (CEC 2012) found that the costs of the energy efficiency measures required for homes designed to perform 30% better than the state's 2013 code (a requirement for the most generous Tier II incentives through the state's New Solar Homes Partnership) ranged from $3,380 to $5,330 for a 2,100-square-foot home, depending on the state climate zone. Costs for PV to generate electricity equivalent to the efficiency savings ranged from $7,490 to $36,650.

Other studies find similar costs for ULE new homes. An analysis of the costs and savings associated with the DOE Challenge Home program estimated that the incremental first cost of meeting the Challenge Home criteria relative to the 2012 International Energy Conservation Code (IECC, the national model code) in climate zones 3 (Fort Worth) and 5 (Indianapolis) ranged from $3,900 to $4,660 (DOE 2013b). Amortized over a 30-year mortgage, these costs were less than the projected monthly energy cost savings, leading to positive monthly cash flow for the home buyer. The largest portion of incremental costs ($1,700 to $1,875) was attributable to program requirements related to indoor air quality, installation of renewable-ready features, and rating and certification of HVAC system

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[6] Incremental first costs including PV ranged from $10,500 to $25,730, depending on climate zone. Separate costs for efficiency measures and PV were not available.

quality installation. Other higher-cost measures included duct encapsulation in the warmer climate (approximately $700), insulation in the colder climate (approximately $760), and heating and cooling equipment ($300–$770). The added cost of meeting the more stringent airtightness requirements was less than $300.

At present, many energy-efficient technologies have higher product and installation costs than today's baseline technologies. In the new construction market, these initial costs—particularly installation costs—may be lower than in the retrofit or replacement market because the home is designed to accommodate the new technology. The incremental cost of ULE home construction varies substantially by climate and by the features, amenities, and strategies chosen to achieve the ULE performance. While envelope and mechanical system measures yield significant savings and drive costs, lighting and plug loads offer relatively low-cost savings opportunities.

COMMERCIAL BUILDINGS

Data from existing ULE and ZNE buildings provide a wealth of information on the real-world energy performance of high-performance buildings and the most effective strategies for achieving the desired outcomes. Measured energy use data give an indication of the level of energy performance achievable, initial targets for projects with ULE or ZNE goals, and a sense of the scale of energy efficiency improvements necessary to meet these goals. Figure 3 compares the energy use intensities of existing buildings, code-compliant new construction, and ULE/ZNE buildings for a variety of common commercial building types. To achieve ZNE performance, new buildings will need to improve energy efficiency 60–75% relative to typical buildings and 30–50% relative to current building codes.

Experience to date and analysis of the technical potential for ZNE in commercial buildings finds that while a ZNE target is feasible for most building types, some will fall short for a number of reasons. High-rise offices, like high-rise multifamily buildings, lack adequate roof space for installation of sufficient PV. There are other commercial building sectors that have uniquely high energy use intensity that may prevent ZNE performance (e.g., health care facilities, food service), yet can still achieve significant reductions in energy intensity relative to current practice. These buildings may have the opportunity to install onsite renewables, but they may not be sufficient to meet their high energy demands. Energy codes may not reach ZNE levels for every single new building, but as indicated in figure 3, the specialty building types where this level of performance is more of a challenge make up a smaller portion of the building stock. Codes for these buildings can focus on achieving the most energy efficiency possible.

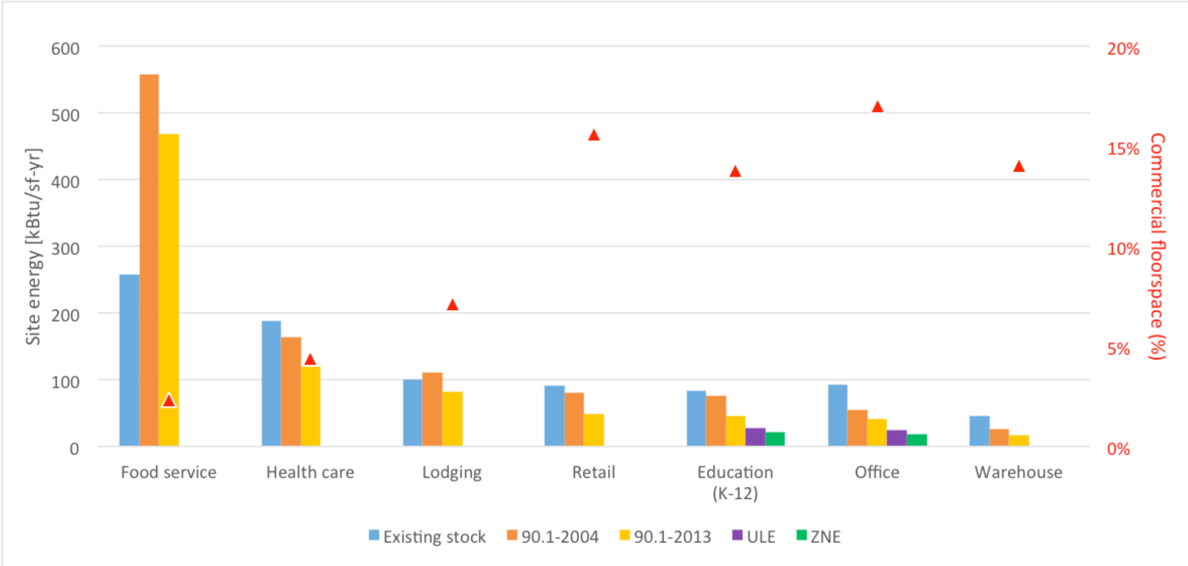

Figure 3. Commercial building energy use intensity, existing stock versus recent codes and ULE/ZNE construction. The percentage of commercial floor space is reported for existing building stock as of 2003. *Source:* EIA 2008; Goel et al. 2014; Halverson et al. 2014; NBI 2014.

Energy Efficiency Strategies

The first key to achieving ULE/ZNE performance cost effectively is adherence to an integrated design process in which the owner, design team (architects and engineers), construction trades, commissioning agent, operations staff, and in some cases occupants are engaged from the initial stages of the project. From the outset, the building owner and design team must be committed to the ULE or ZNE goals of the project. An explicit energy performance target or energy budget for the building is developed and adopted during the early design stages and communicated to all parties involved. Experience shows that adherence to integrated design principles and buy-in by all parties play critical parts in ensuring that energy performance goals are prioritized throughout construction and into the operations and occupancy phase of the building (NBI 2014). At present, few small buildings receive this type of engagement and support through design and construction; increasing access to and use of these tools by smaller buildings is a significant need.

REDUCE LOADS High-performance building design is dominated by load-reducing design features to meet energy performance objectives. Design options for reducing energy loads in commercial buildings include:

- Building and site orientation to maximize passive heating and cooling strategies while minimizing unwanted heat gain
- Daylight optimization through building layout, skylights, and other glazing options; light shelves; and light colors for interior finishes to reduce electric lighting loads
- Envelope performance measures, including window-to-wall ratio, size, and orientation, as well as materials selection, double skins, and so on
- Shading to minimize heat gain and reduce internal glare
- Design and location of stairways to reduce reliance on elevators

- Turning previously interior spaces into exterior spaces, thereby reducing overall conditioned floor area (e.g., covered circulation areas in schools) (NBI 2014; Arup et al. 2012).

INSTALL HIGH-EFFICIENCY SYSTEMS Once the major building design strategies are determined, the selection of technologies and systems to deliver key building services offer tremendous opportunities for efficiency improvement. Passive systems such as radiant heating, chilled beams, and natural ventilation can reduce or eliminate fan loads. Separate systems for space conditioning and ventilation can also reduce fan loads while addressing the significant losses associated with duct leakage in forced-air systems. Examples include space conditioning with variable refrigerant flow and related technologies, ground source heat pumps, evaporative cooling and ice storage and ventilation through dedicated outside air supply units, demand control ventilation, and operable windows. Careful system selection, design, and installation are essential to achieving energy savings and high performance from these systems.

Lighting is a much larger end use in the commercial sector with much greater energy savings potential. In addition to the savings from higher-efficiency light sources (most notably LEDs), commercial buildings generally present greater opportunities for savings through efficient lighting design, daylighting, and sophisticated lighting control strategies. The additional costs of these strategies can be offset through incentives, but also through the potential for building owners to provide significant demand response capabilities (i.e., reducing building energy loads during critical peak load periods) through lighting system control.

MANAGE BUILDING ENERGY LOADS The number and types of building energy management systems (EMSs), sensors and controls, and load management strategies available to commercial buildings is large and growing. Building owners and managers have access to a variety of options for monitoring and managing their energy loads in real time, or for working with outside vendors who offer energy-use monitoring and diagnostic services for ongoing optimization of building energy use. As these systems become more advanced, building owners and occupants can more proactively manage building energy loads, including the plug loads that have not been accounted for in traditional building EMSs, to align with the goals and objectives for ULE building operations. New tools for providing feedback on energy use in smaller buildings are expanding access to energy data and energy efficiency services to businesses without EMS or other mechanisms to help them understand and manage the energy efficiency of their facilities.

Cost Effectiveness

Recent studies demonstrate that many ULE and ZNE construction projects are cost effective, with overall project costs falling within the same range as conventional new construction projects. An analysis of the costs associated with ULE and ZNE buildings finds that the costs for achieving this level of performance are difficult to distinguish from overall project costs because "the design and technology tradeoffs due to the advanced systems blur the line of incremental costs" (NBI 2014). A comparison of 88 high-performance buildings (green, LEED Platinum, ZNE, or Living Building Challenge) found that total construction costs for these buildings were comparable to the building costs for a control group of conventional buildings; this held true for community centers, K-12 schools, low-rise office buildings, and wet labs (Morris, Matthiessen, and Lesniewski 2014). This was particularly true for buildings identified as "mainstream" rather than demonstration projects that were designed and built to showcase new technologies and unique architectural or design features without consideration of added costs.

A recent comparison of the costs for achieving ZNE in Washington, DC, found that energy efficiency measures added 1–6% to the cost of a new office building (energy efficiency and renewables added 5–10%), with a return on investment of just over 9% (ILFI, NBI, and Skanska 2014). A study of the cost of ZNE buildings conducted for the state of California supported the findings of these other studies, determining that commercial buildings can "achieve ZNE (or near-ZNE) status at little or no additional cost" and concluding that the opportunity to achieve ZNE performance cost effectively is greater in commercial buildings, where the more detailed design process, the number and availability of cost trade-offs, and the energy synergies are greater (Davis Energy Group 2012). Figure 4 illustrates the types of cost trade-offs available.

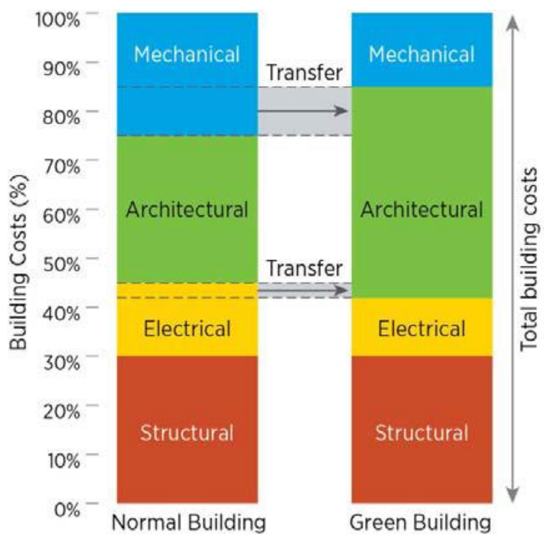

Figure 4. Cost trade-offs of ZNE buildings. *Source:* Davis Energy Group 2012.

Moving Energy Codes Toward Zero Net Energy

Building energy codes establish minimum energy efficiency standards for the design, construction, and renovation of buildings. Although the United States does not have a uniform national building energy code, the federal government has taken an active role in developing national model energy codes and in encouraging state governments to adopt and implement codes, as well as in providing education, training, and tools to assist state and local agencies, builders, and contractors in meeting code requirements.

The IECC and ASHRAE Standard 90.1 serve as national model codes for residential and commercial construction, respectively. The International Code Council (ICC) and ASHRAE update each code on a three-year cycle. Once a new edition of the IECC or ASHRAE 90.1 is published, U.S. DOE issues a determination of the relative efficiency of the new version of the code compared to current model code versions.

States have the flexibility to adopt amendments to the model codes.[7] Although states often amend the model codes to align with regional building practices or specific energy efficiency policies and goals, only a handful of states have developed their own code rather than using the model code or an amended model code.[8] In some states, municipalities have adopted codes that are substantially more stringent than the state code.

CHALLENGES AND OPPORTUNITIES IN CODE DEVELOPMENT

Diverse stakeholders play active roles in the development of building energy codes in the United States; their involvement presents opportunities and challenges to movement toward zero net energy codes. The stakeholders and decision-making rules in the respective code development processes determine the extent and pace of change in each cycle.

The model code for commercial buildings is ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings (i.e., buildings other than single-family buildings and multifamily buildings of three stories or less above grade). The standard is developed in accordance with American National Standards Institute practices following a consensus process guided by a committee of ASHRAE members. The Standing Standard Project Committee (SSPC) membership for the 90.1 standard is made up of 45 individuals representing a wide range of interests.[9]

The SSPC sets improvement goals at the outset of the code development cycle (e.g., for 90.1-2013, the SSPC set a goal of 40% whole-building energy efficiency improvement relative to ASHRAE 90.1-2004) and works to meet the goals through adoption of new or strengthened prescriptive requirements, performance targets, and HVAC equipment efficiency standards. SSPC members' experience and technical expertise lead to well-informed debates for even advanced technical proposals. As design elements and technical requirements for ZNE buildings are proven cost effective, technically feasible, competitive in the marketplace, and fair to end users, there is a strong likelihood that they will be adopted into ASHRAE 90.1.

For single-family homes and low-rise multifamily buildings, the model code is the IECC. The code is developed through a consensus process, with a cycle of hearings in which stakeholders are allowed to introduce amendments for a vote. A wide range of stakeholders can testify and submit statements in support of or opposition to amendments, but voting is limited to representatives of government building code agencies.

In contrast to the ASHRAE 90.1 process, the IECC development process is more responsive to local pressures. ICC does not set goals for efficiency improvements for the IECC. Instead,

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[7] When adopting amendments to commercial codes, the state code must meet or exceed the model code baseline (although there is no consequence for noncompliance). For residential codes, states must consider how amendments would impact energy use relative to the model code baseline.

[8] California, Florida, Oregon, and Washington have developed their own codes.

[9] In November 2012, ACEEE was named to a permanent organizational seat on the ASHRAE 90.1 SSPC.

each proposed amendment is considered first by a code development committee, and proposals that pass through committee face a final vote by code officials. In the current process, the nine-person development committee includes four representatives from the construction industry who to date have often voted as a bloc and have not been receptive to many proposals supported by the efficiency community. In practice if not principle, code proposals must be acceptable to this bloc to pass out of committee or face a more challenging approval process requiring two-thirds of the final vote. In the 2015 IECC development cycle (completed in 2013), this made it more difficult for innovative efficiency measures to pass through committee. This could present ongoing challenges to the adoption of more aggressive code requirements in support of ZNE construction.

A recent change to the ICC process could introduce further political jockeying among stakeholders—nationwide electronic voting on code proposals. Beginning in 2014, the ICC will allow code officials to cast electronic ballots on code proposals without attending the final public comment hearings. A two-week voting window will open after the final hearings. The prospects for strong code proposals will depend on the demand for efficiency gains by voting code officials and the jurisdictions they represent. Efficiency advocates and those hoping to roll back efficiency measures or maintain the status quo will be competing for support for their positions. The stakes are much higher for the 2018 IECC hearings and vote scheduled for 2016, and there is reason to assume that stakeholders will invest significant time and resources to influence code officials' positions. While it is too early to predict the effects of these changes on the IECC provisions, the change increases uncertainty about the prospects for moving the code toward ZNE building performance.

Another challenge to development of ZNE codes stems from the interplay of minimum equipment efficiency standards and code requirements. Under federal law, efficiency standards promulgated by DOE preempt code requirements. In other words, building energy codes cannot establish more stringent efficiency requirements than the federal standards for those products covered by DOE standards.[10] Minimum efficiency standards are developed based on the technical feasibility and cost effectiveness of product efficiency levels for the market as a whole. Since the equipment replacement market vastly outsizes the new construction market, the economics of the replacement market dominate in the standards rulemaking process. High-efficiency technologies, particularly installed equipment and systems such as HVAC, water heating, and light fixtures, may cost significantly less to install in new construction, where the design and construction plans can accommodate the system. As a result, standards are often set at levels below what is cost-effective for new construction.

Crafting Zero Net Energy Building Codes

The current versions of the national model residential and commercial building codes, the 2012 IECC and ASHRAE 90.1-2013, respectively, represent significant improvements in energy performance relative to earlier codes. Figure 5 shows the efficiency gains from each

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[10] Commercial HVAC equipment presents something of an exception to this rule. ASHRAE establishes minimum performance requirements for this system through the 90.1 process. DOE then either adopts these requirements as the federal minimum efficiency standards or sets stronger requirements based on its own analyses.

code cycle since the first national model codes were adopted in 1980. The past 10 years have witnessed dramatic increases in the energy efficiency requirements of both residential and commercial building codes, while the number of states that have adopted recent versions of the codes (i.e., 2009 and 2012 IECC and 90.1-2010) has increased twofold relative to 2007.

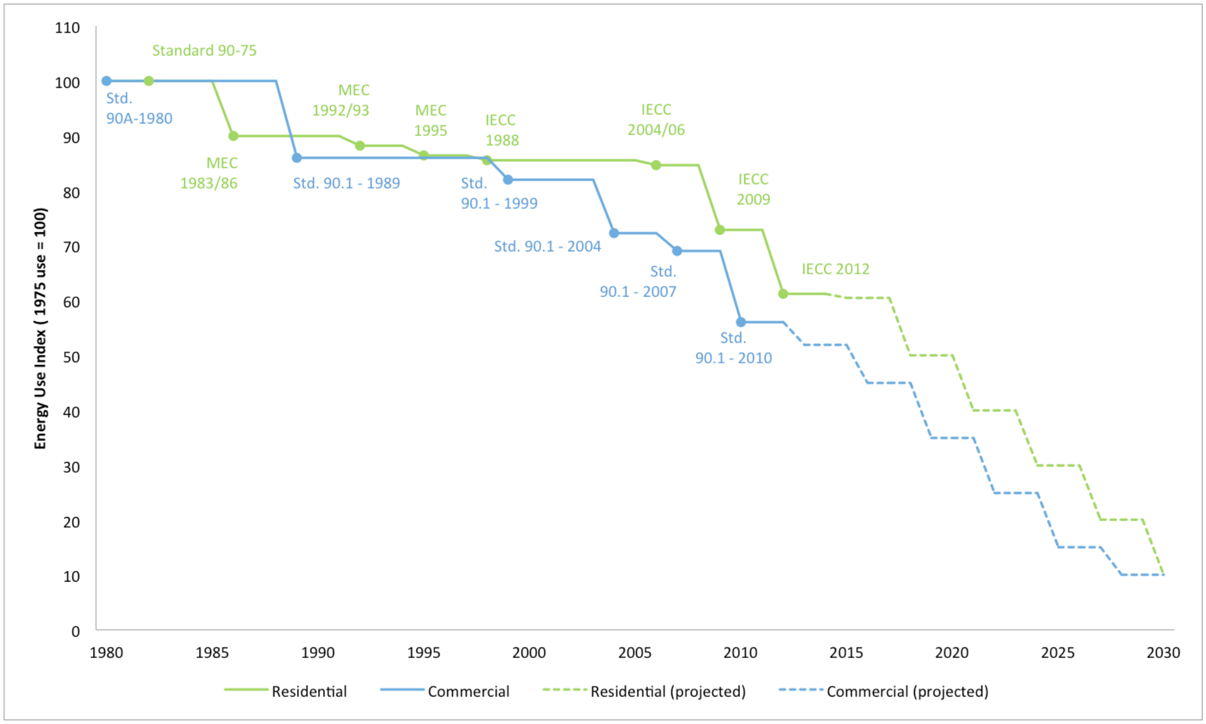

Figure 5. History of U.S. building codes, 1980–2012. *Source:* Data from U.S. DOE Building Codes Program.

Building on these recent improvements to achieve greater energy efficiency and, ultimately, ultra-low-energy code requirements will be challenging if not impossible, given the current design and structure of our building codes. The largest obstacles to ZNE in current codes include:

- The limited set of regulated end uses covered by the codes (primarily envelope materials, HVAC, water heating, and lighting)
- The diminishing energy savings opportunity in a number of regulated equipment types
- Federal preemption of code requirements for equipment efficiency for products covered under the federal appliance standards program
- Reliance on prescriptive requirements and/or performance methods based largely on modeling of building design
- A lack of available mechanisms to account for or address building operations and maintenance

Addressing these obstacles in the time available presents an enormous challenge for policymakers, design professionals, and the code development community. Still, there is a growing consensus that the move to ZNE codes is necessary to meet our national energy and environmental protection goals. Work is underway to devise specific strategies for ZNE codes that can overcome these obstacles in a timely and effective way (Cohan, Hewitt, and Frankel 2010).

Returning to the building design rubric outlined in table 2, building codes have traditionally been concerned with the first two steps (reduce loads and install high-efficiency equipment). With recent advances, codes have begun to address the third step (install systems to manage loads), but much more work is needed. To achieve ULE performance, the codes must be expanded to fully incorporate steps three, four, and six (install systems to manage loads, incorporate energy recovery mechanisms, and monitor and manage energy use post-occupancy); for ZNE buildings, step five (use renewables) must be addressed.

CAPTURE SAVINGS ACROSS ALL BUILDING ENERGY END USES

Current model codes form a baseline for new building energy use; they contain prescriptive requirements and/or performance criteria for materials and equipment including:

- Building shell: walls, floor, and ceiling
- Doors and windows
- HVAC systems and some equipment
- Lighting systems and equipment (hardwired)
- Water heating systems and equipment
- Water fixtures and water-consuming appliances

In the years since the advent of energy codes, the energy use picture in homes and commercial buildings has changed substantially, as illustrated in figures 6 and 7.

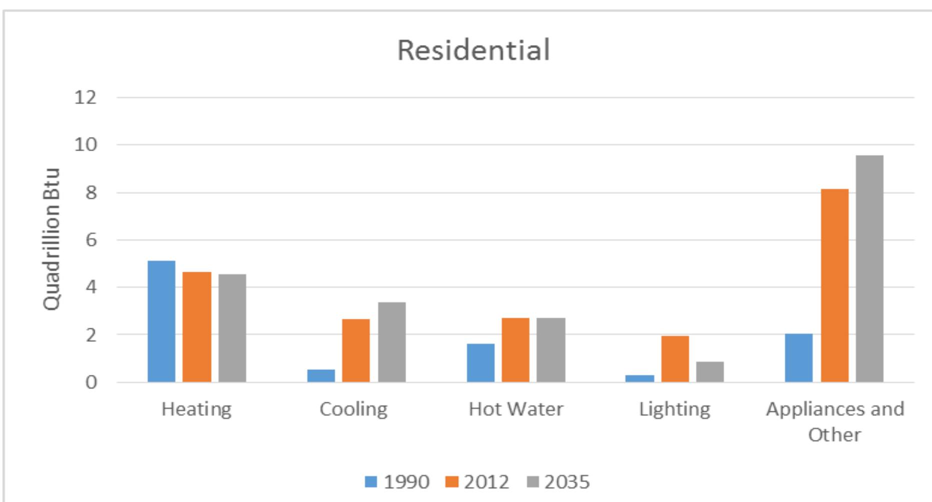

Figure 6. Residential energy consumption by end use, 1990 and 2010 versus 2035 projection. *Source: Annual Energy Outlook 1994* (EIA 1994) and *Annual Energy Outlook 2014* (EIA 2014).

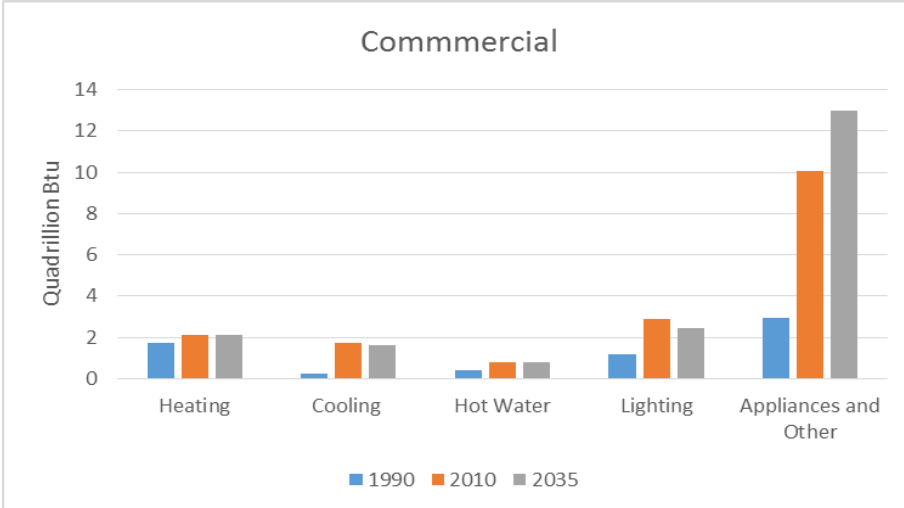

Figure 7. Commercial energy consumption by end use, 1990 and 2010 versus 2035 projection. *Source: Annual Energy Outlook 1994* (EIA 1994) and *Annual Energy Outlook 2014* (EIA 2014).

Energy codes and minimum appliance and equipment standards coupled with the emergence of ratepayer-funded energy efficiency programs—investing $7.7 billion in 2013 alone, primarily in the building sector (Gilleo et al. 2014)—have resulted in tremendous improvements in building envelopes and major energy end uses. As the energy consumed for heating and lighting becomes a smaller portion of the building energy use pie, the contribution of other equipment and systems is garnering greater attention. At the same time, new end uses are proliferating—most notably consumer and office electronics—and along with shifts in energy-using behaviors now receive serious consideration as energy savings opportunities. These trends are expected to continue as miscellaneous end uses—including a number of plug and process loads—are projected to account for 28% of residential and 49% of commercial building energy consumption in 2035 (EIA 2014).

Efficiency programs and equipment standards have expanded their coverage to address a much wider range of end uses, particularly plug loads and process loads. Energy codes have been slower to expand their scope of coverage to address these loads, a much more complex task within the existing code structure, but one that must be completed to achieve ULE goals. By failing to include appliances, plug loads, and portable light sources, current codes fail to account for well over 30% of residential and commercial building energy use. The main barrier to including plug loads in code is that it is difficult to establish acceptable values or limits on plug-load energy use given the variability in energy use. This variability depends on the number of occupants, the number and types of plug loads in the home or of business-process loads in commercial facilities, and occupant behavior and lifestyle. For example, a household with a full home office to accommodate telecommuting is likely to have a greater number of plug-load devices and higher usage of those devices than similar homes in which the occupants are employed outside the home. ASHRAE has taken an initial step toward addressing plug loads by requiring sweep or occupancy controls on 50% of power outlets in open offices and computer classrooms; controlled outlets must be labeled as such. California is taking steps to account for unregulated loads; the modeling software for the 2013 version of the state's building energy code includes a number of nonregulated loads (e.g., interior and exterior lighting, appliances, and other plug loads).

One promising approach for dealing with this complexity is to move the emphasis from improving specific regulated end uses (and prescriptive component performance) to improvements in whole-building energy use. Under such an approach, designers of buildings with high plug-load requirements would be able to compensate for them by further improving the building shell and other systems. ASHRAE has taken the initial steps in making Standard 90.1 a true whole-building energy use standard. Recent updates to the purpose and scope of the standard allow the SSPC to include previously unregulated loads, new equipment or building systems that are part of industrial or manufacturing processes, plans for operations and maintenance, and utilization of onsite renewables in future code revisions beginning with 90.1-2016. The 2015 IECC now includes an Energy Rating Index that provides a whole-building path to code compliance using home energy rating systems.

DEVELOP SYSTEM METRICS TO MOVE BEYOND COMPONENT EFFICIENCY

Innovation in building materials, systems, and components have allowed for significant advances in building codes and equipment standards over the past two decades. Moving forward, the potential for additional efficiency gains diminishes as we reach the maximum efficiency limits for many equipment types (e.g., limits on Carnot efficiency in cooling systems). Where there are still gains to be made, the incremental energy savings are a smaller and smaller percentage of overall building energy use and contribute less toward the reductions needed for ULE and ZNE performance. In the commercial sector, current codes already push the limits of equipment efficiency for chillers, a type of cooling system commonly used in large buildings.

While we may be reaching the max-tech efficiency level of a specific equipment type, there are still ways to deliver the specified building service more efficiently. For example, there is little room for additional improvement in the minimum chiller efficiency requirements in Standard 90.1, but a much greater potential for savings in the HVAC system as a whole (e.g., the chiller and associated pumps, fans, and so on). To capture these savings, ASHRAE is beginning to look to system metrics that set efficiency requirements for the total performance of all mechanical equipment within the boundary of a defined system rather than focusing on the individual components of the system. Trade-offs among all the equipment within the system boundary could be allowable as long as the system performance metric is met. This would allow the HVAC system metric to move to a higher level over time to reflect available improvements in systems design best practices, equipment efficiency, and controls. In the residential sector, establishment of an envelope U-value is another example.

In October 2013, the Standard 90.1 mechanical committee began work on a system efficiency metric for chilled water systems for inclusion in the 90.1-2016 standard. Other candidates for a system performance metric include building shell and lighting in the commercial sector. In the residential sector, mixed performance/prescriptive measures might make more sense, such as requiring all ductwork and other thermal conversion and distribution to be inside the thermal envelope and requiring a specified minimum delivered air volume per kWh consumed.

SHIFT THE FOCUS TO ACTUAL BUILDING ENERGY USE

"Every building is a forecast. Every forecast is wrong." —Stewart Brand

ULE and ZNE buildings are a means to reach energy and environmental goals. To meet those goals, these buildings must meet stringent EUI targets not only on paper or in computer models, but also in actual, ongoing operation. Studies comparing predicted building energy performance based on modeling to actual metered in-use performance demonstrate the limitations of current energy models.

Today's codes govern building design and, to a degree, system and component efficiency, but not building energy use. The first building codes were purely prescriptive, and current codes continue to provide prescriptive requirements for the building shell and systems. Performance-based codes offer an alternative compliance pathway for builders, allowing for trade-offs in energy efficiency between covered building systems as long as the end result is equivalent to or better than prescriptive code. While performance-based codes allow for greater flexibility and the opportunity to incorporate new technologies and practices that may not yet be recognized by prescriptive codes, they share many of the limitations of prescriptive codes and fail to deal with actual energy use.

To address this disconnect, many in the building community have been working on the concept of outcome-based energy codes. At the broadest level, outcome-based codes "refers to any code requirement or code mechanism (such as enforcement) based on actual energy outcomes after the building is occupied" (Denniston 2012). In practice, outcome-based codes will require establishment of performance targets (or target energy outcomes, TEOs) "derived from the actual performance outcomes from a survey of buildings" (Hewitt, Frankel, and Denniston 2010). Compliance is determined by comparing actual post-occupancy building energy use with the relevant performance target. Another potential benefit is that by simplifying the metrics that need to be examined, outcome-based codes may eliminate pressure for code officials to have extremely sophisticated engineering knowledge and skills to enforce the code for complex commercial buildings. A version of this compliance approach has been incorporated into the 2015 International Green Construction Code by the final votes of the ICC's code officials in November 2015. This could provide early experience and lessons on implementation of an outcome-based code prior to wide-scale adoption.

For Standard 90.1, ASHRAE is working to improve its existing alternative to prescriptive compliance, the Energy Cost Budget, by incorporating the proposed Addendum *bm* to the Appendix G Performance Rating Method (Rosenberg and Eley 2013). Figure 8 illustrates the evolution of 90.1 compliance from a purely prescriptive method through the proposed Addendum *bm*. While this development represents positive movement toward greater consistency in performance-based modeling for code compliance and voluntary certification programs and in setting energy savings targets for future code development, it falls short of a move to codes based on actual building energy use.

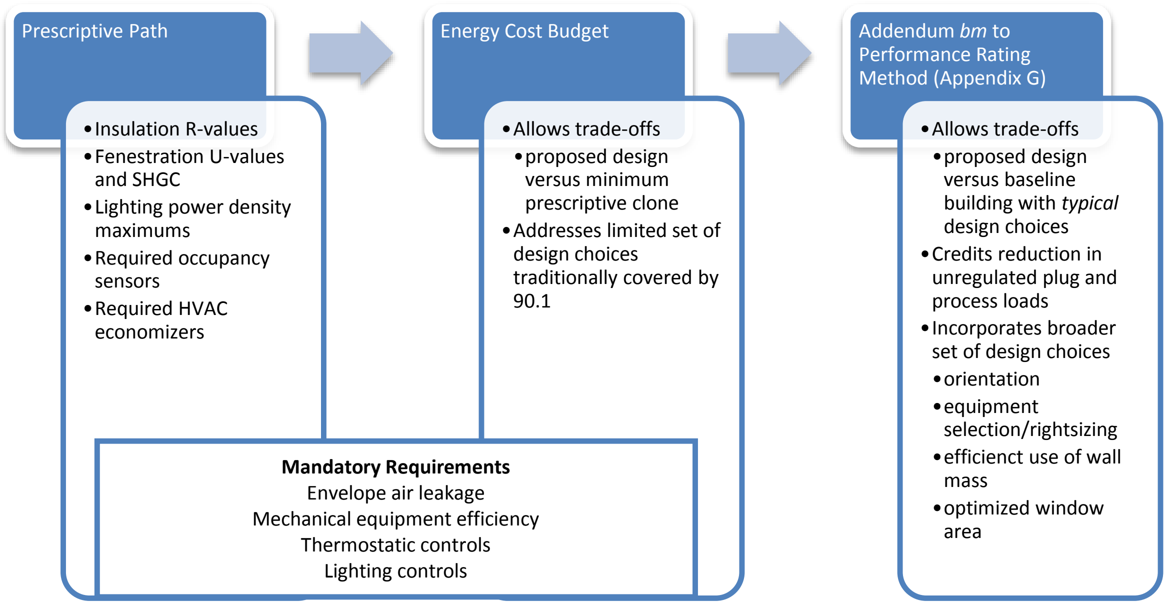

Figure 8. Evolution of Standard 90.1 compliance methods

Further progress toward outcome-based codes will require addressing a number of outstanding questions and concerns about their structure and implementation, including:

- Who is ultimately responsible for code compliance? Architect, builder, buyer/owner, others?
- How is the code enforced post-occupancy? Who is held accountable for noncompliance and how are deficiencies remedied?
- Can an outcome-based code cover mixed-use buildings and unusual types of buildings?
- Can a TEO approach address concerns about higher EUIs for buildings with high occupant density? These buildings may have lower per capita EUI and meet other policy objectives (e.g., reduced transportation energy, reduced sprawl). What is the appropriate metric for TEO? Is there a role for considering other objectives in the code?

CONSIDER OPERATORS AND OCCUPANTS

Numerous studies have demonstrated the impact of building operators and occupants on building energy consumption. In commercial buildings, retrocommissioning yields average whole-building energy savings of 16%, largely through improved operations and maintenance practices and correction of operational deficiencies, even in relatively new buildings (Mills 2009). Studies of both new and existing building commissioning have found a high level of persistence of savings, which can be attributed to the emphasis on operator training and the installation of monitoring and feedback systems to facilitate ongoing tracking of energy performance and identification of additional efficiency measures (Mills 2009).

In homes, research demonstrates differences in energy use attributable to occupant behavior among virtually identical houses and within the same house after a change in residents (Seryak and Kissock 2003). These behavioral differences can translate into wide variations in energy consumption among households. The impact of occupants' decisions may be amplified in ULE homes, with their vastly reduced thermal losses.

To effectively ensure ULE/ZNE performance post-occupancy, building energy codes need to consider the impact of building occupants and operators on building energy use. One way to do this is through commissioning requirements. The commercial building code in Seattle and California's Title 24 both incorporate language requiring commissioning of new facilities. Provisions for installation of metering equipment necessary for post-occupancy monitoring and verification and the shift to outcome-based codes discussed above would expand the focus of codes to include the people using the building. Expanded deployment of feedback mechanisms, sensors, and controls could provide occupants with the tools they need to more effectively manage home and building energy performance.

While research and building case studies demonstrate the feasibility of low-energy design and construction, more evidence of the operational requirements for achieving actual ULE/ZNE levels of energy performance in building operation are needed. As the number of buildings constructed to ZNE guidelines increases, ongoing monitoring and reporting of their energy performance will provide critical insights and lessons. Post-occupancy evaluations of buildings that have incorporated new technologies, integrated systems, and user-engagement strategies can be used to identify the most effective approaches and glean insights into how to incorporate them into codes when feasible.

DESIGN CODES THAT ANTICIPATE THE FUTURE

The emphasis of this report is on getting to codes that achieve ULE/ZNE construction by 2030. In the interim, codes can be designed with this low-energy future in mind so that buildings constructed before 2030 can also achieve this level of energy performance with relatively straightforward retrofits or equipment replacements at a later date. This type of future-proofing would obviate some of the built-in obsolescence found in legacy construction.[11]

One example of this type of anticipatory provision is in the 2013 version of California's Title 24 Building Energy Efficiency Standards. The code includes requirements for solar-ready roof construction for residential and commercial buildings to facilitate post-occupancy installation of solar PV or solar thermal panels. Similarly, the DOE Zero Energy Ready Home program requires builders to follow a checklist to ensure that homes are renewable energy ready. Other potential future-proofing provisions include installation of drains to accommodate heat-pump water heaters and heat-pump dryers and of piping for solar thermal systems.

[11] Stover, Sachs, and Lowenberger (2013) provide an overview of areas in which codes in general, not just energy codes, inhibit the introduction and broader adoption of energy efficiency technologies.

Another aspect of anticipating the future is ensuring the persistence of high-efficiency performance in building components and installed systems. Current rating methods for building equipment and systems only measure the energy use or efficiency of new products. The limited amount of data on energy performance over the life of components and systems leaves many unanswered questions about which types of equipment, system components, and installation or construction techniques deliver the best energy performance over time. Further research could provide valuable information on the best strategies for ensuring the persistence of efficient performance over time that could in turn be incorporated into codes and standards.

Key Issues and Targets for the Upcoming Code Cycles

For each of the strategies outlined for crafting ULE/ZNE codes, near- and longer-term priorities with corresponding targets for emphasis in each successive code cycle can be identified. Tables 5 and 6 represent a first attempt to map these strategies into specific issues for each of the IECC and ASHRAE 90.1 code development cycles between now and 2030. Beyond the specific items included here is the assumption that with each code cycle, there will be incremental increases in the prescriptive requirements for building materials and equipment (although, as 2015 IECC experience shows, this might not always be the case).

Table 5. Potential issues for upcoming IECC development cycles

Strategies	IECC 2018	IECC 2021	IECC 2024	IECC 2027	IECC 2030
Capture savings across all building energy end uses	Add covered loads: builder-installed plug loads (e.g., hardwired loads)	Add covered loads: plug-load management			
Develop system metrics to move beyond component efficiency	Water heating (e.g., structured plumbing)	HVAC: beyond National Appliance Energy Conservation Act minimums			
Consider operators and occupants	Residential feedback		Post-occupancy metering and reporting		
Shift the focus to actual building energy use	Require submeters: phase in by building size or type over two code cycles		Establish outcome-based performance path		Require outcome-based performance path for some building types

Table 6. Potential issues for upcoming ASHRAE development cycles

Strategies	90.1-2016	90.1-2019	90.1-2022	90.1-2025	90.1-2028
Capture savings across all end uses	Elevators (hoist power and standby), plug-load management	Process loads	Process loads		
Develop system metrics	Large chilled water systems	Lighting energy use (not just LPD), water heating	Smaller built-up HVAC, package HVAC		
Consider operators and occupants	Require O&M plans	Cx requirements		Post-occupancy metering and reporting	
Shift the focus to actual building energy use	Require submeters: phase in by building size type over two code cycles		Develop TEOs, establish outcome-based performance path		Require outcome-based performance path for some building types/sizes
Design for the future and inherent uncertainties	Solar-ready roofing and connections		Address persistence (component/ equipment efficiency)		

Federal guidance or targets for model codes could stimulate progress toward codes that incorporate new approaches and achieve higher levels of efficiency. Harris et al. (2010) outline the role that proposed federal legislation in 2009 and 2010 had in prompting wider support for stronger code provisions. The proposed language directed DOE to take over model code development if the code development organizations failed to meet multiyear code stringency and compliance targets. More limited targets in the American Recovery and Reinvestment Act of 2009 (ARRA) tied receipt of stimulus funds to state commitments to adopt codes meeting or exceeding the 2009 IECC or ASHRAE 90.1-2007 and to develop plans for achieving 90% code compliance by 2017. In the years immediately following passage of ARRA, code adoption rates accelerated. DOE has increased its focus on technical assistance and support for state building code efforts, including development of a methodology for measuring code compliance rates.

Strategies to Ease the Transition to Ultra-Low-Energy Codes

While getting building energy codes to ZNE by 2030 will be challenging, much can be done to ease the transition and increase the likelihood of achieving this goal. Complementary policies, targeted research, market transformation and related activities, and focused coordination of efforts and advocacy directed toward the overarching goal can establish the foundation for ZNE while providing energy savings and related benefits in the interim.

COMPLEMENTARY POLICIES

Federal, state, and local energy efficiency policies can help bridge the transition to ZNE codes by increasing our understanding of building energy performance, boosting demand for more energy-efficient homes and buildings, increasing market capacity for high-efficiency construction, and introducing more certainty for market actors about future code requirements. A strong suite of policies can pave the way for the aggressive code changes that are needed.

Building Labeling, Rating, and Disclosure

Data collected through benchmarking and disclosure ordinances and other policies that mandate reporting and/or disclosure of building energy use can be used to understand how buildings are performing, particularly newer buildings. This provides a new mechanism for gathering actual building energy use data on a statistically significant set of buildings representing a number of building types and uses, data that would be crucial to developing performance targets for outcome-based energy codes.

In addition to benchmarking and disclosure of energy performance for existing buildings, there is a role for rating and/or labeling the estimated efficiency of new buildings. Existing rating and building labeling programs such as the Home Energy Rating System (HERS) and ASHRAE's Building Energy Quotient (bEQ) As Designed label are mechanisms for communicating information on expected building energy use based on well-vetted and robust rating methods. Both are particularly well suited for new construction and could serve this function. In the case of HERS rating, mandatory home energy ratings would prepare the market for the adoption of codes (like the 2015 IECC) that include the use of HERS ratings as an alternative compliance pathway. Endorsement labels certifying building energy efficiency, such as DOE Zero Energy Ready Homes, are another tool.

Public Sector Leadership

The public sector has a unique role to play in research, development, and deployment of new technologies and practices with significant social benefits. In the buildings sector, government agencies at all levels have taken the lead in demonstrating sustainable building practices, energy-efficient procurement, building benchmarking, and, to a lesser extent, advanced building operations and maintenance. The low cost of capital for public sector agencies coupled with longer acceptable payback periods and lower thresholds for return on investment make it easier for the public sector to invest in emerging technologies that often entail higher initial costs. Just as governments were early adopters of the LEED green building certification, governments can adopt strategies for ULE buildings, serve as demonstration sites for geographically appropriate low-energy strategies, and document their experiences to help drive acceptance and demand in the broader market.

Stretch Codes, Green Codes, and Beyond-Code Guidelines

States may allow local jurisdictions to adopt more stringent code requirements, called "stretch codes." Cities may elect to adopt a more recent version of the model code as a stretch code or to develop specific provisions to address particular issues. These advanced codes can serve as a proof of concept for new code requirements or alternative compliance mechanisms. In recent years, states and cities have adopted some novel approaches, using codes to encourage innovative building practices and to pave the way for next-generation building technologies. Stretch codes can be mandatory or voluntary; in some jurisdictions, the local government entices builders to use a voluntary stretch code by allowing higher-density development, offering accelerated permit review, or other tangible benefits.

Of particular note, Massachusetts was the first state to adopt an above-code appendix to its state code, the 120.AA Stretch Energy Code.[12] The stretch code is an enhanced version of the 2009 IECC, with greater emphasis on performance testing and prescriptive requirements (e.g., blower doors, duct leakage). It was designed to be approximately 20% more efficient than the base energy code for new construction (at the time, the 2009 IECC). As of October 2014, the stretch code had been adopted by 146 of Massachusetts's 351 cities and towns, representing more than 52% of the state's population (MA DOER 2014). In July 2014, the 2012 IECC became the statewide base code for Massachusetts; the state is now considering changes to the stretch code so it will continue to represent substantial savings relative to the base code. Other states using stretch codes include California and Oregon.

At the local level, Austin demonstrates another approach to advanced codes. In 2006, Austin committed to achieving a goal that all new homes be zero energy capable by 2015.[13] In accordance with this commitment, the city developed local amendments to the IECC as well as a set of incremental targets for each code through 2015 to ensure that homes meet the energy efficiency levels required for zero energy capable homes. Similar forecasting approaches have proven effective for achieving efficiency improvements in lighting and appliances.

In response to the growing interest in sustainable buildings, ASHRAE and the ICC have introduced green building standards (ASHRAE 189.1 and the International Green Construction Code [IgCC], respectively). Recently, ASHRAE, ICC, and the U.S. Green Building Council (USGBC) announced a new agreement to coordinate development of Standard 189.1 and the IgCC, to combine them into a single regulatory tool for local code adoption, and to collaborate with USGBC to align with elements of the LEED program for green buildings (ASHRAE 2014). As more states and municipalities take steps to adopt stretch codes, these green standards can serve as models so each jurisdiction is not left to devise its own stretch code requirements. In addition, ASHRAE is currently working on a revitalized residential building standard (ASHRAE Standard 90.2), with a stated goal of making 90.2 a leadership standard designed to yield higher efficiency levels than each successive iteration of the IECC.

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[12] Amendments to the Massachusetts building energy code (including Appendix AA, the stretch code provisions) can be downloaded from http://www.mass.gov/eopss/docs/dps/8th-edition/115-appendices.pdf.

[13] A home is zero energy capable when it is energy efficient enough to achieve net zero energy consumption over the course of the year with the addition of onsite renewables. The City of Austin defines a net zero capable home as a single-family home that is 65% more energy efficient than a typical home built to the Austin Energy Code in 2006.

Valuing Energy Efficiency in Financial Transactions

Public policy also has a role to play in reducing financial barriers to greater investment in energy efficiency. To date, the financial markets have been slow to adopt mechanisms to address the lack of information about energy costs in relevant financial transactions. One mechanism for dealing with this is to require disclosure of anticipated building energy use requirements to potential buyers at the time of mortgage underwriting. Just as sellers are required to disclose the estimated annual costs of property taxes, interest, and insurance, underwriting rules could be updated to include estimated energy costs (which often exceed annual insurance costs). If this information was visible, home buyers could then make better-informed decisions about the total cost of ownership of various properties. Building energy rating and disclosure policies can serve a similar function.

Other Policies

The transition toward increasingly performance-based codes and ultimately outcome-based codes will require expanded use of submetering and mechanisms for data collection and data sharing with code officials. Early submetering requirements can pave the way by getting data needed to establish robust TEOs. The Washington state code has included submetering requirements for commercial buildings since mid-2010; Seattle has added submetering requirements to its code, as has the IgCC. In New York City, submetering requirements are being phased in for new and existing commercial and large multifamily buildings.

RESEARCH NEEDS

With the established goal of ULE/ZNE by 2030 and the interim targets for each code cycle in mind, it is easier to identify research needs and priorities. A list is provided here, but further efforts to develop a research agenda that prioritizes needs and coordinates efforts would be very valuable. These efforts can build on the work of the National Institute of Building Sciences (NIBS), the National Institute of Standards and Technology (NIST), and others in this area.

Data

Forty years after the first energy crisis, our understanding of how energy is dissipated in buildings is still lacking; a better understanding is key to devising better building codes and achieving ULE building operation. Larger-scale metering and submetering data from a broader set of buildings would greatly inform our understanding of whole-building and system-level energy flows and the most crucial and effective avenues for reducing buildings' energy consumption. New technologies can facilitate the collection and aggregation of field data on a scale unimaginable in the past. Pervasive interconnection, inexpensive wireless sensors, and software allowing for load disaggregation make it possible for residents, building operators, and other facility staff to deploy these technologies.

This type of large-scale data collection can be augmented with targeted studies of specific design and operations strategies to identify the best opportunities and mechanisms to incorporate into code and to establish strong but feasible targets for outcome-based codes. Strong targets can draw on these data to determine the expected savings from measures that are difficult to incorporate into code requirements (e.g., stair and elevator locations).

Technology Development

Technology research and development efforts are needed to increase energy savings and lower the cost of efficiency improvements in building components and systems. As outlined in the "State of Ultra-Low and Zero Net Energy Construction" section above, the tools, technologies, and practices for constructing ULE/ZNE homes and buildings are generally available off the shelf today; what is missing are the techniques and economics to rapidly scale up those technologies and practices into mainstream construction. Priority research areas include the following.

IMPROVED CONSTRUCTION QUALITY, EFFICIENCY, AND PRODUCTIVITY IN CONSTRUCTION TRADES As shown in figure 9, over the 40 years from 1964 to 2004, productivity in the construction trades remained flat while productivity in other industries grew at a fast pace. Research in this area could focus on improving techniques for site-built construction as well as on increasing productivity by better incorporating manufactured building components such as wall assemblies. This has been one area of research pursued through the Building America program. Improvements in this area could help to accelerate the pace of adoption of new technologies and practices in the construction sector.

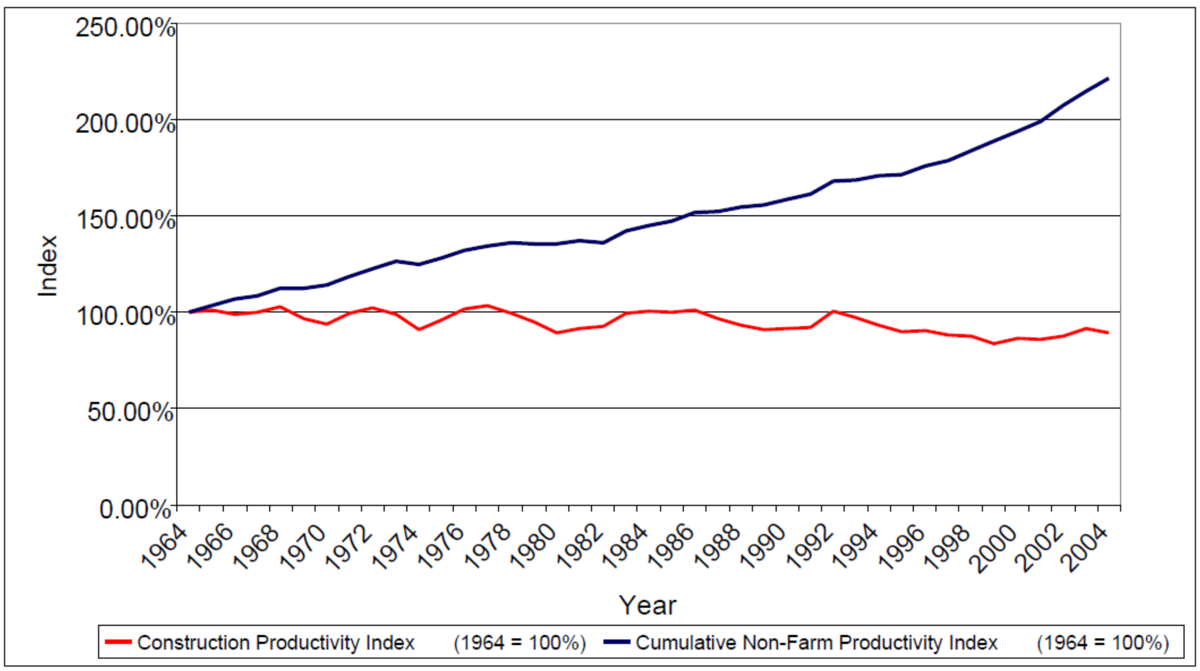

Figure 9. Labor productivity index, non-farm versus construction trades, 1964–2004. *Source:* U.S. Department of Commerce, Bureau of Labor Statistics

ADVANCED HEATING AND COOLING SYSTEMS Research in this area could focus on developing and bringing to market heating and cooling systems that can effectively and efficiently condition buildings with low loads through the use of tight envelopes, low fenestration heat gains, and good natural ventilation strategies. This could include small-capacity systems, advanced integrated systems to deliver space heating from the domestic water heating system, and so on. Other priority areas for exploration include identifying building types and applications where decoupling space conditioning from ventilation makes the most sense and is cost-effective. In its review of ZNE buildings, NBI (2014) found many successful examples of buildings using variable refrigerant flow systems, dedicated outside air systems (DOAS), and similar approaches in place of traditional variable air volume or VAV-based systems. In California, however, the latter were found to offer similar performance in buildings with small internal loads (Arup et al. 2012).

The federal government has made the realization of ZNE buildings the objective of several research and demonstration programs. In its Green Proving Ground program, the U.S. General Services Administration is working with the national laboratories to demonstrate and evaluate the performance of precommercial and newly commercialized technologies in the government's large portfolio of facilities and to make recommendations on their suitability for real-world applications and their roles in ZNE buildings. Results have been published on 15 to date; 9 additional technologies were selected for evaluation in 2014, with results anticipated in 2016 (GSA 2014).

Human Dimensions

Research with occupants can help determine the best ways to reliably engage them as part of a building's operating and control strategies. In terms of ZNE, occupant studies are particularly relevant where occupants can perform the functions of sophisticated daylighting and natural ventilation strategies that rely on sensors, controls, and automated function by, for example, raising or lowering window shades, opening or closing windows, and using stairs rather than elevators because the stairs' location encourages their use for travel between two or three floors. Deeper usability studies of building controls, automation, and related technologies can help designers and building owners.

MARKET TRANSFORMATION AND RELATED ACTIVITIES

Efficiency programs have a central role to play in sparking demand and building the infrastructure for ULE construction. As more ULE and ZNE buildings are completed, we will have better information on the most effective technical approaches and the costs of various design strategies. This information can be used to determine the most cost-effective approaches; where superior technical approaches are overlooked because of high cost, market transformation programs can focus on bringing costs down. While the most obvious opportunities come from new construction programs, other programs in an administrator's portfolio can play a part in accelerating the transition to ULE construction.

New Construction Programs

To date, the number of residential and commercial programs specifically targeting ZNE remains small. Of the several dozen active residential new construction programs in operation around the United States, only a handful have an explicit focus on ZNE.[14] A slightly larger and growing number of programs are creating better incentives and a more concerted focus on higher-efficiency tiers to encourage builders to pursue further efficiency gains. In the commercial sector, new construction programs typically offer a range of design

[14] Residential programs with an explicit focus on ZNE include the California Advanced Homes Program, Efficiency Vermont New Construction Program (high-performance tier), Connecticut Zero Energy Challenge, Energy Trust of Oregon Live Net Zero designation, NYSERDA Low-Rise Residential New Construction Program (net zero energy performance tier), and California ZNE Production Pilot Initiative.

assistance, including integrated design support for more complex projects and prescriptive incentives to yield savings over conventional construction. Programs with a singular focus on ZNE are limited. With the emergence of new platforms for ULE and ZNE construction such as DOE Zero Energy Ready Homes, Passive House, and NBI Advanced Buildings®, program administrators have access to a growing body of tools and expertise to support program delivery. Recent experience from leading-edge residential and commercial new construction programs offers valuable insights into the effective approaches for accelerating market development related to ULE and ZNE construction.

Advanced programs focused on design teams, design strategies, and the design process, with an emphasis on meeting performance targets, will be important in the near term. Initially, these may focus on larger and/or higher-end buildings and homes. Lessons and experience from these projects and programs can be used to develop design templates and models for easier adoption and use in production-scale home building and commercial design–build projects, which have traditionally been more interested in pursuing prescriptive code compliance pathways.

Programs should consciously anticipate items for the next code cycle—drawing from stretch codes and the code development targets identified above—and build experience with them. In states that adopt new codes relatively early (such as Illinois and Maryland, where adoption of the latest version of the IECC is required upon its publication), programs that help to prepare the construction industry for new code requirements could be of particular value, especially as more significant changes in code requirements and new compliance approaches are adopted. New-construction programs should be mindful of demonstrating ULE and ZNE in a variety of building types and using a variety of approaches. NYSERDA and Building America are using this approach in their research. Building on this, utilities may be able to get credit for code-related energy savings if they participate in code development and implementation activities (see "Codes and Standards" section below).

Experience from new construction programs provides critical data to support code development and implementation efforts. The more data that programs can collect to support these longer-term goals, the better the outcomes will be and the more value they will provide. Examples of critical data needs include energy and demand savings; installed costs (materials and labor); availability of products and skilled installers; training needs; compatibility with other codes, standards, and industry practices; impact on home durability; and consumer acceptance (Eilert 2014).

As California lays the groundwork for adoption of a ZNE-ready code by 2020, it has recently revamped its Advanced Homes Program to help meet this goal. One change has been to uncouple the program's targets from code level (i.e., incentives tied to percent better than code) and concentrate on tools and methods to better tie program outcomes to actual home energy performance. Program experience is demonstrating that reliance on percent-better-than-code metrics, code compliance modeling, and related tools may hinder adoption of more advanced technologies and techniques, stymie innovation, and lead to distorted incentives aligned to code rather than to actual home energy performance (Christie et al. 2014).

Programs and strategies that target a balanced mix of buildings with the highest EUIs (e.g., health care, food service) and those with the highest projected construction volume (e.g., offices, retail) can help the design and construction industries hone the best approaches for delivering ULE performance across the largest energy users. Data from the Commercial Buildings Energy Consumption Survey (CBECS) can be used to identify the best targets for different regions. The most recent CBECS data on commercial buildings' EUIs by building type and climate zone across the United States are more than 10 years old. In 2013, EIA completed field data collection for a new CBECS; preliminary building characteristics data were released in the spring of 2014. Publication of energy consumption and expenditures data is expected in the spring of 2015.[15]

Encouraging district-scale ultra-low-energy projects can improve efficiency in the design and delivery of projects, establish models for cooperative partnerships, and accelerate uptake. A total of 23 commercial districts were identified by NBI (18 ZNE and 5 ULE), representing a total of 100 million square feet of commercial space. Other programs are specifically targeting the development of ZNE housing through promotions and incentives for residential ZNE communities.

Finally, new construction programs can increase their impact by coupling with demand-response and peak reduction program efforts. The Sacramento Municipal Utility District (SMUD) found that homes in its Premier Gardens ZNE project had an average summer peak demand (July) of 2.02 kilowatts, a 55% reduction relative to average new homes in their region and 73% lower than a home in an adjacent community that was not built to zero energy building goals (Keesee and Hammon 2005).

Existing Buildings

While new construction is the most obvious target for advancing along the pathway toward ZNE building codes, the stock of existing buildings is much larger. Therefore, programs addressing whole-building performance or comprehensive retrofits have a lot to offer. Working with the much larger stock of existing buildings—rather than limiting efforts to the smaller new construction market—offers more opportunity to accelerate education and training of the construction trades on implementation and installation of integrated design strategies and systems approaches and enhance their experience working with advanced high-efficiency technologies and construction practices. Working through this much larger set of buildings will provide valuable experience to a significant portion of the trades, a process that would take longer to achieve with new construction projects alone. This can yield near-term savings and pave the way for better performance down the road, as stronger codes kick in. To make the most of this opportunity, existing building programs should match incentives to the use of integrated design strategies and the highest-efficiency measures and equipment. Beyond whole buildings, programs targeting emerging technologies and other products that hold promise for meeting ULE/ZNE performance goals can help to accelerate adoption and lower costs.

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[15] All CBECS data and updated information about the expected release of new data can be found at http://www.eia.gov/consumption/commercial/index.cfm.

Codes and Standards

Equipment efficiency standards and market transformation efforts to accelerate adoption of stronger standards are particularly critical for building types with high EUIs if significant energy use reductions (not just percentage gains) are to be realized and especially to bring energy intensity down to a level where onsite generation can adequately meet energy demands.

Utility engagement in code development, adoption, and implementation can increase code strength and code compliance while reducing the burden on code officials and facilitating the builders' and trades' transition to new construction practices and installation of high-efficiency systems and equipment. A small number of states (e.g., California, Massachusetts, and Arizona) allow utilities to claim credit for savings associated with codes and code-related activities (Misuriello et al. 2012). Since 2000, utility involvement has increased in the development and implementation of codes and standards. In California, investor-owned utilities (IOUs) spent more than $8 million on codes and standards activities over the 2006–08 program cycle, and for the first time they were able to claim savings attributable to these activities. Total savings from the IOU codes and standards activities account for 8–9% of electricity savings goals, 11–12% of demand reduction goals, and 9–17% of gas savings goals (York, Kushler, and Witte 2008). IOU expenditures for the 2010–12 program cycle increased to $29 million, an average of $9.7 million per year (CPUC 2014). Utility activities include research on potential new design practices and technologies for new codes, campaigning to influence the code development process, and developing training and tools for building departments and the building industry and trades.

Case Study: California's Tactical Plan for Zero Net Energy Homes

To meet California's statewide goal for ZNE residential new construction by 2020, the California Public Utilities Commission, California Energy Commission, California IOUs, and other stakeholders developed a tactical plan to guide and focus their efforts toward accomplishing the goal. The plan stipulates roles for the CPUC, CEC, and utilities in developing the policy infrastructure and market capacity to meet the 2020 goal. California's experience on the forefront of ZNE code development can provide valuable insight to policymakers, program administrators, and the code community around the country.[16] Key elements of the ZNE-ready tactical plan center on incorporating the measures needed for ZNE-ready energy performance into state building codes and equipment standards, establishing criteria and data collection requirements for effective evaluation of ZNE performance, and aligning cost-effectiveness testing for new construction programs to the new ZNE paradigm.

The CEC and California IOUs have identified critical measures for codes and standards adoption prior to 2020 (see table 7 below) and are mapping out pathways for moving measures from the emerging technologies program and the IOU efficiency program portfolios into codes and standards (figure 10). The IOUs are also using their workforce

[16] As one example, DOE could adopt a more coordinated policy to translate successes from its research, development and demonstration programs (RD&D) into code advances by introducing and advocating code proposals based on their RD&D.

education and training programs to prepare the building trades to incorporate new techniques and products required for ZNE construction. Based on these efforts, the CPUC and IOUs will work to better align utility program portfolios with the plan for ZNE-ready codes in 2020. At the same time, the IOUs advocate for strong federal appliance standards to increase savings for products beyond the state's jurisdiction.

Table 7. Targets for 2016 and 2019 Title 24 for single-family and low-rise multifamily buildings

2016: Prepare market and ramp up efficiency	2019: ZNE-ready
ZNE tier for CALGreen reach code	Quality insulation installation and inspection
Whole-building (HERS) model, including deemed plug loads	Low volatile organic compound and other pollutant sources and ventilation effectiveness
All high-efficacy lighting	High-slope cool roofs
Ducts in conditioned space or high-performance attics with insulated roof deck or ductless systems	Fault detection diagnostics (cubic feet of air per minute per watt, refrigerant charge, condensates)
Walls: R-21 + R-5 in hot (or all?) climate zones	Shower/bath heat recovery above first floor or compact water piping
Tankless water heater (energy factor > 0.82)	High-efficiency white goods
Dual-flush toilets, low-flow sinks	Controlled receptacles
	Compressorless cooling
	Dual-path PV with high-efficiency HVAC and domestic hot water

Source: Eilert 2014

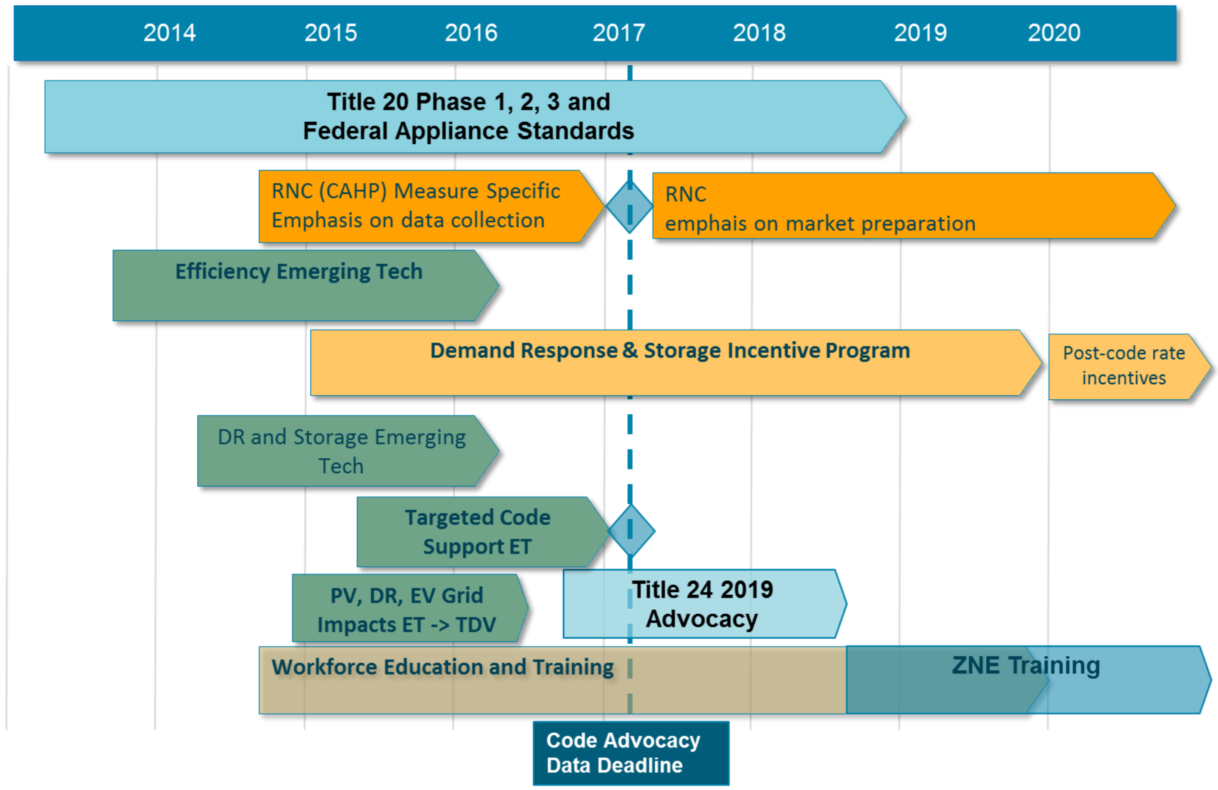

Figure 10. Tactical planning: residential ZNE work streams for the 2019 code cycle. *Source:* Eilert 2014.

COORDINATION AND ADVOCACY EFFORTS

Progress on the strategies outlined throughout this section will require a greater level of coordination among the energy efficiency community and allied stakeholders. A well-coordinated advocacy effort will also be required. Several key areas of focus stand out.

Cost-effectiveness tests. Developing and implementing cost-effectiveness methodologies that use an integrated analysis to capture design strategy costs and benefits rather than relying on a measure-based approach will be required. Allow for programs with near-term negative net benefits in advance of high post-code cost effectiveness.

Code development process. Recent successes in strengthening the IECC demonstrate the value of a coordinated campaign-style approach that expands and diversifies participation in the code development process (Harris et al. 2010). As code proposals for more innovative technologies and new code approaches are put forward, the need for strong and coordinated advocacy grows. These efforts will be particularly critical in advance of the 2018 IECC code adoption hearings, when online voting will be introduced.

Code compliance and enforcement. Adequate funding of federal code implementation support to assist state and local governments as they work to meet near-term ARRA compliance requirements as well as longer-term ZNE targets. High levels of code compliance will be crucial to a codes-based strategy for moving to ULE and ZNE buildings.

Federal legislation. Federal leadership has played an important role in advancing the development of stronger codes and accelerating code adoption at the state level. The efficiency community should continue to pursue opportunities to leverage federal action toward ZNE goals.

Appliance and equipment standards. Efforts to ensure that these standards keep pace with improvements in code will be required. This is especially important for buildings that may rely on a prescriptive path rather than pursuing performance pathways to code compliance, because the code cannot currently require equipment efficiency levels that exceed National Appliance Energy Conservation Act (NAECA) minimums. Industry and advocates should continue to pursue options for differentiating standards for products installed in new construction versus those for the replacement market, where cost and building constraints in existing structures make a single standard cost prohibitive or otherwise unfeasible.

Conclusion

Great progress in building technologies and construction techniques has made ultra-low-energy and zero net energy buildings technically feasible and increasingly cost effective. It is certainly reasonable to assume that these goals will be achievable for most building types in most climate zones within the next 5–10 years. But to make buildings that meet ULE or ZNE in design and operation the standard practice for new construction, it will be necessary to develop codes that require it. Effective codes for high-performing buildings of this level will not only focus on building design and construction, but also building operation to ensure that critical goals related to building energy use will be met. Working backward from the year 2030, the series of targets identified for each successive code cycle will incorporate crucial new elements and features into our national codes while also establishing progressively stronger efficiency targets. The targets provide a road map for policymakers, the construction industry, and other stakeholders, demonstrating that the long-term goal is achievable and that there is a pathway to meeting the goal in a systematic way without undue disruptions.

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