Pathways to Zero Energy Buildings through Building Codes

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Contents

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Abstract

Designers can use superior building design and energy management strategies to create buildings that produce at least as much energy as they consume. These are called zero energy buildings (ZEBs). ZEBs exist in the United States and Canada now; however building energy codes will have to be continuously improved to achieve widespread ZEBs by 2030, a common goal of many cities and some states. Two codes, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 and the International Energy Conservation Code (IECC), set the standard for US commercial and residential building codes. They are amended on a three-year cycle. During each cycle, proponents of energy efficiency can suggest and support code changes. Energy advocates can also look to stretch codes, standards, and certifications like zero energy certification and the Passive House standard as models for upgrading the ASHRAE and IECC codes. Other organizations and jurisdictions such as Architecture 2030 and the state of California have also started to craft their own versions of a zero energy code.

Two metrics make measuring zero energy buildings increasingly easy: Home Energy Rating System (HERS) ratings for residential and Zero Energy Performance Index (zEPI) scores for commercial. Despite the simplicity of these metrics, ZEBs still face obstacles. Some observers feel that energy efficiency can be disregarded for solar energy in ZEBs; however this fails to account for the current economics and nonenergy benefits provided by efficiency. Stakeholders also debate whether to require onsite renewable energy (in the scope of building energy codes) or to allow community-generated energy (outside the scope of building energy codes). While onsite renewables can be used for many buildings, accommodations for buildings where enough onsite renewable energy is not possible will likely be needed.

Advocates and policymakers should start considering incremental energy code changes now so that progress can continue. Potential improvements range from an outcome-based performance path, which helps building owners measure and verify energy savings, to solar-ready roofing and connections, which provide buildings with the option to install onsite solar energy as costs continue to fall. Energy advocates at the national level should continue to submit and defend proposals that move the codes closer to zero energy. Policymakers at the local level should start evaluating the best method to achieve zero energy through their building codes. Developing voluntary programs and zero energy stretch codes now can be important initial steps toward transitioning to a minimum ZEB code in the future.

Background

Zero energy buildings (ZEBs) generate more energy than they consume when production and consumption are averaged over the course of a year. ZEBs are built to the most stringent energy efficiency performance levels to minimize energy consumption while staying cost effective. The remaining load is typically met with onsite renewable energy, primarily solar photovoltaic (PV) rooftop panels.[1] Cities, states, code organizations, and other groups have pledged commitment to zero energy buildings by setting goals for achieving ZEBs by a certain date. The latest counts show nearly 500 commercial and almost 3,000 single-family residential ZEB projects in the United States and Canada (NBI 2018; Edminster and Sankaran 2017).

Clean energy advocates often view zero energy as the long-term end goal of building energy codes. Green codes and guidelines (typically voluntary), such as ASHRAE (American Society for Heating, Refrigerating and Air-Conditioning Engineers) 189.1 and LEED (Leadership in Energy and Environmental Design), are expected to achieve zero energy use first. It will then extend to the baseline (minimum) standards and codes, primarily International Code Council's International Energy Conservation Code (IECC) and ANSI/ASHRAE/IES Standard 90.1 (ASHRAE 90.1).[2]

A 2014 report from the American Council for an Energy-Efficient Economy (ACEEE) outlined amendments to ASHRAE 90.1 and the IECC codes that could help get the codes to zero energy around 2030 (Amann 2014). Figure 1 shows the six steps to achieving zero energy buildings identified in that report.

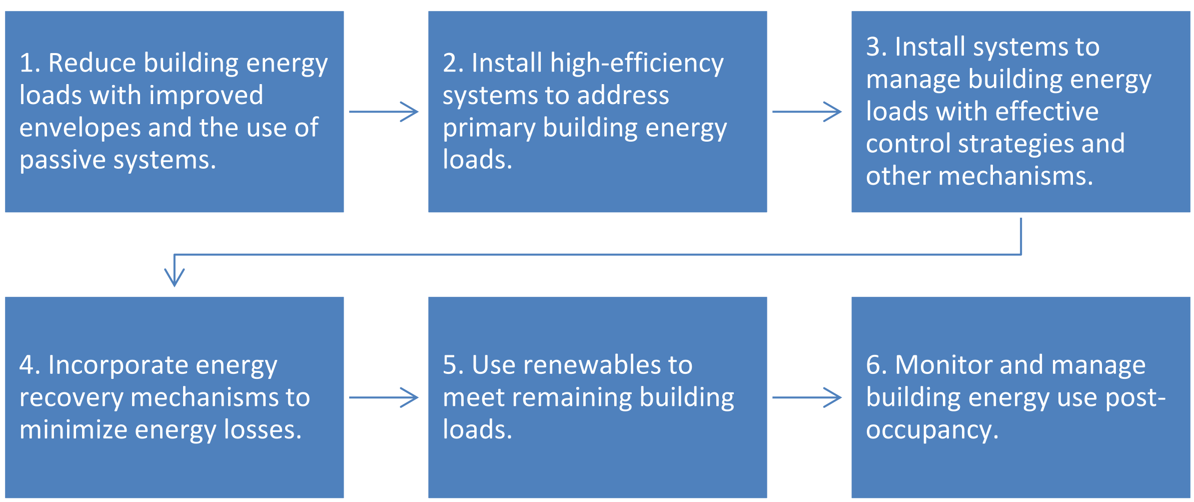

Figure 1. Steps to achieving zero energy buildings. *Sources:* PG&E 2012; Cortese and Higgins 2014.

[1] Some zero energy housing developments or communities use community solar in place of onsite energy; however the focus of this paper is on individual ZEBs, not ZEB communities.

[2] American National Standards Institute (ANSI); American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); and Illuminating Engineering Society of North America (IES).

This white paper examines the current state of zero energy codes and provides an update on avenues to achieving zero energy codes by 2030. It presents an overview of current efforts to achieve zero energy and similarly high-performing buildings, example code proposals that help move the needle toward ZEBs, and thoughts on additional issues and barriers.

Building Energy Codes

Building energy codes can be divided into two primary frameworks, prescriptive and performance. Both offer opportunities to improve energy efficiency on a path toward zero energy buildings. Prescriptive codes assign specific minimum criteria that must be met when constructing a building (e.g., minimum heat reflectivity [R-value] for insulation and installation and control requirements for HVAC systems). Relative to other types of codes, prescriptive requirements are straightforward—think of a checklist of minimum requirements. A common complaint is that these codes do not allow building designers much creativity.

Performance codes provide a designer with greater flexibility by reducing the prescriptive requirements and setting a minimum energy performance target.[3] After meeting certain mandatory requirements, the building architects and engineers can decide the best way to meet the targets. For example, a building in a cold climate may achieve more benefit by emphasizing high-performance insulation over window design. In a marine climate, designing windows to take advantage of natural sunlight may provide more benefit than upgrading insulation. To determine the optimal combination of efficiency measures for performance codes, designers use software tools for modeling and compliance (e.g., EnergyPlus, REM/Rate, REScheck, or COMcheck).[4] A drawback of the code is that anticipated energy savings are based on a building's design and do not account for its actual ongoing energy use (which is affected by changes in occupancy, operation, and so on).

Both primary US energy codes, ASHRAE 90.1 and IECC, include options to comply through prescriptive and performance methods. Similarities and differences between the two codes are described here. Stretch codes, standards, and certifications provide a third path to ZEBs.

ASHRAE 90.1

Standard 90.1 is the US national commercial building model energy code. It establishes minimum energy efficiency requirements for new construction, alterations, and major renovations in commercial and high-rise multifamily residential buildings. Standard 90.1 has been a benchmark for commercial building energy codes in the United States and a basis for codes and standards around the world for more than 35 years. The code is updated every three years, with 2016 the most recent published version. The next update is planned for 2019. Industry experts and professionals make up the ASHRAE 90.1 committee and its subcommittees (i.e., envelope, lighting, mechanical, energy cost budget, and format and compliance). This group develops proposals for cost-effective energy efficiency improvements. It also reviews and responds to proposals from the public and votes to

[3] Performance code targets may be based on the performance of a building relative to energy cost or relative to the energy consumption of a modeled building meeting a specific version of the code.

[4] energyplus.net/. www.remrate.com/. www.energycodes.gov/software-and-web-tools.

accept proposals for each code cycle using the approved American National Standards Institute (ANSI) consensus process.

IECC

The International Energy Conservation Code (IECC), managed by the International Code Council (ICC), serves as the US national residential building model energy code. It includes detached one- and two-family dwellings, townhouses, and multifamily buildings up to three stories in height. The IECC also contains a commercial chapter. Most US states adopt the residential and commercial IECC codes as a package.[5] The IECC commercial code permits the use of ASHRAE 90.1 as an alternative compliance path. The code process is managed by soliciting code proposals from the public and holding public hearings to defend or criticize proposals. Governmental member voting representatives (GMVRs) then cast votes online to determine which provisions are included in the code.[6] A majority or supermajority is required for passage.

STRETCH CODES, STANDARDS, AND CERTIFICATIONS

Various stretch codes, standards, and certifications may offer benefits similar to zero energy codes. However most do not set an explicit target of achieving zero energy building performance by a given date. These codes and certifications were developed to accomplish different goals (e.g., a percentage reduction of energy use compared to the minimum code, use of passive systems), but they can overlap with zero energy codes. Here are some examples:

ASHRAE 189.1. This is a more sustainable and energy-efficient version of the ASHRAE 90.1 code. Ideally, provisions are tested in 189.1 (which is adopted by some jurisdictions) before becoming part of the 90.1 base code. The ICC's green code, the International Green Construction Code (IGCC), recently announced it would be integrated with ASHRAE 189.1 starting with the 2018 code.[7]

LEED. This certification program uses holistic point-based sustainability rating systems for new buildings, existing buildings, homes, and more. LEED's scope includes metrics for water use and specification of low/nontoxic construction materials.[8]

Living Building Challenge. Structured similarly to LEED, but more rigorous, the Living Building Challenge requires an integrated, natural building design that produces more energy than it consumes on a net annual basis.[9]

New Buildings Institute 20% stretch code. This stretch code was developed to achieve a 20% energy performance improvement over the ASHRAE 90.1-2013 baseline code. This

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[5] A minority of states adopt ASHRAE 90.1 directly as their commercial code.

[6] GMVRs typically include a jurisdiction's building code officials, sustainability department, and fire officials.

[7] www.ashrae.org/technical-resources/bookstore/standard-189-1.

[8] new.usgbc.org/leed.

[9] living-future.org/lbc/.

improvement is the first step in a larger project to develop stretch codes. It is also referred to as the model reach code.[10]

Passive House Institute US Certification. This program emphasizes "passive" building systems in homes and commercial and multifamily buildings. Passive buildings take advantage of tight building envelopes and passive solar heat/lighting to minimize the use of heating and cooling systems.[11]

State- and jurisdiction-specific stretch codes. States such as Massachusetts and New York have developed their own versions of stretch codes that can be adopted by cities. Other jurisdictions (e.g., Santa Monica and British Columbia) have developed their own zero energy codes for specific building types.[12]

Zero Energy Advanced Energy Design Guide (AEDG). ASHRAE published its first zero energy AEDG for K–12 school buildings. The authors emphasize zero energy schools as a way to foster student interest in sustainability and environmental stewardship.[13]

Zero Energy Certification. This certification verifies that a building's energy consumption is 100% offset by onsite renewable energy.[14]

Zero Energy Ready Home. This program was developed by the US Department of Energy. A home that is zero energy ready meets specific energy efficiency requirements and contains solar-ready roofing and connections.[15]

Calculating Zero Energy Building Performance

The energy efficiency industry uses a diverse set of metrics to gauge the energy performance of buildings, including energy use intensity (EUI), site/source energy, and emissions/cost-weighted energy.[16] Two rating systems developed to simplify home energy performance comparisons also set a specific threshold for zero energy buildings: home energy rating score (HERS) and zero energy performance index (zEPI).

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[10] newbuildings.org/resource/model-stretch-code-provisions-20-percent/.

[11] www.phius.org/phius-certification-for-buildings-products/phius-2015-project-certification/phius-certification-overview.

[12] newbuildings.org/code_policy/utility-programs-stretch-codes/stretch-codes/.

[13] www.ashrae.org/technical-resources/aedgs/zero-energy-aedg-free-download.

[14] living-future.org/net-zero/certification/.

[15] www.energy.gov/eere/buildings/zero-energy-ready-home.

[16] Energy use intensity (EUI) is equal to the building's energy use divided by its floor area. Site energy is the total energy use at the building site, while source energy accounts for site energy as well as energy to generate and transmit the energy. The cost-weighted energy metric accounts adjust the value based on the cost of the fuel source. A central agency sets the fuel cost values. Emissions-weighted is similar to cost-weighted, but it weighs the energy use by emissions from generating the energy source, instead of cost (Fairey and Goldstein 2016).

HERS and zEPI gauge a building's performance on a relative scale from 100 (high energy use) to 0 (zero energy use) for residential and commercial buildings, respectively.[17] The metrics can also be used to evaluate a code's progress toward achieving zero energy. For example, to comply with ASHRAE 90.1-2004, a building needs to meet a zEPI score of 75, but compliance with ASHRAE 90.1-2013 requires a zEPI score of 54 (NBI 2017).[18] The advantage of these metrics is that the rating scale remains constant over time, unlike those based on other metrics that can change along with the (societal or dollar) value of different fuel sources (Fairey and Goldstein 2016). The HERS Index rates homes on a similar scale, with the 2018 IECC requiring scores of 57 to 62 (depending on climate zone) in its energy rating index (ERI) compliance path option.

Figure 2 shows the progression of building codes relative to the zEPI scale along with a comparison of various codes and building energy performance goals.

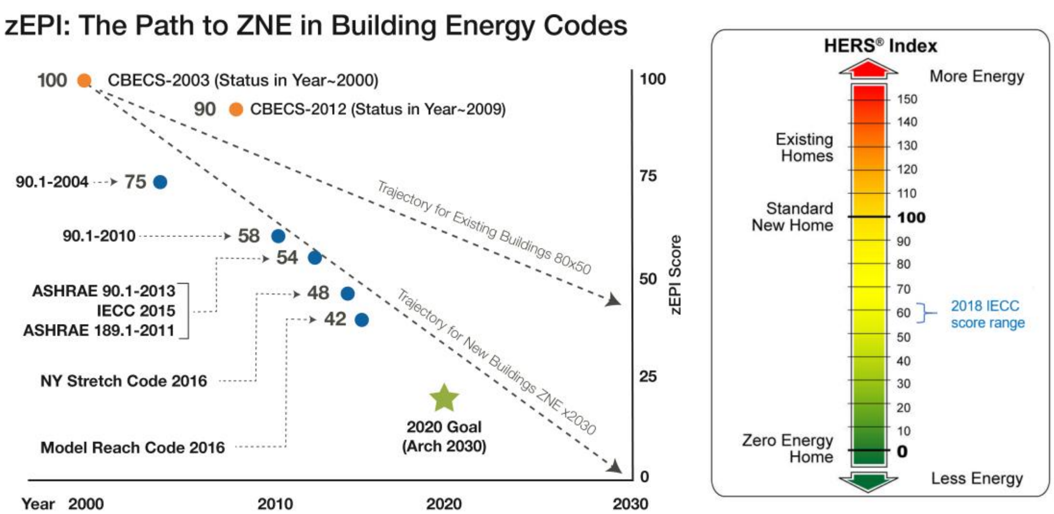

Figure 2. Left: zEPI scale showing 100 (CBECS 2003 average) down to 0 (zero energy buildings). ZNE stands for zero net energy. Right: HERS Index showing 100 (standard new home) down to 0 (zero energy building). *Sources:* NBI 2017; RESNET 2012, image modified by ACEEE.

Barriers to Achieving ZEBs through Codes

One barrier to zero energy building codes is that some casual observers have the perception that zero energy buildings require only the addition of solar energy. They believe that energy efficiency upgrades like better insulation or high-efficiency HVAC equipment are unnecessary. Although the price of solar is declining, energy efficiency is usually the most economical choice on a per-kilowatt-hour basis (Nadel 2016). In addition, energy efficiency provides significant nonenergy benefits to building owners and occupants. For example, installing a high-efficiency variable-speed HVAC system will provide greater comfort to building occupants than a single-stage unit. High-efficiency insulation and windows can improve a building's resilience by helping it maintain acceptable thermal conditions in the

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[17] A home conforming to the 2004/2006 IECC has a HERS Index of 100. A building conforming to the CBECS 2003 average energy use has a zEPI score of 100.

[18] ASHRAE 90.1-2016 has not yet been evaluated against the zEPI scale.

event of a power outage. The best design practice is still to reduce building loads with energy-efficient measures first, and then use solar to meet the remaining loads.

Another potential barrier is a debate over onsite solar versus community solar. Although many organizations may agree with the general idea of achieving zero energy new building construction, they may disagree about the best way to achieve it. Some groups contend that building codes can, and should, consistently be improved until we achieve the goal of ZEBs at the individual building level. Others argue that we should instead focus efforts on community renewable energy because installing onsite renewable energy on every building is not cost effective or practical.

ASHRAE 90.2: A More-Efficient Residential Code

The recently revamped ASHRAE 90.2 residential building code (tentatively to be released in 2018) could offer a more-efficient alternative to the IECC. The code does not contain a prescriptive path, but instead uses a performance-based Energy Rating Index (ERI) approach based on the HERS Index scoring system developed by RESNET. It is significantly more stringent than the IECC and includes other useful verification provisions. For example, builders must install HVAC and water-heating equipment in accordance with ANSI/ACCA standards and verify envelope tightness using ANSI/ACCA, ENERGY STAR®, or similar standards.

Both arguments have merit. Community renewable energy can help buildings with little access to onsite renewable energy (e.g., due to lack of available roof area or excessive shading) achieve zero energy. Particularly energy-intensive buildings may not achieve ZEB performance without community solar. However community-scale renewable energy is largely outside the scope of building energy codes, and therefore other policies would be required to coordinate building energy efficiency, onsite PV, and community systems, adding substantial complexity.[19] In addition, the community-scale argument focuses primarily on the economics and less on consumer preference. Given that some consumers prefer their own rooftop PV and others prefer community solar (Mittal and Krejci 2017), the future of buildings might reasonably include both zero energy buildings with onsite solar (mandated through codes) and zero energy communities with community solar (e.g., as an exception or alternative pathway).

Another potential barrier is resistance to energy code improvements. ASHRAE has committed to making net-zero energy projects financially viable by 2030 (Horwitz-Bennett 2011). This has helped create a culture that seeks regular efficiency improvements each code cycle. However the ICC, which manages the IECC process, has not set such a goal. The process is driven by a combination of stakeholders. Some push for efficiency in the code, while others push back on energy efficiency changes that have a cost, even if proven to be cost effective. These conflicting interests have gridlocked the residential IECC code the past two cycles (2015 and 2018) and resulted in little to no energy efficiency progress in the IECC for six years. Even passing minor efficiency gains, like improved floor insulation

[19] The goal of a community, jurisdiction, or municipality is more often climate related.

requirements or fenestration U-factor requirements, proved challenging in the 2015 code cycle. A fundamental shift in either the stated goals of the ICC or the composition of the committees will be necessary to advance the IECC toward zero energy.

Examples of Current Zero Energy Codes and Initiatives

California: Zero Net Energy Action Plan

As early as 2007, California began publicly stating its "Big Bold Goals" to achieve zero energy homes by 2020 and commercial buildings by 2030. Stakeholders, including the California Public Utilities Commission (CPUC), California Energy Commission (CEC), California investor-owned utilities (IOUs), homebuilders, and architects, provide input to continue increasing the efficiency of the code. In 2016 California updated its code with the goals of preparing the market and ramping up efficiency through proposals like establishing a zero energy tier for the CALGreen reach code, requiring whole-building (HERS) modeling, and mandating ducts be installed in conditioned space.[20] The 2019 California building code, which will take effect in 2020, will combine rooftop solar panels with energy efficiency measures (e.g., insulation and better windows) so that all new single-family homes and low-rise apartments will use net-zero electricity (e.g., solar can serve all electrical needs on an annual basis, but space heating with natural gas or propane is not offset with solar). New provisions include parallel prescriptive paths (i.e., one for mixed fuel and one for all-electric homes) to create a level playing field for all electric equipment, requirements and compliance options for solar and storage, and smart-grid harmonization control strategies (Bozorgchami, Shirakh, and Strait 2018).

Architecture 2030: ZERO Code

Architecture 2030 was founded in 2002 with a goal of reducing greenhouse gas emissions from buildings. The organization developed its ZERO Code as part of its 2030 Challenge, which calls for all buildings, developments, and major renovations to be carbon neutral by 2030. For its minimum energy efficiency requirements, the code references the most updated ASHRAE 90.1-2016 code (both prescriptive and performance paths); however the ZERO Code allows use of more-stringent minimum codes like ASHRAE 189.1-2017. To meet the zero energy designation, the code allows for some flexibility by permitting onsite renewable energy generation as well as off-site procurement. To simplify the implementation process, Architecture 2030 created a free web-hosted open-source calculator to help estimate the off-site and onsite renewable energy potential (Architecture 2030 2018).[21]

Oregon: Path to Zero Program

The Energy Trust of Oregon has been developing its voluntary Path to Net Zero program since 2010 (Moersfelder et al. 2010). Therefore the building industry was well positioned to respond to Governor Kate Brown's 2017 executive order that set a strict plan for improving the energy efficiency of new buildings through different strategies (including building codes). Selected strategies include important components of zero codes, such as development of a plug-load management strategy for state buildings (by 2019) and solar-

[20] It also allowed locating ducts in high-performance attics with insulated roof deck or using ductless systems.

[21] zero-code.org/energy-calculator/.

ready requirements (2020 for residential, 2022 for commercial), as well as mandatory zero energy-ready home equivalence (by 2023) (Oregon 2017).

BRITISH COLUMBIA: ENERGY STEP CODE

British Columbia has developed a performance path in its energy code designed to achieve zero energy homes by 2032. The step code increases the stringency of the code over time, using modeling software and onsite testing to ensure the home meets the desired performance level. The step code is a voluntary compliance path; however local governments may adopt different steps to help them achieve their energy and climate goals (British Columbia 2018).

VOLUNTARY INCENTIVE PROGRAMS

Voluntary incentive programs provide money for building to ZEB standards, which can be accomplished in a variety of ways. For example, the Energy Trust of Oregon's Path to Zero program provides incentive money for zero energy design charrette (i.e., stakeholder meeting), metering, functional testing, solar installation, zero energy certification, and other aspects (Energy Trust of Oregon 2018). New York State Energy Research and Development Authority's (NYSERDA's) multifamily new construction program offers incentives based on three tiers. Tier three represents the highest performance, including up to a ZEB level (NYSERDA 2018a). NYSERDA also developed residential and commercial stretch codes that ramp down to zero energy. These can be adopted by cities in New York as voluntary or mandatory codes (NYSERDA 2018b). Programs like these could be an important way to increase acceptance and adoption of ZEB design and construction methods. Implementing such incentive programs now increases the possibility of mandating ZEB codes in the future.

Proposed Code Changes

In the most recent code cycles (i.e., IECC-2018 and ASHRAE 90.1-2016), interested parties submitted proposals similar to those identified by Amann (2014) to help push the codes toward zero energy buildings.

IECC

The IECC includes both residential and commercial codes. Because the politics of the residential code are more challenging and recent progress has stagnated, some energy efficiency advocates have focused greater efforts on improving the commercial code. In addition, the IECC commercial code is inextricably linked to ASHRAE 90.1 because the ICC and ASHRAE typically adopt each other's proposals. The following proposed updates to the IECC-2018 are among those that most closely align with a zero energy code pathway.

Commissioning. NBI submitted a proposal requiring commissioning of air barriers in the commercial code.

Outcome-based performance path. NIBS, NBI, IMT, and NIA jointly proposed an outcome-based compliance pathway for the commercial code.[22]

Plug-load management. IMT and the National Association of State Energy Officials (NASEO) submitted a proposal to require controlled receptacles (with automatic shutoff capabilities) in the commercial code. A similar provision was included in ASHRAE 90.1-2013.

Solar-ready roofing and connections. The Solar Energy Industries Association (SEIA) proposed moving the section on solar-ready provisions from the appendix to the main body of the residential code, which would make it a requirement.

Submetering. IMT and NASEO proposed submetering requirements in the commercial code for specific end-use categories (e.g., HVAC, lighting, plug loads, etc.) in buildings over 25,000 square feet.[23]

Water heating. The Natural Resources Defense Council (NRDC) submitted a residential code proposal to limit the distance between the water heater and certain fixtures.

All these proposals were defeated during the final online vote, meaning they were not included in the 2018 IECC.

ASHRAE 90.1

ASHRAE 90.1 has consistently adopted efficiency improvements in the past few versions of the code; 90.1-2016 includes a few updates with relevance to the ZEB pathway.

Commissioning. A commissioning working group was formed in 2015 as part of the ASHRAE 90.1 committee to help improve the commissioning requirements within the ASHRAE 90.1 code. For the 2016 ASHRAE Code, it included an informative appendix on commissioning 90.1 items. The group's stated goal for the 2019 standards is to add specific commissioning, testing, and verification requirements to 90.1.

Economizer diagnostics. Air-cooled direct expansion cooling units with economizers are now required to have monitoring systems, essentially fault detection and diagnostics for economizers.

Elevator efficiency. Design documents must now include both category and efficiency class. This is the first step toward establishing minimum elevator efficiency requirements.

Recommendations for Upcoming Code Cycles

Drawing on recent code cycles and conversations during code meetings, we have identified several potential priority areas for the upcoming code cycles.

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[22] National Institute of Building Science (NIBS), New Buildings Institute (NBI), Institute for Market Transformation (IMT), and National Insulation Association (NIA).

[23] ASHRAE 90.1 already includes a similar provision.

Zero energy appendix. Many cities and jurisdictions want to better understand how they can implement ZEB codes and policies. They are requesting resources like a zero energy appendix that can be adopted to support local climate policies. NBI and NRDC are developing a zero energy appendix proposal for the residential section of the 2021 IECC. This appendix will identify a target ERI score that a building must meet through efficiency measures before satisfying the remaining energy load with onsite renewables.

Outcome-based performance path. An outcome-based performance path emphasizes the building's ability to achieve the expected energy performance as it is continually operated and maintained. We recommend including an outcome-based performance path in both ASHRAE 90.1 and the IECC. An outcome-based performance proposal is being developed for the ASHRAE 189.1 code.

Plug-load management. Plug-load energy use is increasing in homes and offices but is often overlooked in initial building design. ASHRAE 90.1 already requires automatic receptacle control for a portion of the receptacles connected in certain room types. These receptacles use time-of-day controls, occupancy sensors, or other control systems to shut off power when not in use. Additional measures should be considered to help curb the growing use of plug loads. For example, buildings anticipated to have high plug loads could be designed with improved building envelope or HVAC to offset this energy use.

What Are Outcome-Based Codes?

An outcome-based approach to codes relies on regular energy use measurement and data reporting to verify that a building is meeting its energy targets once it is occupied. This approach addresses the common concern that a building designed to perform efficiently does not actually operate that way. To many, outcome-based codes are the next logical step in the progression of code design. The biggest obstacles to outcome-based codes include determining how to set the energy targets, deciding who will be responsible for maintaining performance, and figuring out how to enforce the code (Colker, Hewitt, and Henderson 2011).

Solar-ready roofing and connections. The 2015 IECC introduced a solar-ready appendix into the code, providing guidance for jurisdictions that choose to mandate solar-ready home construction. Although California will mandate solar energy in its code after 2020, solar energy is only cost effective in some regions and therefore premature for adoption as a mandatory requirement throughout the country. However onsite solar energy is a key component of ZEBs and prices are falling rapidly. Building codes should include mandatory provisions for solar-ready roofing and connections now to reduce the cost and inconvenience of future installation.

HVAC efficiency. Federal standards limit the adoption of energy code provisions requiring high-efficiency heating and cooling equipment and other products covered under the 30-year-old federal preemption rule (Edelson and Lyles 2017). However creative solutions can lead to installation of more-efficient equipment. For example, ASHRAE 90.1-2013 began requiring large water heater systems (i.e., 1 million Btuh or greater) to meet essentially condensing levels (i.e., at least 90% thermal efficiency). The key to this proposal is that setting higher efficiency levels for an entire system, not just a piece of equipment, does not trigger federal preemption. A similar proposal is being considered for large boiler systems in ASHRAE 90.1-2019.

Data and feedback. Measuring building performance and providing feedback to building managers and occupants are key aspects of designing and operating ZEBs. New technology and tools can enhance our understanding of building energy use and present it in a way that occupants can easily understand. For example, submetering separate systems (e.g., lighting, HVAC, and plug load) will enable improved data collection and sharing, not just to occupants but also to code officials, program administrators, energy managers, and so on. ASHRAE 90.1 now requires submetering and reporting for major systems; the IECC does not.

Tight envelope and ventilation. Building envelopes generally last the life of a house or building. One of the best ways to achieve long-term building efficiency is to ensure that the original design includes premium windows, insulation, roofing, and air-sealing measures (such as those required by Passive House standards). However, as buildings become tighter, ventilation for occupants becomes increasingly important. Very little research has been published about the appropriate ventilation rate to ensure the health of building occupants. The industry should invest greater resources into ventilation rate research, update ASHRAE's ventilation standards 62.1 and 62.2, and ensure that the most recent versions are adopted into the energy codes.

Performance path scores. As builders increasingly use performance path options like ERI to meet the residential IECC code, the ERI scores must continue to improve with each code cycle on a path to ZEBs. Commercial buildings do not have an equivalent to the residential ERI performance path. Therefore the first step for commercial buildings would be to institute a performance path that references a metric like zEPI. Then the scores could be improved each code cycle.

Amann (2014) identified pathways to achieve ultra-low- and zero energy codes. These were plotted out over the subsequent code cycles up to (or near) 2030. This paper revises these tables to account for changes made in the most recent code cycle. For example, ASHRAE 90.1 requires electrical energy monitoring and reporting of end uses, including HVAC systems, interior lighting, exterior lighting, and receptacle circuits, so we acknowledged that submetering has advanced in ASHRAE 90.1. In addition, the tables include new proposals and other developments, like the zero energy appendix in the IECC and the commissioning appendix in ASHRAE 90.1.

Table 1 shows a timeline of issues for the upcoming IECC development cycles; table 2, for ASHRAE 90.1.

Table 1. Recommended strategies for upcoming IECC residential development cycle

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: builder-installed plug loads (e.g., hardwired loads)			
		Add covered loads: plug-load management →	Add covered loads: plug-load management		
Develop system metrics to move beyond component efficiency	Water heating (e.g., structured plumbing) →	Water heating (e.g., structured plumbing)			
		HVAC: beyond National Appliance Energy Conservation Act minimums →	HVAC: beyond National Appliance Energy Conservation Act minimums		
Consider operators and occupants	Residential feedback →		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
Improve access to ZEB design guidelines		Zero energy appendix			
Design for the future and inherent uncertainties		Solar-ready roofing and connections			
Update ERI score	57–62	50–59	40–49	30–39	20–29

Gray text and arrows indicate the measure was proposed in Amann 2014 but was not included in the IECC 2018 code, so it is being proposed in a later code. Green text means that the proposal was completely or partially accomplished. Peach-colored cells indicate newly added rows or proposals.

Table 2. Recommended strategies for upcoming ASHRAE 90.1 development cycle

Strategies	90.1-2016	90.1-2019	90.1-2022	90.1-2025	90.1-2028
Capture savings across all building energy end uses	Elevators (hoist power and standby) Plug-load management	Elevators (hoist power and standby) Plug-load management Process loads			
Develop system metrics to move beyond component efficiency	Large chilled water systems	Large chilled water systems Lighting energy use (not just LPD) Water heating HVAC: beyond National Appliance Energy Conservation Act minimums	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	Require O&M plans Commissioning requirements Commissioning appendix		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 target energy outcomes, 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	Solar-ready roofing and connections	Address persistence (component/ equipment efficiency)		
Update zEPI score	Establish zEPI performance path at 50-60	40–49	30–39	20–29	10–19

Gray text and arrows indicate the measure was proposed in Amann 2014 but was not included in the ASHRAE 90.1-2016 code, so it is being proposed in a later code. Green text means that the proposal was completely or partially accomplished. Peach-colored cells indicate newly added rows or proposals.

Next Steps

Various stakeholders have important roles in pushing the model codes toward zero energy. Any interested parties can develop and/or support proposals that improve efficiency in the code toward ZEBs, such as those mentioned in this paper.[24] Proposals have a greater success rate when they have been thoroughly researched and vetted. Users can attend public code hearings and voice support for IECC proposals or submit written comments. For the ASHRAE process, once a code change proposal is submitted, the public may offer comments to the ASHRAE committee or address questions from the committee.

At a higher level, it would be valuable for ICC (like ASHRAE) to create big, bold goals to achieve zero energy buildings by 2030 (or some defined date). If the ICC clearly stated its mission to achieve ZEBs, it would help justify the continual improvement in efficiency of the code. Interested parties such as energy advocates and building officials should consider making this explicit request to the ICC.

Defining the best structure of zero energy codes requires more research. For example, it is important to understand the pros and cons of counting onsite, off-site, or community renewable energy as the generation portion of ZEB codes. Another key issue is to determine how much of a building's energy load should be met through energy efficiency and then through onsite renewable energy and develop criteria for when community and onsite solar are acceptable. These percentages will not be static. We expect they will change over time as the economics of efficiency and renewable energy continue to change. They will depend on factors such as climate zone, energy prices, and building type. The use of software like the National Renewable Energy Laboratory's BEopt, which simulates efficiency designs and measures for homes and multifamily buildings, can help improve our understanding of the optimal efficiency/renewable mix for ZEBs.[25]

Cities: Influencing the Model Codes

When cities choose to adopt (or not adopt) certain proposals or code amendments from the model code, it can, in turn, influence future cycles of the model code. For example, the City of Seattle included a section in its residential code that requires the user to incorporate additional energy efficiency measures (Section R406), such as improved building envelope, more-efficient HVAC equipment, and renewable energy (SDCI 2015). This type of provision is already in the commercial chapter of the IECC and will be proposed for the residential chapter of the 2021 IECC. Cities can act as pilot programs before a proposal is adopted at a national level.

In-depth analysis of the effectiveness of codes and other building energy standards like California's zero energy building code and PHIUS+ will help determine the best path forward for ZEB codes. We can learn valuable lessons about ultra-efficient and zero energy building design to implement in new codes. This evaluation can also help policymakers and

[24] For more information about the process of developing code proposals, see DOE's reference here: www.energy.gov/eere/buildings/articles/how-are-building-energy-codes-developed.

[25] Building Energy Optimization (BEopt) software: beopt.nrel.gov/.

program administrators understand the optimal mix of codes, standards, and policies to push toward ZEBs. For example, Oregon found success implementing a voluntary zero energy incentive program first. They are now working on leveraging this in their building codes to achieve the stated goal of zero energy new buildings. Voluntary incentive programs like Oregon's can help accelerate and expand adoption of zero energy buildings and can be used as a first step toward achieving mandatory zero energy codes. Each state, city, and jurisdiction can decide the best way to use voluntary incentives and stretch building codes to accomplish its zero energy goals.

Advocates for zero energy codes can look to existing initiatives for ideas, from state or municipal policies to stretch codes and standards like ASHRAE 189.1 or Passive House. To achieve the goal of mandatory ZEB new construction by 2030, we can start including measures now in the minimum codes, ASHRAE 90.1 and IECC. Installing solar-ready roofing connections makes sense now, as the price of renewable energy continues to fall. Outcome-based codes help ensure not only that a building is designed to be energy efficient, but that it continues to perform that way. Voluntary programs at a state level and through a zero energy appendix can also help prepare building owners, occupants, and builders for a ZEB future. The effort we put into including ZEB provisions in model codes and developing ZEB programs now will determine whether we can achieve newly constructed zero energy buildings by 2030.

References

Amann, J. 2014. *Energy Codes for Ultra-Low-Energy Buildings: A Critical Pathway to Zero Net Energy Buildings*. Washington, DC: ACEEE. aceee.org/research-report/a1403.

Architecture 2030. 2018. *ZERO Code™: Architecture 2030 Building Energy Standard*. Santa Fe: Architecture 2030. zero-code.org/wp-content/uploads/2018/04/ZERO-Code.pdf.

Bozorgchami, P., M. Shirakh, and P. Strait. 2018. *2019 Building Energy Efficiency Standards: Adoption Hearing*. Docket No. 17-BSTD-02, May 9. Sacramento: California Energy Commission. efiling.energy.ca.gov/GetDocument.aspx?tn=223411.

British Columbia. 2018. "BC Energy Step Code." www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code.

Colker, R., D. Hewitt, and J. Henderson. 2011. "Developing Effective Codes and Standards for Net-Zero Energy Buildings." In *Zero and Net-Zero Energy Buildings + Homes*, edited by J. Schneider, 38–41. Arlington Heights, IL: Building Design+Construction. newbuildings.org/sites/default/files/5_Developing_Effective_Codes_and_Standards.pdf.

Cortese, A., and C. Higgins. 2014. *2014 Getting to Zero Status Update: A Look at the Projects, Policies and Programs Driving Zero Net Energy Performance in Commercial Buildings*. Vancouver, WA: NBI (New Buildings Institute). newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf.

Edelson, J., and M. Lyles. 2017. *Federal Preemption as a Barrier to Cost Savings and High Performance Buildings in Local Energy Codes*. Portland, OR: NBI (New Buildings Institute). newbuildings.org/wp-content/uploads/2017/06/NBI_FederalPreemptionAsaBarrier.pdf.

Edminster, A., and S. Sankaran. 2017. *To Zero and Beyond: Zero Energy Residential Building Study*. Richmond, CA: NZEC (Net Zero Energy Coalition). netzeroenergycoalition.com/wp-content/uploads/2017/06/2017-06-14_NetZeroEnergy17001_zero-energy-homes-booklet_a01_fnl_screen-1.pdf.

Energy Trust of Oregon. 2018. "Get on the Path to Net Zero." www.energytrust.org/commercial/new-buildings-path-to-net-zero/?storyID=4693.

Fairey, P., and D. Goldstein. 2016. "Metrics for Energy Efficient Buildings: How Do We Measure Efficiency?" In *Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings* 9: 1–13. Washington, DC: ACEEE. aceee.org/files/proceedings/2016/data/papers/9_421.pdf.

Horwitz-Bennett, B. 2011. "Net-Zero Energy Buildings: What the Case Studies Teach Us." In *Zero and Net-Zero Energy Buildings + Homes*, edited by J. Schneider, 8–16. Arlington Heights, IL: Building Design+Construction.

www1.eere.energy.gov/buildings/publications/pdfs/rsf/netzero_energy_buildings_and_homes.pdf.

Mittal, A., and C. Krejci. 2017. "Integrating Consumer Preferences in Renewable Energy Expansion Planning Using Agent-Based Modeling." In *Proceedings of the 2017 Winter Simulation Conference*, Industrial and Manufacturing Systems Engineering Conference Proceedings and Posters: 105. lib.dr.iastate.edu/imse_conf/105.

Moersfelder, S., D. Boleyn, B. Walker, E. Rowe, A. Robbins, and G. Hansen. 2010. "Energy Trust of Oregon Path to Net Zero Pilot: Pushing the Limits in the Oregon New Construction Market." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 4: 206–18. aceee.org/files/proceedings/2010/data/papers/2025.pdf.

Nadel, S. 2016. "Solar and Energy Efficiency Need to Work Together Like Peanut Butter and Jelly." *ACEEE Blog*, September 20. aceee.org/blog/2016/09/solar-and-energy-efficiency-need-work.

NBI (New Buildings Institute). 2017. *Methodology Used to Calculate zEPI Jurisdictional Score Values*. Portland, OR: NBI. newbuildings.org/wp-content/uploads/2015/12/JurisdictionalScoreMethodologyFactsheet_2017.pdf.

———. 2018. *2018 Getting to Zero Status Update and List of Zero Energy Projects*. Portland, OR: NBI. newbuildings.org/wp-content/uploads/2018/01/2018_GtZStatusUpdate_201808.pdf.

NYSERDA (New York State Energy Research and Development Authority). 2018a. *Multifamily New Construction Program (MF NCP): Program Opportunity Notice (PON) 3716*. Albany: NYSERDA. portal.nyserda.ny.gov/servlet/servlet.FileDownload?file=00Pt0000004FOXhEAO.

———. 2018b. *NYStretch Code – Energy 2018: Development Overview*. Albany: NYSERDA. www.nyserda.ny.gov/-/media/Files/Programs/energy-code-training/NYStretch-Code-Energy-Presentation-2018.pdf.

Oregon. 2017. *Executive Order No. 17-20, Accelerating Efficiency in Oregon's Built Environment to Reduce Greenhouse Gas Emissions and Address Climate Change*. Salem: Office of the Governor, State of Oregon. drive.google.com/file/d/1UN8oQ6PtM90XaIuWDMPt8s8yPALepA6y/view.

PG&E (Pacific Gas and Electric Company). 2012. *The Technical Feasibility of Zero Net Energy Buildings in California.* Prepared by Arup North America Ltd. San Francisco: PG&E. www.energydataweb.com/cpucFiles/pdaDocs/904/California_ZNE_Technical_Feasibility_Report_Final.pdf.

RESNET (Residential Energy Services Network). 2012. "U.S. Department of Energy to Use RESNET HERS Index on DOE Challenge Home Certificate." *RESblog*, May 25.

www.resnet.us/blog/u-s-department-of-energy-to-use-resnet-hers-index-on-doe-challenge-home-certificate/.

SDCI (Seattle Department of Construction and Inspections). 2015. *2015 Seattle Residential Energy Code*. R32–6. www.seattle.gov/DPD/cs/groups/pan/@pan/documents/web_informational/p2623013.pdf.