Unlocking Ultra-Low Energy Performance in Existing Buildings

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About the Author

Jennifer Thorne Amann directs the Buildings Program at ACEEE. She has authored dozens of publications and articles on building technologies, retrofits, and new construction. Her current research interests include deep retrofits in homes and buildings, program and policy interventions to advance zero-energy buildings, affordable housing, and next-generation building codes and equipment standards. Jennifer also leads content development for ACEEE's consumer information resource, smarterhouse.org.

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Abstract

This paper catalogs current deep retrofit activities in existing buildings. A review of completed ultra-low energy building (ULEB) retrofit projects demonstrates that deep energy savings are technically feasible. These projects show which approaches are being used and which are most successful. While some buildings need extensive interventions requiring significant investments of time and money, others can meet aggressive targets at relatively low cost. Some projects incorporate cutting-edge technologies and techniques, while others use tried-and-true weatherization methods. In some cases, building owners and occupants are willing to adopt new behaviors and practices to meet energy efficiency goals. We identify opportunities to expand the number of existing ULEBs through policies and program designs that promote market development and leading-edge technologies and retrofit techniques. Moving forward, further work is needed to understand the best models for delivering savings and standardizing approaches that will work at scale.

Introduction

A highly efficient building stock is one of the cornerstones of a prosperous clean energy future. Today's buildings consume roughly 40% of all energy used in the United States, making improved building efficiency critical to reducing energy use and energy-related pollution emissions and to creating jobs and a robust economy. A transition to ultra-low energy buildings (ULEBs) is being widely discussed—and increasingly adopted—as a strategy for meeting clean energy goals and utility energy efficiency targets. ULEBs are energy-efficient homes or commercial buildings that could, with the adoption of a renewable energy system, produce on average as much renewable energy as they use.[1]

Just over a decade ago, zero energy was an aspirational goal that sparked imaginations and many conversations, but only a few actual zero-energy homes and even fewer commercial buildings were operating in the United States.[2] At that time, one-off designs and niche technologies were used to achieve the efficiency gains needed for zero-energy buildings (ZEBs). Over the ensuing years, much progress has been made as advances in technologies, products, and construction techniques have permitted significant improvements in the energy efficiency of new construction while bringing down the associated costs. This progress has led to the completion of more than 200 commercial buildings and 6,000 homes operating as ZEBs (NBI 2016; Net Zero Energy Coalition 2015). In addition, a number of ULE homes and buildings are certified ZEBs, awaiting verification of zero-energy performance, or have the potential for zero energy given their low levels of energy consumption.

To date, ULEB policies and programs have focused on new construction, where opportunities to incorporate new construction techniques and equipment are less disruptive, easier, and less expensive. Moving ULEB concepts and practices from new construction to existing buildings is an important step in transforming the buildings sector. It is estimated that more than half of the homes and buildings that will be in use in 2050 are already built and in use today. Yet efforts to scale up retrofit activity in both the residential and commercial sectors lag far behind the market potential, even for standard retrofits that do not target deeper energy savings. Deep retrofits are reaching only a tiny niche.

To meet future building sector goals for reduced energy consumption, such as recently adopted state and local ZEB and carbon reduction goals, existing buildings must be retrofit. Such retrofits could play a role in scaling up and accelerating the full transition of the building stock. Existing buildings provide a much larger stock of buildings to work with in developing, demonstrating, and improving advanced design strategies, technologies, and practices. Moreover this energy savings opportunity is much greater than that in new

[1] The US Department of Energy (2015a) has established a consensus definition of a zero-energy building: "an energy-efficient building, where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy. Ultra-low energy buildings (also referred to as zero-energy ready) are energy-efficient homes or buildings that could operate as zero energy with the additional of on-site renewables.

[2] The theme of the 2006 ACEEE Buildings Summer Study captured the emerging buzz around ZEBs: "Less Is More: En Route to Zero Energy Buildings."

construction, particularly for homes. Since older homes are less efficient on average than new homes (EIA 2013), retrofitting an existing home to ULE will save more energy than moving a new home from current construction practices to ULEB or ZEB status.[3] Can the benefits associated with ULEB—including energy savings and improved comfort—overcome barriers and other factors contributing to the lagging market for retrofits? Can progress toward addressing the barriers that even basic retrofits face help unlock markets for deep retrofits?

Residential and Commercial ULE Retrofits

Signs of Progress

Our research has led us to conclude that the increase in the number of newly constructed ULEBs is beginning to carry over into existing building retrofits. As we discuss below, a few deep energy retrofit approaches and strategies have proven successful at delivering ULE homes and buildings that meet a range of owner objectives, including vastly improved comfort, resilience, and durability. Our review of research reports, case studies, and other compilations of deep energy retrofit projects suggests that dozens of existing homes and buildings are operating at ULE levels. A sizeable portion of these are ZEBs. We are beginning to see home and building retrofits that yield energy efficiency improvements of 50–90%, the levels needed to achieve zero-energy performance with the addition of renewables. This level of savings goes far beyond the 15–30% savings resulting from typical retrofit projects.

As figure 1 shows, ULEBs can be found in several states and represent a range of building types in various climate conditions.

[3] The average energy use intensity (EUI) of homes declines by decade of construction. Homes built before 1960 have an average EUI of 52 kBtu/sf/yr. EUI declines for homes built in each decade since then to a low of 37 kBtu/sf/yr for homes built 2000–2009 (EIA 2013).

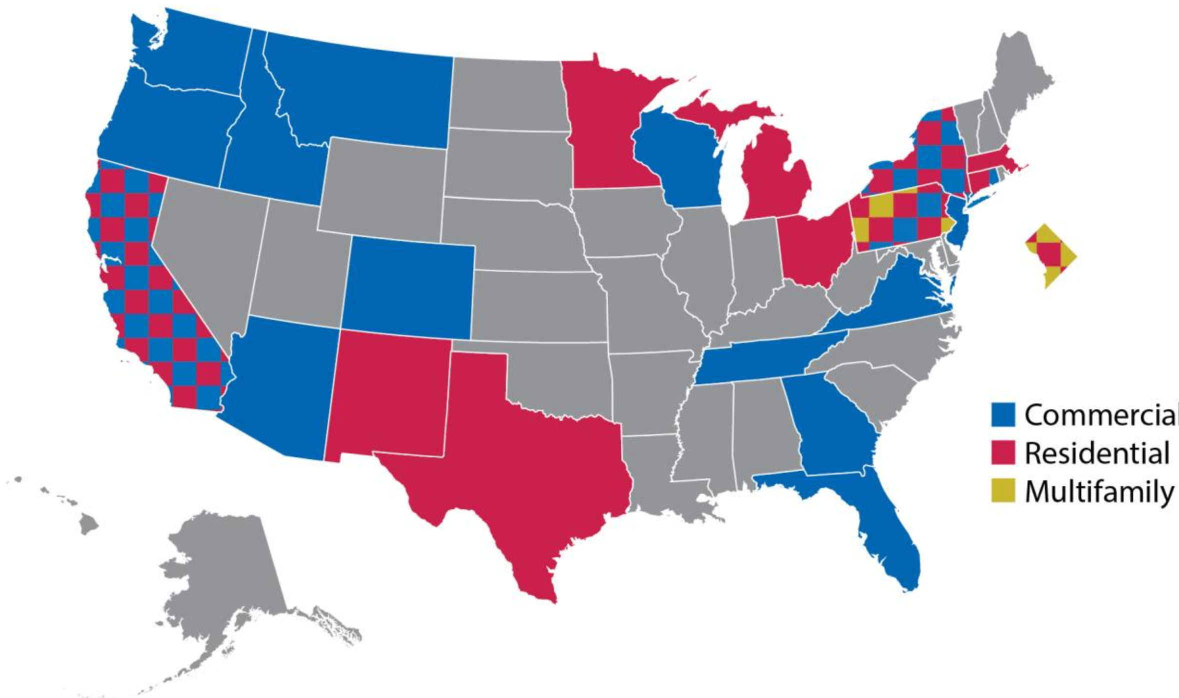

Figure 1. States with ULEBs, by sector.

TECHNICAL OPPORTUNITIES AND CHALLENGES

Table 1 shows the steps involved in achieving ULE performance in homes and commercial buildings.

Table 1. Design steps and technology options for ULEBs

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 post-occupancy building energy use.	Monitoring-based commissioning, occupant engagement

Sources: PG&E 2012; NBI 2014.

Achieving ULE performance in existing buildings presents a different set of technical challenges than those found in new construction. As table 1 shows, the first step in designing a ULEB is to reduce building energy loads. In new construction, designers can position the building on the site to optimize natural daylighting, passive heating and cooling strategies, and roof orientation for photovoltaic (PV), and specify materials and methods to ensure an airtight, well-insulated building envelope. With an existing building, the design team has little to no control over building orientation (except in cases of very extensive renovations/rebuilds) and may face limitations in achieving envelope performance levels found in high-efficiency new construction due to construction type, structural features, or historic designations. To address these challenges, ULE designs for existing buildings may rely more heavily on the installation of super-efficient equipment and the use of sophisticated energy management and controls, and place greater emphasis on strategies to reduce plug loads.

Beyond the envelope, some retrofit projects face constraints on equipment choices. The cost and disruptions associated with changing heating, cooling, or water distribution systems can pose a significant hurdle. But, as project planning proceeds, the strategies and technical options available for existing buildings are very similar to those for new construction. Existing buildings can benefit from the same advances in appliance, equipment, and lighting efficiency, energy management and control strategies, energy recovery, and occupant engagement, although costs are sometimes higher and continue to present a barrier in retrofit situations.

THE ECONOMICS OF ULE RETROFITS

While much of the first cost differential for zero-energy new construction has been eliminated for many building types (District Department of the Environment 2014; PG&E 2012), retrofits continue to present cost burdens. In new construction projects, the design process affords opportunities to identify cost reductions to offset higher component, material, or construction costs. In contrast, retrofits often present building owners with costs they could avoid (by simply not doing the project, delaying the project, or opting for basic equipment replacements and repairs), and the effort to pursue deeper savings often requires materials and labor beyond those of a simple retrofit project. Costs associated with removing existing equipment, completing repairs or remediating defects, and changing or enhancing structures can add other costs that are unique to retrofit projects.

Retrofit project costs can be divided into three broad categories: materials, equipment, and labor. Energy-efficient building materials (e.g., insulation) are often among the lower-cost components in a retrofit (with the exception of high-performance windows) and, since many of these materials represent mature technologies and products, the potential for further cost reductions is small.

The cost of many high-efficiency appliances and equipment types has declined as standards increase the baseline efficiency, growing market share leads to economies of scale, and the learning curve allows manufacturers to reduce production costs. For example, the cost of general service (A-lamp) and directional LED lamps dropped roughly 50% from 2012 to 2014 and are projected to decrease another 10–20% by 2020. LED replacements for linear fluorescent lamps dropped 40% from 2012 to 2014 and already cost less than the 2020 projections developed for DOE in 2014 (DOE 2015b; DOE 2014). Ductless heat pumps costs declined steadily from 2009 to 2016; this trend is expected to continue as the market grows (NEEP 2017). These products are among the innovations that enable ULE homes and buildings.

Finally, labor costs are a significant portion of retrofit costs, though they vary widely depending on the specific measures and the project's scope, the needed maintenance or repairs, and the degree of structural change, demolition, or other labor the project requires. Evidence is emerging that the cost of ULE retrofits is declining as experience and understanding of the most effective measures and techniques grows. For example, as we discuss below, the Vermont Zero Energy Now pilot program is achieving significant energy efficiency gains for less than half the cost of earlier deep retrofit pilots, with an anticipated return on investment averaging 9% (R. Faesy, principal, Energy Futures Group, pers. comm., February 3, 2017; Cluett and Amann 2014).

MARKET TRENDS

Retrofit activity in both the residential and commercial sectors lags far behind the market potential and the level needed to meet increasingly aggressive energy savings and environmental goals. Nadel (2016) identified comprehensive retrofits of homes and buildings as an important measure in efforts to halve US energy use in 2050 relative to baseline projections for that year. By 2040, retrofits could contribute 11% toward that goal under the assumption that 50% of homes and 75% of commercial floor space are retrofit with an average savings of 30%. In the residential sector, roughly 2% of the existing housing stock must be retrofit each year to meet this goal—for each year this number is missed, the rate must be higher in future years or savings must ramp up beyond 30%.

Current retrofit rates fall far short of these levels. Since 2002, less than 1% of existing single-family homes have been retrofit through comprehensive home retrofit programs. If we add in the roughly two million homes that have been weatherized through the federal Weatherization Assistance Program since 2000, the total is still less than 3.5% of the stock. In the commercial sector, an estimated 2.2% of floor space, or 2 billion sq. ft., are retrofit each year, with median energy savings of roughly 11% per building relative to average building energy use intensity (EUI) (Kwatra and Essig 2014; EIA 2016a). If we are serious about energy savings goals, both the scale and scope of retrofit activity must be accelerated far beyond current levels.

ULE in Existing Homes

FROM BASELINE TO ULE

To understand the challenges and opportunities facing any broad effort to retrofit existing homes to ULE performance, it is helpful to get a handle on the current baseline condition. How efficient is our existing housing stock? What is the current rate of retrofit activity? What programs and initiatives are underway?

The energy performance of existing homes varies widely with climate, construction type, occupancy, and other factors. Among the close to 80 million single-family homes, average site EUI ranges from roughly 40,000 British thermal units (Btu) per square foot per year (40 kBtu/sf/year) in hot-humid, mixed-dry/hot-dry, and marine climates to 45 kBtu/sf/yr in mixed-humid climates to 50 kBtu/sf/yr in cold/very cold climates (EIA 2013). Associated household energy expenditures range from $1,420 to $2,150 per year on average.

What does it take to make an existing home ULE? While no set specification or energy performance determines whether a home qualifies as a ULEB, the performance of existing ULE homes and levels proposed by leading ULE home programs suggests that the maximum site EUI for ULE homes is on the order of 15 kBtu/sf/yr. Figure 2 shows the average EUI for existing single-family detached homes in different regions compared to the requirements or results of a few ULE retrofit initiatives. Based on these data, retrofits must yield savings on the order of 70–85% to operate as ULE or ZEB.

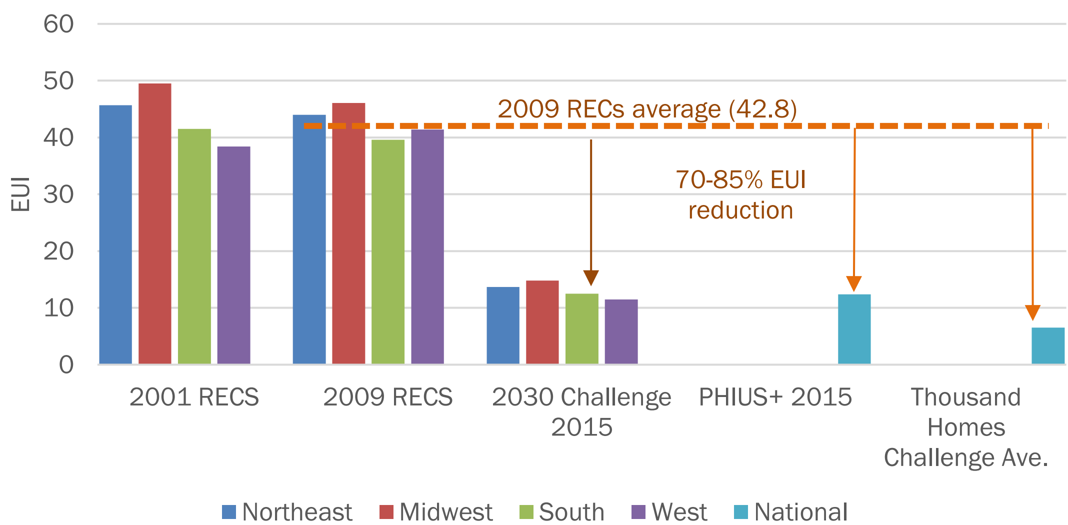

Figure 2. Average EUI for existing single-family homes and selected ULE retrofit initiatives

Retrofits are often classified based on percentage energy savings relative to pre-retrofit energy use (which may or may not be known). Typical retrofits may save anywhere from 10% to 35%—for example, savings for weatherization projects average 12% (Blasnik et al. 2014). The more comprehensive retrofit projects, typical through the Home Performance with ENERGY STAR (HPWES) program, yield an average of 25% whole-home energy savings (E. Jacobsohn, program manager, DOE, pers. comm., July 25, 2016). Retrofits yielding much higher savings (50–90%) are considered deep retrofits. This classification doesn't tell us much about the final result; post-retrofit energy use in homes with the same percentage reduction may still vary widely. Percentage reduction is also very hard for residents to track, as energy bills vary significantly throughout the year and in response to other factors (such as change in occupancy, schedules, or installed loads), making it hard to judge whether savings meet expectations.

PROGRESS TO DATE

Approximately 607,000 retrofit projects were completed through the HPWES program from 2002 to 2016, according to the Department of Energy (2017). Adding the roughly 115,000 homes retrofit through the Better Buildings Neighborhood Program (BBNP) and the total number of home performance retrofits completed through the leading program efforts approaches 725,000—impressive, but still less than 1% of US single-family homes. Another two million homes weatherized through the Weatherization Assistance Program over this time period bring the total to 3.5%. While this number doesn't include retrofits completed outside of these programs (including those completed through direct install or other single-measure retrofit programs), it does illustrate the need to scale up retrofit activity to capture the energy savings available.

Nationally, the number of projects completed through HPWES declined by 5% in 2015 and another 10% in 2016 after years of growth (DOE 2017). Reasons for the decline include unsustainable funding at the state or utility program level, the impact of weather and low energy prices on program cost-effectiveness and customer demand, program contractor retention, lack of consumer awareness in many markets, and challenges contractors face in finding qualified employees (E. Jacobsohn, program manager, DOE, pers. comm., July 25, 2017). As HPWES works to address these challenges, its experience can help inform ULE retrofit efforts. At the same time, it is important to consider how ULE programs can better engage homeowners, programs, and contractors to expand HPWES participation and savings.

There is no comprehensive tally—or even a reliable estimate—of the number of existing US homes that have undergone a deep retrofit to ULE performance levels. Of the 2,971 housing units included in the Net Zero Energy Coalition's 2015 census of zero-energy residential buildings, 31 homes were identified as deep energy retrofit projects that could potentially operate as ZEB (Net Zero Energy Coalition 2015). All of these projects participated in the Thousand Home Challenge (described below), which reports that 7 of its 31 projects have achieved zero energy (Wigington 2017). The number of deep energy retrofit homes increases to between 100 and 150 when we add these 31 retrofit projects to those participating in and/or certified through other ULE or deep retrofit programs, some of which we now describe.

Programs, Approaches, and Initiatives

There are multiple pathways to ULE homes, and various approaches can drive energy efficiency and improved home performance. This is true for new construction and existing buildings. Different technical approaches, platforms, and programs offer the potential for ULE. Experience to date demonstrates these approaches and offers initial lessons regarding the most successful and cost-effective methods.

Passive House

The *passive house* approach builds on concepts of passive building and building science principles to achieve high levels of energy efficiency with an emphasis on maintaining occupant comfort. Key elements of passive design include an extremely air-tight building envelope, continuous insulation, high-performance windows, mechanical ventilation (with recovery of heat and/or moisture as needed), and management of solar thermal gain. The design accounts for internal heat loads from occupants and plug loads (e.g., appliances, electronics, and lighting) to ensure that heating and cooling systems are right-sized to maintain consistent indoor temperatures in all seasons.

Passive building principles are being applied to single-family homes, multifamily buildings, and commercial buildings of all sizes. Like ZEB, the passive house approach is more prevalent in new construction, but it is being used in retrofits as well. In the United States, homes and buildings built using passive building principles can certify their performance to the PHIUS+ Passive Building Standard—North America, which was developed by the Passive House Institute US (PHIUS) and the Building Science Corporation with DOE support. In addition to offering climate-specific criteria to align with diverse US climate types, the standard sets specific requirements for source energy consumption, heating and cooling demand and peak load, airtightness, ventilation, thermal envelope, and window performance. Criteria are the same for new construction and existing homes, except that existing homes may receive an allowance for existing structural thermal bridges.

According to PHIUS, buildings designed and built or retrofit to the standard will consume 60–85% less energy than those built to the 2009 International Energy Conservation Code (IECC), depending on the type of building and climate (PHIUS 2017).[4] Source energy use limits vary based on occupancy, as determined by the number of bedrooms according to this formula:

Primary energy use = (# of bedrooms +1(6200kWh/year * 3.412 Btu/kWh))/square footage*

So, for a 2,000 sq. ft. three-bedroom home, source EUI cannot exceed 42.3 kBtu/sf/year (which translates to a site EUI of 12.4 kBtu/sf/yr for an all-electric home). PHIUS has announced its intention to lower the base energy use limit from 6,200 kWh to 4,200 kWh over the next few years (Wright and Klingenberg 2015). This would lower the EUI cap in our three-bedroom home example to 28.6 source EUI and 8.4 site EUI.

As of March 2017, the list of 159 single-family projects in the PHIUS certification database includes a total of seven projects (five certified and two precertified) in California, Connecticut, New Jersey, New York, and Texas. Additional projects have been completed using the passive house approach and criteria that have not been PHIUS certified.

Thousand Home Challenge

The Thousand Home Challenge (THC) is an independent initiative coordinated by Linda Wigington Associates to support an integrated approach to reducing energy use in existing homes through technical, behavioral, and community approaches. The THC differs from many other ULE initiatives by focusing on deep energy reductions (rather than deep energy retrofits) to demonstrate a range of creative solutions for reducing actual home energy use by 70–85%. With this framing, THC participants look to combine efficiency retrofit measures with renewables, behavior choices, and broader community solutions to create an energy reduction package that meets their own household needs and lifestyle.

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[4] The International Energy Conservation Code (IECC) is the national model building energy code and establishes minimum energy efficiency standards for the design, construction. and renovation of buildings. The IECC is updated on a three-year cycle. To date, 41 states have adopted the IECC or developed their own equivalent code. Given IECC's widespread implementation, it is often used as a baseline for advanced building efficiency standards or certifications.

THC participants commit to reducing their actual home energy consumption to meet their own customized household energy use threshold. This threshold is determined using one of two options: Option A requires a demonstrated 75% reduction in actual site energy use relative to the home's previous baseline usage; Option B sets a customized site energy use allowance to reflect a challenging high-performance energy target based on climate, house size/type, heating fuel, and number of occupants. Option B can be more challenging, but is often preferable for those who have already taken steps to reduce their home energy use over a period of time.

Another goal of this initiative is *market transformation*. While many of the early THC projects used a custom retrofit approach, the program seeks to develop and disseminate efficiency packages for common housing types that can be more readily adopted and replicated at scale. The THC was designed to use these packages, along with an emphasis on technology demonstration and workforce development, to help scale up the transition to ULE homes.

As of December 2016, 105 active projects are participating in the THC, including 31 homes that have officially met the THC (that is, they have a full year of energy bills to verify energy use reductions). Of the 31 homes that have met the challenge, 26 have on-site PV, including 7 that are net zero or net positive. Interestingly, 11 homes met the THC thresholds without the use of PV. These projects have resulted in very low EUI levels averaging just 6.5 site kBtu/sf/yr (Wigington 2017). Interestingly, the homes show no correlation between energy performance and vintage. Table 2 summarizes details of the THC homes.

Table 2. Details of homes meeting the Thousand Home Challenge

Characteristic	Data
Vintage	Ranges from 1869 to 2008 32% built 1900–1930; 32% built 1961–2000
Size (finished floor area)	Ranges from 576 to 3,650 sf Average: 2,245 sf
Locations	CA: 12
	MA: 8
	MN: 1
	NM: 1
	NY: 3
	OH: 4
	ON: 1
	PA: 1
Occupancy	Average: 2.62 occupants

Characteristic	Data
Housing type	28 single-family homes
	3 duplexes
Annual energy use savings	Average 84% reduction
EUI (kBtu/sf/yr)	Average site EUI: 6.5

Source: Wigington 2017

Vermont Zero Energy Now

In 2016, Vermont launched the Zero Energy Now (ZEN) program as a comprehensive approach to move existing homes (and small commercial buildings) toward zero energy. The program is intended to support Vermont's goal of supplying 90% of all state energy demands in 2050 using renewable sources. The 2016 pilot program was developed and implemented by the Building Performance Professionals Association of Vermont (BPPA) with support from Green Mountain Power (GMP). BPPA has expanded on the traditional home performance retrofit approach by combining weatherization measures with cold-climate heat pumps (and high-efficiency biomass heating), on-site and community PV, incentives, and low-cost financing to create a single comprehensive package.

Under the program, homeowners work with a specific certified contractor throughout the process to select and complete the right mix of weatherization, equipment selection, and renewables and to secure financing and incentives. Qualifying projects must result in a minimum 10% reduction in envelope heat loss and a 50% reduction in combined fossil fuel and grid electricity use.[5] Half of the household's total energy consumption must come from renewable electric, biomass, or other renewable sources (Faesy and Kramer 2016). GMP, through ratepayer-funded programs, offers participants incentives tied to the energy savings achieved ($50/MMBtu saved), along with existing incentives for weatherization and heating equipment through the Vermont Home Performance with ENERGY STAR program. State and federal tax credits for pellet stoves and PV also reduce project costs. The remaining costs can be financed through low-cost loans or property-assessed clean energy (PACE) financing.

A total of 22 projects were completed from April to December 2016. Three projects had additional or unique components beyond the scope of a typical deep energy retrofit, so they are excluded from average costs and savings values reported here. As table 3 shows, savings from the first set of projects are compelling. With the average cost for efficiency measures at $16,657 and projected average first-year efficiency-related cost savings of $2,406, the projects are yielding an average of 9% return on investment (R. Faesy, principal, Energy Futures Group, pers. comm., February 3, 2017). While efficiency-related project costs are roughly double the average for HPWES and BBNP, unlike typical home performance projects,

[5] The 10% figure seems low, but it is intended as a minimum threshold and was designed so that newer homes could participate in the program. The program developers expect that most homes will achieve much greater envelope improvements and, in fact, will need to in order to meet the 50% energy use reduction requirement (Faesy and Kramer 2016).

almost all of the ZEN projects included major equipment replacements. Further, the costs are significantly lower than the costs found in early deep retrofit studies, which typically started at $50,000 (Cluett and Amann 2014).

Projected energy efficiency savings average 61MMBtu per project, or almost triple the average project savings from the VT HPWES program over the 2013-2106 period (Stebbins 2017). Energy efficiency related savings are significant relative to average Vermont household energy costs of $3,700 per year (Faesy and Kramer 2016), and they represent a 55% reduction relative to average annual energy use for homes in cold and very cold climates (EIA 2013). Building on the lessons learned in 2016, Efficiency Vermont has expanded its HPWES program to include ZEN as a new deep energy retrofit tier.

Table 3. 2016 Zero Energy Now program results

	Project Cost			Savings (MMBtu)*			Savings ($)	
	Total	EE	PV	Total	EE	PV	EE	ROI
Total	$1,203,884	49%	51%	2,096	66%	34%	$56,330	7.1%
Minimum	$22,435	37%	53%	42	57%	38%	$1,185	3.3%
Maximum	$169,918	60%	40%	163	68%	40%	$4,372	16.9%
Average	$41,209	40%	60%	90	68%	32%	$2,406	9.0%

	Project Cost			Savings (MMBtu)*			Savings ($)	
	Total	EE	PV	Total	EE	PV	EE	ROI
Total	$1,203,884	49%	51%	2,096	66%	34%	$56,330	7.1%
Minimum	$22,435	37%	53%	42	57%	38%	$1,185	3.3%
Maximum	$169,918	60%	40%	163	68%	40%	$4,372	16.9%
Average	$41,209	40%	60%	90	68%	32%	$2,406	9.0%

*Energy savings are projected based on models calibrated to pre-retrofit energy bills. *Source:* R. Faesy, principal, Energy Futures Group, pers. comm., February 3, 2017.

Energiesprong International

In the Netherlands, a new market transformation approach to deep home retrofit has been developed to address many of the barriers to traditional retrofit approaches. The Energiesprong ("Energy Leap") program pursues a mass-customization strategy, incorporating prefabricated facades and insulated roofing systems along with advanced heating and cooling and PV to deliver ZEB retrofits. Factory-built components minimize time and disruption. The projects are completed in one week and come with a 30–40 year guarantee on indoor comfort and energy performance. Project costs are financed through energy bill savings and reduced maintenance outlays. The Energiesprong model originally targeted affordable rental housing with a goal of moving into private housing once it was ready to fully scale (Energiesprong 2017a).

More than 6,000 of the initial goal of 111,000 retrofits have been completed to date. By working with large housing providers (government and nonprofit social housing) Energiesprong created a guaranteed aggregated demand that gave the building industry the confidence to invest in innovative techniques. The volume of projects brought about solid cost reductions: over the first three years of the program, project costs dropped 55% relative to the first-year pilot project costs. Energy performance improved at the same time, so that many of the projects are operating as net-positive energy suppliers (Energiesprong 2015). The installation period also improved from two weeks for pilots to less than one week, and in some cases as little as one day.

Energiesprong International is now working in France, the UK, Germany, and New York State; it is also consulting on a program under consideration in San Francisco. In New York, the New York State Energy Research and Development Authority (NYSERDA) has pulled together a market development team, RetrofitNY, to tailor the approach to the state's multifamily building stock. The initial request for proposals is anticipated in late 2017 for construction projects beginning in 2018 (Energiesprong 2017b). In California, San Francisco is working with Rocky Mountain Institute and other partners on business model concepts for the city's affordable housing market through the REALIZE project (RMI 2017). As they work on these programs, US market development teams are attempting to adapt the Energiesprong concept to the vast scale and diversity of the US housing stock, as well as to our unique climate considerations and lower energy costs.

ULE in Existing Commercial Buildings

As with homes, energy performance in existing commercial buildings varies widely with climate, construction type, and occupancy. Specifics of a building's commercial use also drive energy use. Average site EUI (in kBtu/sf per year) in US commercial buildings ranges from 33 for warehouses to 78 for offices to 231 for hospitals to more than 282 for restaurants (EIA 2016b). Figure 3 illustrates how these values compare to other commercial building types and to targets for ULEB/ZEB performance. Based on these data, retrofits must yield savings on the order of 60–70% to operate as ULE or ZEB.

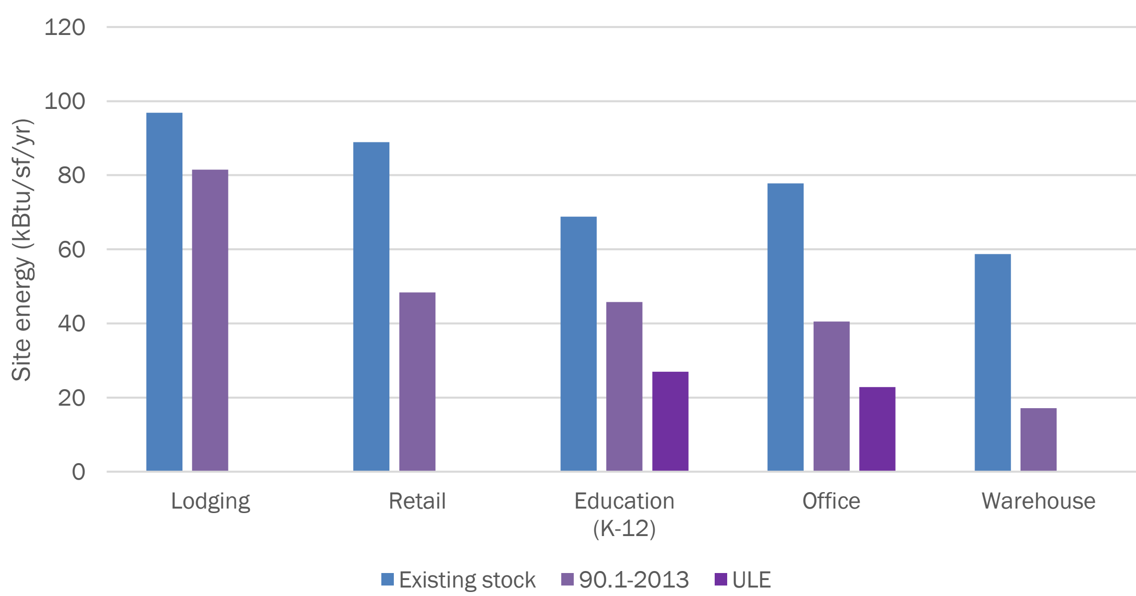

Figure 3. Existing building stock EUI compared to building codes and standards

In commercial buildings, typical retrofits yield savings of 10–30%. Kwatra and Essig (2014) reviewed results from a number of comprehensive retrofit projects[6] and found savings of 10-–40%. Since publication of that report, several high-profile commercial deep energy retrofits have been completed—most notably, the Empire State Building—with results within this range. A few projects have achieved deeper savings and are operating as ULEB.

PROGRESS TO DATE

Unlike homes, commercial buildings undergo more routine retrofit and refurbishment to meet business needs and help their owners and operators stay competitive. An estimated 2 billion sq. ft. of commercial floor space—approximately 2.2% of the total—is retrofit each year (EIA 2016a). These retrofits are estimated to save an average of 11% of building energy use (Kwatra and Essig 2014). While this retrofit rate would cover roughly one-third of the existing commercial building stock by 2030, unless the resulting energy savings substantially improve, these retrofits will fall far short of the energy savings goals adopted by states and cities (outlined below) as well as energy use reductions necessary to support national goals for 2050 greenhouse gas emissions (Nadel 2016).

To date, the number of commercial retrofit projects with documented energy savings greater than 50% remains quite small. Of the 332 zero energy and ULEBs and districts tallied by the New Buildings Institute (NBI) in 2016, only 35 are retrofit projects. Of these, 9 were verified as ZEB with at least one year of zero-energy operation, another 21 are emerging ZEBs that have yet to verify their performance over a full year, and 5 are ULEBs without on-site renewables (NBI 2016). The verified and ULEB projects demonstrate energy performance ranging from 10 to 31 site EUI, comparable to the zero net energy new construction projects in the NBI database. In addition to these projects, two commercial retrofit projects are certified to PHIUS standards, another two are pre-certified to those standards, and roughly 25 additional retrofits are highlighted in case studies or other reports, for a total of roughly 65–70 existing commercial ULEBs (PHIUS 2017; RMI 2015; NEEA 2011).

PROGRAMS, APPROACHES, AND INITIATIVES

As in the residential sector, there are multiple pathways to ULE commercial buildings, including some of the same platforms and approaches adapted for the residential sector.

Architecture 2030

Architecture 2030 is a nonprofit initiative working "to rapidly transform the global built environment from the major contributor of greenhouse gas (GHG) emissions to a central part of the solution to the climate crisis" (Architecture 2030 2017a). The organization works with the building design and construction industry, building owners, planners, governments, and others on research, education, and the development of 2030 Districts to meet stringent energy, water, and emissions reduction goals. The 2030 Challenge sets targets

[6] The report defines a comprehensive retrofit as "a suite of measures, across multiple energy systems, undertaken to improve building energy efficiency by using an integrated whole-building approach to achieve savings larger than those possible from the installation of isolated measures."

designed to move the buildings sector to carbon-neutral buildings by 2030.[7] Figure 4 illustrates how the 2030 Challenge envisions this shift, along with its interim targets.

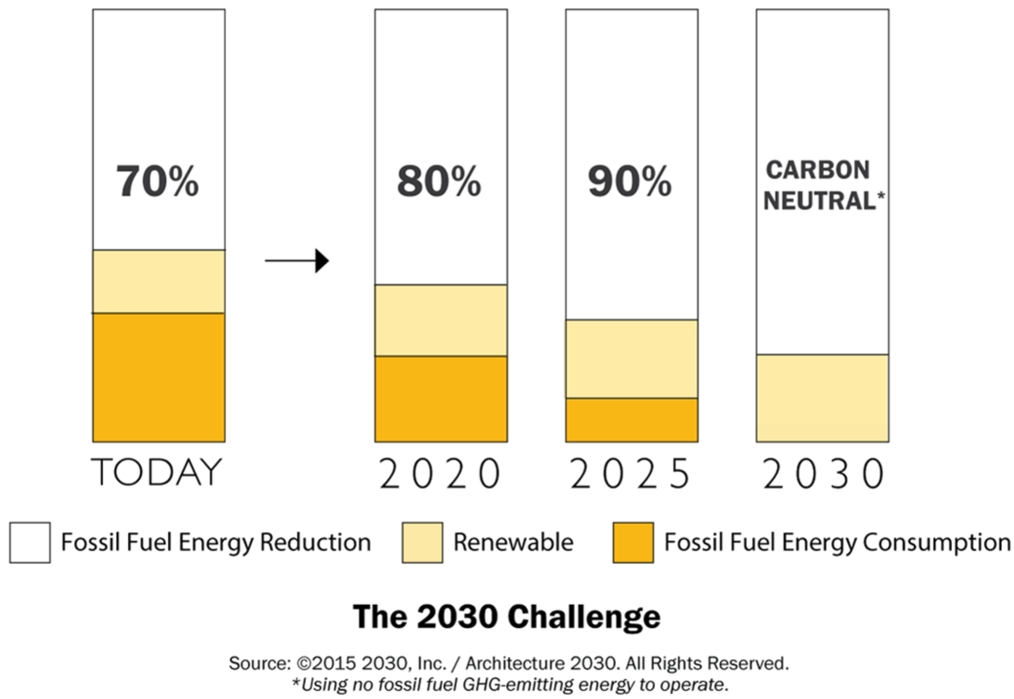

Figure 4. The 2030 Challenge: 2015 ("Today") and forthcoming targets

The 2030 Challenge is intended to address both major building renovations and new construction. Under the Challenge, major renovations are projects with total costs exceeding 25% of the building's value (not including land value) or those in which the renovation project includes more than 25% of the building envelope. From its inception, the 2030 Challenge set increasingly stringent energy use targets toward the overall 2030 goal. As of 2015, the target calls for new construction and major renovations to achieve site EUI (kBtu/sf/yr) 70% below the regional average for the building type. Further, the Challenge calls for the same 70% EUI improvement in the retrofit of as much existing building floor space as has been newly built or renovated (Architecture 2030 2017b). The targets will increase to 80% in 2020 and 90% in 2025 before reaching carbon-neutral in 2030. Targets can be met through energy efficiency, on-site renewables, and/or a maximum of 20% off-site renewable energy purchases.

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[7] Architecture 2030 defines a carbon-neutral building as "a building that uses no fossil fuel, greenhouse-gas-emitting energy to operate. In contrast, a net-zero energy building must produce as much energy on site as it consumes." architecture2030.org/2030_challenges/2030-challenge/design_faq/.

The 2030 Challenge has been adopted by the federal government, a number of municipal governments, the American Institute of Architects, ASHRAE, the US Conference of Mayors, and others.

General Services Administration National Deep Energy Retrofit Program

The General Services Administration (GSA) launched the National Deep Energy Retrofit program (NDER) to expand use of innovative technologies and renewable energy to move federal building retrofits toward zero net energy. Through the initial program, GSA ultimately awarded 10 energy savings performance contracts (ESPC), valued at a total of $172 million, to seven ESCO partners. Retrofit projects covered 14.7 million sq. ft. of space in 23 buildings. Collectively, annual project energy savings totaled 365 billion Btu, with a first-year guaranteed cost savings of $10.8 million.

The program was developed in response to federal goals established by Congress and under Executive Order calling for increased energy and water savings, greater use of renewable energy, and expanded ESPC projects in federal buildings. Expected per-project savings for nine of the retrofit projects ranged from 16% to 60%, with an average of 38%, which is double the average proposed energy savings from traditional federal ESPC projects. The 10th project was a zero-energy retrofit (Shonder 2014). For the most part, projects relied on a wide range of traditional energy savings measures. Analysis of the program found that emphasis on deeper energy savings—including setting aggressive energy savings goals for each project, creating a Project Management Office as a centralized source for contracting and technical assistance, and using an integrated design process—were important to achieving higher savings than traditional federal ESPCs (RMI 2015; Shonder 2014).

The NDER program is just one of several federal government initiatives pushing deep energy retrofits. RMI (2015) profiles eight GSA retrofit projects completed under ESPCs, including three of the NDER projects, with a minimum of 40% energy savings. Other federal government initiatives pushing deep retrofits include the Obama administration's President's Performance Contracting Challenge which spurred federal agencies to leverage more than $4 billion in performance contracts with expected energy savings of $8 billion over 18 years (Harada 2016) and the Army Net-Zero Initiative.

Passive House

The PHIUS+ 2015 standard for commercial buildings is very similar to that for residential buildings described above. As table 4 shows, the main distinction is in the source energy requirement. Unlike homes, the PHIUS+ EUI requirement for commercial buildings is not adjusted for occupancy. Source EUI cannot exceed 38 kBtu/sf/yr, equivalent to a site EUI cap of 11.1 for an all-electric building. Additional allowances for commercial process loads may be granted on a case-by-case basis. As of March 2017, a total of 16 commercial buildings are included in the PHIUS certification database. This includes four retrofit projects: two certified projects in New York and Pennsylvania, and two precertified projects in Connecticut and Oregon.

Table 4. PHIUS+ 2015 requirements

<table>
<tr><th></th><th>Heating demand/ load*</th><th>Cooling demand/ load*</th><th>Air-tightness (cfm50/sf envelope)</th><th>Source energy demand</th><th>Renewable generation for source zero</th></tr>
<tr><td>Single family</td><td rowspan="3">1-16.8 kBtu/sf/yr
0-7.6 Btu/hr/sf</td><td rowspan="3">1-23.4 kBtu/sf/yr
1.3-9.5 Btu/hr/sf</td><td rowspan="2">0.05</td><td>6200 kWh/person/yr</td><td rowspan="4">>Source energy demand</td></tr>
<tr><td>Commercial</td><td>38 kBtu/sf^2/yr</td></tr>
<tr><td>Multifamily</td><td>0.08**</td><td rowspan="2">6200 kWh/person/yr
38 kBtu/sf/yr</td></tr>
<tr><td>Retrofit</td><td>As above plus allowance for existing thermal bridges</td><td>As above plus allowance for existing thermal bridges</td><td>0.05/
0.08**</td></tr>
</table>

* Maximum climate specific targets for each individual project. ** Buildings with 5+ stories, noncombustible construction.
Source: PHIUS 2016.

Policies Supporting ZEB for Retrofits

Just as new construction has been the focus of considerable ULEB project activity and investment, attention in the policy arena has been directed largely toward new construction in the form of energy performance mandates for new public buildings and targets for some or all new homes and commercial buildings. As knowledge and awareness of what is possible evolves, several jurisdictions have enacted policies to explicitly encourage and eventually require ULE performance in existing buildings.

The most common policy approach to date establishes goals or targets for building energy efficiency and carbon reduction. California has adopted what is arguably the most comprehensive set of targets for moving the state's building stock to ZEB. In addition to new construction ZEB targets of 100% of new homes and commercial buildings by 2020 and 2030, respectively, the state has established ZEB targets for existing buildings. Key actions include the following:

- A 2012 executive order setting a ZEB target for existing state-owned buildings. Under the order, 50% of the square footage in existing state-owned buildings will meet zero-energy operations by 2025. All new or renovated state buildings designed after 2025 will be ZEB. The state has also set a target calling for 50% of existing commercial buildings to achieve ZEB in 2030.

- Assembly Bill 758 (AB758), passed in 2009, calls for the development and implementation of a comprehensive plan for significant energy efficiency improvements in existing buildings.

- Senate Bill 350 (SB350), passed in October 2015, calls for "a doubling of energy efficiency savings in electricity and gas retail end uses by 2030" relative to the mid-case estimate of achievable energy efficiency savings in the *California Energy Demand Updated Forecast, 2015-2025*. The California Energy Commission (CEC) released an update to the Existing Buildings Energy Efficiency (EBEE) Action Plan, originally adopted in 2015 to reflect the SB350 mandate with updated goals and strategies and new initiatives (California Energy Commission 2016).

- Assembly Bill 802 (AB802), passed in 2015, creates a new statewide building energy use transparency policy. The bill directs the CEC to develop regulations for whole-building energy use data access and disclosure of benchmarking data; it also repeals earlier transaction-based disclosure requirements, opening the door for annual disclosure requirements for all covered buildings. Another element of the bill is of particular importance to deep retrofit efforts. AB802 calls on the California Public Utilities Commission (CPUC) to authorize utility investments in further efforts to increase existing building efficiency based on "existing conditions baselines." This is expected to increase utility assistance for customers with older buildings and equipment operating far below current code requirements (California Energy Commission 2016). Demand forecasts will also be adjusted to account for existing conditions baselines.

New York and Vermont have also established notable state-level building efficiency goals. New York announced goals to reduce greenhouse gas emissions by 40% from 1990 levels and buildings energy use by 23% from 2012 levels by 2030. As noted above, Vermont has established a goal of supplying 90% of state energy needs with renewable sources by 2050; efficiency is a critical strategy for meeting this goal.

At the local level, Montpelier, Vermont, and Cambridge, Massachusetts, have established ZEB targets. The Cambridge Net Zero Action Plan calls for a 70% reduction in carbon emissions by 2040 through improved efficiency in existing buildings, zero-energy new construction, and other measures. The city has other initiatives for net zero schools and for maintaining its Green Communities Act designation that will help it achieve its net zero community goals.[8]

Montpelier is working to become the first zero-energy state capital in the United States; its goal is to meet 90% of its energy needs with renewable sources by 2030. Net Zero Montpelier is pursuing a range of strategies for all sectors; for buildings, initiatives include weatherization, heat pumps, and retrofits (NEEP 2016).

Beyond targets and goals, policy activity specifying ZEB and/or ULEB is limited. One example is a Cambridge program to assess municipal buildings, which analyzes the city's building portfolio for energy and other improvements and identifies buildings that offer the best opportunity for retrofit to zero energy (NEEP 2016). Another is the New York Clean Energy Fund, which has dedicated $5 billion in funding for 2016–2025 for zero-energy initiatives. And, through New York's Reforming the Energy Vision (REV) initiative,

[8] The Massachusetts Green Communities Act (passed in 2008) requires increasing investments in energy efficiency and renewable energy to improve the state's economy and environment. Key provisions include annual energy savings goals for electric utilities, a renewable portfolio standard, and net metering rules. Local governments earning the Green Communities designation are eligible for state grants to support their clean energy projects.

NYSERDA proposed a state roadmap for deep energy reduction projects in the residential, multifamily, and commercial buildings sectors (NYSERDA 2016).

Moving Forward

Given the scale of the challenge at hand, a comprehensive set of complementary policies, programs, and initiatives, along with strategic research, will be needed to achieve a high level of ULEB performance in our existing building stock. To date, policy and program experience in this area is limited. However that experience, coupled with broader experience in building retrofit markets, provides useful insights and guidance on important next steps.

SET AGGRESSIVE TARGETS AT THE POLICY, PROGRAM, AND PROJECT LEVELS

Targets can provide motivation to pursue new approaches and create space for greater experimentation. At the policy and program level, energy efficiency and climate goals are driving development of new program designs and greater investment in efforts to get deeper building retrofits. Vermont's ZEN program and California's comprehensive EBEE Action Plan are good examples. At the project level, aggressive targets encourage contractors and building owners to try new technologies and look for new opportunities for savings. GSA staff and the ESCOs working on the NDER projects report that the emphasis on deeper savings led them to consider a broader range of measures, including some they had previously dismissed as too costly (Shonder 2014; RMI 2015). Thousand Home Challenge participants use aggressive targets to guide their projects and to determine when they are complete.

Project-level targets based on actual post-retrofit performance (e.g., annual energy use and EUI) are preferable to percentage savings targets. A target number helps the building owner understand whether the project resulted in expected savings and makes it easier to set milestones for a multi-stage retrofit process. For policymakers, regulators, investors, and building owners, these targets coupled with actual post-retrofit measured energy savings data improve decision making.

LEVERAGE EXISTING POLICIES AND PROGRAMS

Current policies and programs will play an important role in expanding ULE retrofits. As research efforts and cutting edge approaches such as passive house and the Thousand Home Challenge identify and standardize the most successful technical methods, established programs such as HPWES and commercial custom programs can deliver them at greater scale. These approaches can help utilities expand their ZEB programs beyond new construction to include a greater emphasis on existing buildings. ULE initiatives can also leverage other public and private investments in research, workforce training and certification, and standards development.

The PHIUS+ 2015 standard provides a valuable example. PHIUS built its standard on EPA and DOE investments in indoor air quality and energy efficiency specifications, and on the RESNET investment in Home Energy Rating System (HERS) rater training and certification. ENERGY STAR, EPA Indoor airPLUS, and the Zero Energy Ready Home specification are prerequisites for the PHIUS+ 2015 standard. PHIUS adds additional performance requirements on top of these base specifications, while specially-trained HERS raters provide the necessary inspection and rating for PHIUS+ certification.

ESTABLISH THE RIGHT REQUIREMENTS

Voluntary programs and policies can help move the market for ULE retrofits, but it is hard to see how we will achieve building retrofits at the scale and scope outlined above without a more aggressive strategy and well-designed policy requirements. Comprehensive policy packages should be explored and enacted, with careful consideration of state and local climate, building stock, and market conditions. Good candidate policies include specific targets for ULE retrofits, expanded building energy use transparency (with increased attention on the residential sector, where such policies are lagging), expanded code requirements for existing buildings, retrofit ordinances or other requirements for regular upgrades/retrofits, and scheduled retrocommissioning requirements for commercial buildings. Many jurisdictions will already have some of these policies in place and can add or adjust existing policies to meet deeper retrofit goals. Not all of these policy options will result in ULE retrofits, but they can be useful in moving the baseline and putting numerous buildings on the path toward ULE.

Requirements for building energy efficiency improvements at critical decision points can ensure that efficiency upgrades are completed when the parties involved are most open to them, the project and transaction costs are lowest, and, ideally, when the projects are the least disruptive. While these requirements may not lead to the deepest level of savings, they can translate into substantial savings and provide a roadmap for future improvements. Financial incentives such as rebates and loans, along with other financing tools and interventions (like ESPCs), can be used to encourage owners to go beyond requirements to meet stretch codes or other efficiency goals. ACEEE has outlined other ways that retrofit program requirements can be structured for deeper savings (Cluett and Amann 2014; Cluett and Amann 2016).

MEET CUSTOMERS WHERE THEY ARE

Energy efficiency is just one reason building owners may have for pursuing a deep energy retrofit project and, in many cases, it is not their main motivation. Some building owners pursue a retrofit to improve comfort, health, or employee productivity or to make their home or building more resilient to storms, climate change, or other disasters. Others may be interested in installing on-site renewables and may pursue efficiency as a secondary option to get more out of those renewables. Still others might learn about a specific approach (e.g., passive house) that appeals to them and motivates them to take action. Whatever their reasons, programs must meet building owners where they are and offer a range of solutions that reflect the diversity of owners and the building stock. Flexibility in program design allows customers to select the approach that fits their needs and interests.

In Connecticut, the CT Green Bank has discovered the benefits of leading with solar to engage customers on energy efficiency. Working with PosiGen, a solar and energy efficiency service provider targeting low- and moderate-income households, the CT Green Bank is offering the Solar for All program to increase the uptake of rooftop PV and efficiency upgrades, while reducing high household energy burdens. In the markets where it works, PosiGen has found that leading with solar generates greater interest and more sales than an efficiency-first or efficiency-only message, but that efficiency is an easy sell once customers are in the door. And, while 35–40% of homes it evaluates are infeasible for PV or end up canceling the solar contract, all of the homes are candidates for efficiency and can be targeted for further program outreach (Galante and Priest 2017). Customers participating in Solar for All receive applicable utility rebates (through standard or income-eligible programs) and can participate in an Energy Services Agreement to spread out the costs of the efficiency measures. Customer payments are capped at $10 per month and $2,400 total for an average of 25 million Btu annual savings (Galante and Priest 2017). These savings don't meet the threshold for ULE, but they are a start, and the program offers a model for delivering solar and energy efficiency that could work for deeper retrofits.

Phased retrofits are another way to give building owners greater flexibility. Developing a plan for staging deep retrofits over time can help address cost and financing issues, concerns over scheduling and disruptions, or a general unease about undertaking a large project with many components. This approach can also allow building owners to move forward with more near-term retrofit needs as part of a more strategic plan for a deeper building overhaul. France and Germany are in early implementation of phased retrofit programs that use customized renovation roadmaps or "building passports" to identify the full set of retrofit measures needed and to track projects as they are completed (Sebi et al. 2017). Combined with mandatory thermal performance requirements for key envelope measures, these programs are designed to capture significant energy savings through specific retrofit measures while allowing building owners to move forward with specific projects as they meet their own needs and financial constraints.

Call on the Community

Community-based program and project approaches can increase participation and program efficiency and can be a source of ideas for new savings opportunities. Efforts to identify and treat similar housing types with high use can be most effective when targeting homes within the same neighborhood. This type of aggregation may also prove valuable to ongoing work to develop and target standardized retrofit packages that can be more readily replicated across a large number of homes as an alternative to the highly customized approaches common today.

Engage Occupants

Whether in homes or commercial buildings, occupants can determine a ULE retrofit project's outcome. Engaging with occupants around project goals, the use and operation of any new systems, the impact of plug loads, and guidance on efficient behaviors can help owners meet and maintain ULEB performance. Occupant engagement and the development of behavioral strategies are the focus of the Thousand Home Challenge.

Do the Research

Successful ULE retrofit projects demonstrate feasibility using existing technologies. Further research will expand the number and types of technical options and solutions available—including solutions for a wider set of building types—while improving cost-effectiveness and the operator/occupant experience. Key near-term research needs include greater research and development on electric heating and water heating technologies for cold climates; improved plug load strategies, including improved control and sensors and energy management offerings for existing systems; and lower-cost approaches for deep retrofit (particularly for shell, space conditioning/air distribution, and ventilation measures). On the program side, more data on actual building energy performance—pre- and post-retrofit—is needed, especially for homes.

Conclusion

Our review of deep retrofit activities shows the potential for our diverse stock of existing homes and buildings to be retrofit and upgraded to ULEBs. While the level of intervention and the cost required varies widely, the technical solutions exist. Still, current retrofit practice lags far behind the technical potential in both scale and scope. Only a very small portion of the building stock is retrofit each year, and the savings are only a fraction of what is feasible.

Growing experience in construction of new ZEBs along with ZEB policies and programs can be transferred to the existing buildings market. Emerging policies and program designs that address the specific challenges and barriers in existing buildings show promise for driving greater demand for ULE retrofits and the mechanisms for delivering them. Specific targets for energy use and carbon reductions provide a strong impetus for action. To meet these targets, and the related economic and environmental goals, we must expand policy and program efforts, closely track the effectiveness of these efforts, and continue to refine and build on what we learn.

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